1. Dunja LEGOVIĆ, Faculty of Engineering, University of Rijeka, Vukovarska 58, 51000 Rijeka, dlegovic@riteh.hr (corresponding author)
2. Roko DEJHALLA, Faculty of Engineering, University of Rijeka, Vukovarska 58, 51000 Rijeka, roko@riteh.hr

AN OVERVIEW OF MEASURES FOR SHIP'S ENERGY EFFICIENCY IMPROVEMENT

Abstract

The current state of ship energy efficiency measures which are being taken to improve ship efficiency, reduce fuel consumption and lower emissions is presented. Regarding design and construction of a new vessel, the optimization of the hull, appendages, and propulsion systems is discussed. Furthermore, devices that are used to improve the efficiency of propellers are introduced, together with a survey of developing technologies aimed at reducing the hull frictional resistance or using renewable energy sources. Finally, regarding fuel efficiency in service, some operational and maintenance measures that can reduce fuel consumption are addressed. Some of the named approaches can be successfully applied to already existing vessels to improve the current performances.

Keywords in English: ship energy efficiency, overview

PREGLED MJERA ZA POBOLJŠANJE ENERGETSKE UČINKOVITOSTI BRODA

Sažetak

U radu je prikazano trenutno stanje mjera koje se poduzimaju za poboljšanje učinkovitosti broda s energetskog stajališta, te u vidu smanjenja potrošnje goriva i emisije stakleničkih plinova. Razmatraju se mogućnosti optimizacije trupa, privjesaka i propulzijskih sustava u okviru projektiranja i gradnje broda. Nadalje, navedeni su uređaji koji se koriste za poboljšanje stupnja djelovanja brodskog vijka, zajedno s pregledom tehnologija koje se razvijaju u svrhu smanjenja otpora trenja ili koje primjenjuju obnovljive izvore energije. Naposlijetku, razmatraju se mjere koje se odnose na operativnost i održavanje, a izravno utječu na smanjenje potrošnje goriva u službi. Neki od navedenih pristupa mogu se uspješno primijeniti na već postojeće brodove radi poboljšanja trenutnih značajki.

Ključne riječi na hrvatskom: energetska učinkovitost broda, pregled

1. Introduction

In recent years, the world has turned its focus towards cleaner energy sources and the Fukushima Nuclear Plant disaster in Japan demonstrated the importance of this shift. For instance, the European Union has set as target to obtain at least 20 percent of its energy from renewable sources [1]. However, the production of energy is only a part of the equation. It is equally important that the available resources are used effectively. A part of this consumption that cannot be neglected is maritime transport. In 2015, United Nations Conference on Trade and Development Maritime Transport Review estimates an increase of maritime cargo volume by 300 million tons, taking the total to 9.84 billion tons [2].

Given the sheer volume, it is as expected that there is currently a significant effort in creating “greener” ships. This concept is mainly based on reducing the fuel consumption of the vessels. In 2011, IMO introduced regulations that focus on the limits of the CO_2 production of the new built ships, and the regulations keep evolving depending on the deadweight tonnage of the ships [3]. Matching these limitations is possible by going through optimization processes for new vessels. In this case, both the vessel’s hull and its appendages should be paid attention to. In addition to optimization of design, a number of devices are currently in consideration. These approaches cover basics such as methods of reducing the friction resistance to more novel approaches such as the integrating renewable energy sources into vessels.

Regardless of the design decisions, the efficiency is subject to alterations based on the conditions that are encountered during a particular voyage. Captains take decisions regarding the routing of the vessel, that combine with weather conditions and factor on fuel consumption. The loaded and ballast conditions change the draft and trim of the ship from the design draft and affect the performance. Similarly, even under design conditions, calm sea and extreme weather behaviour of the vessel will not be equal. It is, therefore, important to consider the efficiency as a variable value as opposed to a constant. The level of maintenance performed on the vessel then becomes a part of this variable. Both the propeller and the hull conditions reflect on the outcome.

