Energy Efficiency Operational Indicator of the Selected Type of Polish Fleet Fishing Cutter in Dependence of the Main Engine Type

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Abstract In view of the hazards to the environment, special areas were designated and named the Emission Control Areas (ECAs) and an energy efficiency of fishing cutters, this paper presents and comprises an analysis of the Energy Efficiency Operational Indicators’ (EEOI) calculation results as an indicator relating fuel consumption and the emission of CO2 as a harmful gas. In order to determine EEOI the field test results have been applied. The research was carried out on three Polish fishing cutters of the same type on which different types of medium-speed self-ignition internal combustion engines, used as main engines, were installed. Additional, prognosis EEOI for use of modern engines (gas engine and Common Rail fuel injections engine), were done. The conducted analysis allowed for an assessment how an engine type affects the EEOI value.

1. Introduction
The fishing fleets of particular states constitute major food supplier. Accesion of Poland to the European Union (EU) in 2004 and implementing EU directives affected reduction the Polish fishing fleet operating at the Baltic Sea. A particularly large number of fishing cutters in hull length from 15 to 26 m, has been reduced from 411 in 2004 to 142 in 2013 [1,10]. The rising prices of the petroleum products applied on ships (the cost of fuels, oils and lubricants represent 50 – 80% of ship operational costs [2,7] and the requirements of the International Maritime Organization (IMO) regarding the environment protection impose devices and technologies providing the reduction of power consumption and the mitigation of the hazards to the environment by vessel energy systems to be implemented. In pursuit to reduce the environment pollution, in particular as a result of CO2 emission, IMO implemented, commencing on 1st January 2013, the requirement for new-built ships on meeting the developed Energy Efficiency Design Index (EEDI). Furthermore, 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 the power consumption and the hazards to the 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 [3,4,5,6].
For every ship type, on the grounds of the operational research for its energy system, an EEOI may be calculated applying the relation, developed by IMO, as an indicator relating fuel consumption with CO2 emission. EEOI is essential for SEEMP drawing up. Considering the volume of the 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. However, long-term cooperation with shipowners demonstrates their considerable interests in obtaining the highest energy efficiency indicators of their fishing cutters, first and foremost in order to reduce the fuel consumption. For that purpose, this paper, based on the example of three selected fishing cutters of the same type, presents an analysis of energy efficiency indicators by determining their EEOI. The energy systems of the said vessels include different main engines’ types which two have been replaced due to the grants of the European Fisheries Fund. Additional, prognosis EEOI for use of two modern engines (gas engine supplied by LNG, as the fuel of the future [13] and Common Rail fuel injections engine), were done.

2. EEOI application for fishing vessels

The Energy Efficiency Operational Indicator (EEOI) enables a day-to-day assessment of the energy efficiency of ship energy systems. In case of the ships in operation it is possible to verify how designed or implemented technical and operational changes affect the value of the indicator. For the fishing vessels the technical changes may consist of inter alia a replacement of the main engine. The developed formula, including the specificity of operational activities of fishing vessels and applying the relation recommended by IMO [3, 6, 9], to determine EEOIF for the fishing vessels is as follows.

$$EEOI_{fish} = \frac{\sum J FC_j C_{fj}}{m_{fish} D} [g \text{CO}_2/t_{fishnm}]$$ (1)

where:
- $FC_j$ – the mass (in grams) of consumed fuel by main and auxiliary engines and oil-fired boilers during operational task performance,
- $J$ – fuel type (only one fuel type is used on the Polish fishing vessels)
- $C_{fj}$ – conversion factor expressed by the relation of CO2 mass (in tones) generated from combusting a tone of the j type fuel,
- $m_{fish}$ – the weight of fish brought (in tones);
- $D$ – distance in nautical miles corresponding to the operational task performed.

One fuel type is used on the Polish, Baltic fishing cutters to supply internal combustion engines and oil-fired boilers. The value of the conversion factor $C_{fj}$, according to IMO [3, 4, 9] for the fuel closest to the type used in the Polish fishing fleet and Liquefied Natural Gas equals to:

| Fuel Type                     | ISO 8217 DMX to DMC | Liquefied Natural Gas |
|-------------------------------|---------------------|-----------------------|
| Type of fuel                  | diesel/gas oil      | -                     |
| Carbon content [%]            | 85                  | 75                    |
| $C_{fj}$ [gCO2/tfuel]         | 3,206               | 2,750                 |

In the case of the fishing vessels EEOIF relates the amount of CO2 emitted into the atmosphere with consumed fuel and the weight of fish caught and the distance travelled.