This work provides an overview of the factors that increase and reduce the efficiency of the ship under seaway. It starts by briefly detailing the Energy Efficiency Design Index (EEDI), and discusses how the hull and the propeller may be optimized to match the targets. Next, the devices that can be included for new ships and existing ships are described. The final two sections describe what applies to both new-built and existing ships, as they concern maintenance and decision making.

2. Energy Efficiency Design Index (EEDI)

Ships commissioned after January 1, 2013, and weighing 400 GT or more, need to meet the new requirements concerning Energy Efficiency Design Index [4]. The EEDI is based on a formula to calculate vessel’s energy efficiency, taking into account the ship’s emissions, capacity and speed. The lower the value, the more energy efficient the ship is and the lower its negative impact on the environment. The requirements will gradually be tightened: ships built in 2015 need to meet higher standards than those built in 2013, and in 2020 and 2025 the standards will increase further. Figure 1 details the limits introduced in years, as a function of gross tonnage [5].

To satisfy a minimum energy efficiency requirement, ships must not exceed a given threshold, which depends on its type and size, according to [6]. The method assesses the energy consumption of a vessel under normal seafaring conditions, taking into account the energy required for propulsion and the hotel load for the crew. Energy consumed to maintain the cargo and for manoeuvring or ballasting is not considered:

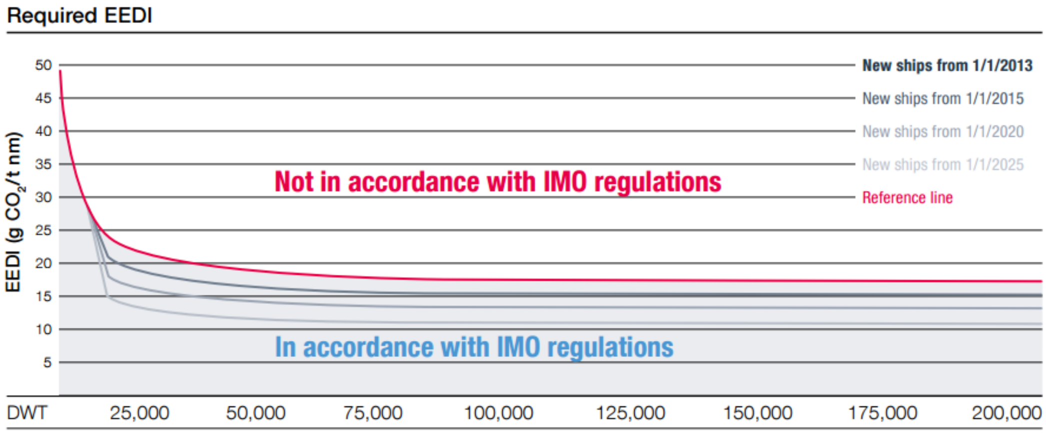

Fig.1. Required EEDI depending on the year of construction [5]
Slika 1. Dozvoljeni EEDI s obzirom na godinu izgradnje [5]

$$\mathrm{EEDI} = \frac{\mathrm{CO_2\ emissions}}{\mathrm{benefit\ cargo}} = \frac{\sum(P \cdot C_F \cdot SFC)}{\mathrm{capacity} \cdot \mathrm{speed}} \tag{1}$$

In Equation (1), *P* represents the individual engine power (main engine, auxiliary engine, shaft motor) taken at 75% Maximum Continuous Rating. C_F is the CO_2 emission factor based on type of fuel used by given engine (main and auxiliary) and *SFC* is the specific fuel consumption (main and auxiliary engine). The capacity is given in deadweight tonnage, while the speed refers to the ship speed at maximum design load conditions.