Analyzing the formula (1) it may be stated that the value of EEOIF is strongly correlated with the distance travelled by a vessel during the operational task performance and the quantity of fish caught. The EEOIF value will be different in various operational states i.e. while free sailing and trawling. For instance, according to the formula (1), it is unfeasible to determine EEOIF while free sailing to a fishery when the vessel does not carry any fish caught. It is advisable to determine EEOIF for the
entire voyage of the vessel with regards to the total distance travelled, the total mass of consumed fuel and the total weight of fish caught.

The mass of consumed fuel is affected by the type of internal combustion engines on the vessel and the degree of their technical and technological advancement related with the engines’ production years. One of the vessels subject to the research had an engine installed during the construction process at the shipyard, while the engines on the remaining two vessels were replaced by the engines of a newer generation.

3. Technical specification of vessels and main engines subject to the research

Three fishing cutters, subject to the research, constructed in the Polish shipyards between 1970 and 1985, are the trawlers adopted to stern trawling and their technical and operational parameters are as follows [1,10,12]:

| Parameter                  | Value       |
|----------------------------|-------------|
| Overall length LC          | 24.56 m     |
| Width BC                   | 6.57 m      |
| Draught H                  | 3.2 m       |
| Gross Register Tonnage BRT | 95 t        |
| Cargo Capacity VH          | 80 m³       |
| Maximum Speed vE           | 10.5 kn     |

A scheme of the energy system for the tested vessels is presented in Fig. 1 [1,10,12].

![Figure 1 Scheme of tested vessels energy system](image)

The energy system presented in Figure 1 is composed of a main engine which through a reduction gear drives the controllable pitch propeller. Belt reduction gearboxes, driving 3.5 kW power generator and a trawl winch, are fixed at the free end of the crankshaft. Auxiliary engine, through belt reduction gearbox, can drive water pump, compressor and generator. Additionally, the energy system includes a two oil-fired boiler.

The energy system of one of the fishing cutters (no.1) has not been modernized since the entry into the operation, while the modernization at the second and the third vessel consisted of the replacement of the main engines into the new generation ones and of different type. The installed engines weren’t the brand new engines.
The technical data of the three installed engines on the vessels subject to the research and two proposed modern engines (manufactured by Volvo Penta and Mitsubishi) are presented in Table 1.

### Table 1

| Cutter no. | Engine manufacturer | Engine type | Nominal power $P_N$ [kW] | Nominal rotational speed $n_N$ [rev/min] | Propeller rotational speed $n_p$ [rev/min] | Comments |
|------------|---------------------|-------------|--------------------------|------------------------------------------|------------------------------------------|----------|
| 1          | Wola-Henschel       | 22 H 12 A   | 290                      | 1500                                     | 375                                      | Original Engine |
| 2          | MAN D2542MLE        | 305         | 1500                     | 375                                      | New Engine                               |
| 3          | Scania CVAB         | 300         | 1600                     | 400                                      | New Engine                               |
| 3          | Volvo Penta D6-400  | 310         | 3200                     | 400                                      | Common Rail Engine                       |
| 3          | Mitsubishi GS6R2-PTK| 315         | 1200                     | 400                                      | Gas Engine                               |

When analyzing the data included in Table 1 it may be noticed that the installed and proposed engines’ power is around 15% higher. An increase of rotational speed of the engine fixed on the vessel 3, with unchanged reduction gears at every vessel, caused that propeller rotational speed rose to 400 rev/min.

### 4. Operational research and results

Prior to the research, a torsiometer to measure a torque and meters to measure the fuel consumption by the main engines were installed at the input shaft to the gearbox. In order to determine the distance travelled and the speed developed by the fishing cutters, GPS system was used. The operational tasks, presented in Table 2, during which the research was carried out, had been specified. For the comparative purposes, it was agreed with the skippers that fish would be caught at the same fisheries and only one trawling would be performed. The fishing cutters stationed in the same port. The research was carried out in the summer, at an interval of 1 week for particular fishing cutters in the same operating conditions (free sailing speed and trawling speed, trawling time) and similar weather conditions. The oil-fired boilers were not used. The fish caught were stored in ice collected at the port. The fuel consumption was determined by means of a measuring tank installed in the energy system of the fishing cutters. The results of the operational research carried out at the vessels and prognosis for modern engines are presented in Table 2.

### Table 2

| Operational task | Distance $D$ [nm] | Speed $v$ [kn] | Time $t$ [h] | Engine power $P_{EM}$ [kW] | Fuel mass flow $m_{fuel}$ [g/kWh] | Fuel consumption FC [t] | Weight of fish $m_{fish}$ [t] |
|------------------|-------------------|---------------|-------------|---------------------------|---------------------------------|------------------------|-----------------------------|
| Fishing cutter no.1 (engine Wola-Henschel 22 H 12 A) |
| To fishery      | 50                | 9,5           | 6           | 184,6                     | 254,8                           | 0,282                  | 0                           |
| Trawling        | 3                 | 2,8           | 1           | 92,5                      | 332,5                           | 0,031                  | 0                           |
| To port         | 49                | 9,4           | 6           | 186,5                     | 255,3                           | 0,286                  | 8                           |
| Total           | 102               |               |             |                          |                                 |                        |                             |
| Fishing cutter no.2 (engine MAN D2542MLE) |
| To fishery      | 50                | 9,1           | 6           | 156,0                     | 251,3                           | 0,235                  | 0                           |
| Trawling        | 3                 | 3,0           | 1           | 118,0                     | 279,7                           | 0,033                  | 0                           |
| To port         | 51                | 9,0           | 6           | 158,0                     | 253,4                           | 0,240                  | 12                          |
| Total           | 104               |               |             |                          |                                 |                        |                             |
As it is apparent from the obtained results of the measurements included in Table 2, the most of the assumed research conditions have been preserved. The difference in free sailing speed for the particular vessels did not exceed the value of 5%. The vessels within the same time travelled a comparable distance during the operational tasks performance. Due to the fact that one trawling was carried out, which lasted an hour, only the quantity of fish caught by individual vessels was significantly different.

5. EEOI for fishing cutters subject to research

The EEOI values for particular fishing vessels were determined by the application of formula 1 and the data included in Table 2. For the calculation purposes the distance travelled by each vessel during the entire voyage was used. The distance is a sum of a route to the fishery, back to the port and while trawling. The calculation results are presented in Table 3.

| Cutter no. | Engine type        | EEOI for tested fishing cutters [gCO2/tkm nm] | Change of unit EEOI [%] |
|------------|--------------------|---------------------------------------------|------------------------|
| 1          | 22 H 12 A          | 2339                                        | 100,0                  |
| 2          | D2542MLE           | 1808                                        | 86,7                   |
| 3          | CVAB               | 1308                                        | 83,6                   |
| 3          | D6-400             | 1581                                        | 79,5                   |
| 3          | Gas Engine         | 1612                                        | 77,3                   |

The analysis of the calculations included in Table 3 allows to notice significant variation in the EEOI values determined for the entire voyage for the particular fishing cutters. While the distance travelled by each vessel was comparable, such calculation results were affected considerably by the quantity of the fish caught. In order to provide the possibility to compare the energy efficiency between the individual vessels, unit EEOI was computed with the reference to 1 tone of fish caught. For the completed research programme, the determined unit EEOIs enable the comparison of the energy efficiency of the vessels in relation to the consumed fuel, and hence in the given case, to the type of the main engine.
6. Conclusion
The programme development and the execution of the research at three fishing cutters of the same type enable the analysis of an impact of the main engine installed on a vessel on the EEOI value. The most major conclusions may include:

- the engine replacement with the engines of new types and generation caused a decrease of the unit EEOI value from 13 to 16%,
- the proposed modern engines can cause a decrease of the unit EEOI value from 21 to 23%,
- a comparative analysis between the fishing vessels is enabled by only the unit EEOI values,
- the EEOI values for fishing vessels should be determined for a distance travelled during an entire voyage.

EEOI may be calculated for the period of a particular operational task performance (i.e. free sailing and trawling) provided that there are fish caught on the vessel.

The paper presents only the considerations regarding the impact of the engine type and generation on changes in the EEOI values. Further reduction of the factor value requires a comprehensive approach to the issue of the energy efficiency of the ship energy systems, mainly by the reduction of power demand. The value of the required power, in particular driving power which constitutes 60-80% of the power generated by the energy systems of fishing cutters, is affected by many technical and operational factors inter alia hull shape, optimal selection of propulsion system components, the technical condition of the hull, heat loss reduction, the use of waste heat, voyage planning, the optimization of trim and sailing speed. The EEOI value is significantly affected by a fuel type (biofuel, LNG) and new methods for the reduction of harmful exhaust gases emission e.g. by a catalytic fuel treatment. The employees of the Faculty of Mechanical Engineering at the Maritime University of Szczecin are engaged in the issues together with the shipowners and other universities within the European research projects [1, 7, 10, 11, 12].

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