At present, the EEDI only applies to vessels responsible for the highest emissions when it comes to maritime pollution. Older vessels are only affected by the standards if they have undergone a major conversion in recent years. Vessels featuring diesel-electric, gas turbine or hybrid propulsion are currently not required to meet EEDI standards. RoRo, RoPax, cruise, offshore and other vessels not explicitly mentioned in the regulations are also exempt. However, based on the results observed in the first phase of the initiative, the IMO intends to expand the EEDI to include additional types of ships in the future.

3. Optimization of the hull, appendages, and propulsion system

The shipbuilding industry continually develops new approaches to hull form optimization. Depending on the capital costs and expected gains in vessel fuel efficiency, two methods are possible in terms of hull optimization. The first approach is to modify the existing and partially optimized hull form. This alteration mostly involves modifications to the fore-body design and stern shape. The second approach is the development of a new design, where hull particulars, propulsion system, and power plant will be adjusted to reach the maximum efficiency. This option is suited when a large series of ships is being ordered, due to the high capital cost of the vessel. In the following sections, both approaches are addressed, and their feasibility is discussed. A brief summary is provided in Table 1.

3.1. Optimizing Ship Particulars

The transport efficiency can be considered in terms of fuel consumption per tonne-mile of cargo moved (g/tonne-NM). If larger capacity vessels are employed, the relative fuel consumption results to be lower due to a higher amount of transported cargo. For example, if the size of a container ship can be increased from 4500 TEU to 8000 TEU, the fuel consumption for propulsion per tonne-mile of cargo transported decreases by about 25% [7].

Table 1. Influence of the ship particulars optimization on fuel consumption [7]

Tablica 1. Utjecaj optimizacije glavnih karakteristika broda na potrošnju goriva [7]

	Savings	**Applicability**	**Ship Type**
Ship-Size Capacity	10-25% of fuel consumption per tonne-mile by increasing ship’s capacity by 50-75%	Largest savings for higher speed ships and smaller sized vessels	All New and existing
Service Speed	12-22% in PFC* by reducing the speed by 1 knot	Depending on the ship type and design speed	All New and existing
Principal Dimensions	3-5% in PFC by increasing the L/B ratio or by reducing the C_B	Depending on the ship type and construction costs	All New

*PFC – propulsion fuel consumption

When optimizing hull forms, the selection of the service speed or speed range depends on many factors, such as the expectations of the shipper, market conditions, route and sea margin. The cost of fuel is a major component of operating expenses, together with the time value of cargo shipped. Considering those, a hull form may be optimized for a slower speed, which usually means a fuller form and higher cargo deadweight. On the other hand, the service speed of an existing ship may be intentionally lowered in certain parts of the route, in order to lower the fuel consumption.

Nowadays, the major shipyards produce ships that are generally well optimized in terms of dimensions. In theory, hull efficiency can also be increased by increasing the length while reducing the beam and maintaining the draft, displacement and block coefficient values. A higher length/beam ratio influences the reduction of wavemaking resistance, while a reduced beam/draft ratio decreases the wetted surface, and, as consequence, the frictional resistance. It is understood that the main particulars and hull coefficients cannot be selected based on hydrodynamic principles alone. Many other factors need to be considered, such as the accommodation of the cargo block and main propulsion units, minimization of required ballast and restrictions from port and canal infrastructure. In such an optimization, economic factors are taken into consideration, with the aim to minimize the fuel consumption along with the operating and construction costs.

3.2. Minimizing Hull Resistance and Increasing Propulsion Efficiency

With the development of CFD software, the optimization process became widely applicable, detailed and accurate. Hull details and appendages can be examined multiple times at the expense of computational time. The forms of optimization are listed in Table 2 and presented below. The general approach to optimizing the hull are presented with a particular discussion on the fore and aft sections.

Shipyards tend to optimize the hull form around the specified design draft, while less attention is paid to the efficiency at the ballast draft, and little or no attention is paid to partial load conditions. These conditions are being recently researched [8]. When a new hull form is being developed, the process of analyses and model tests are iteratively performed. As a part of the optimization process, free surface potential flow calculations have become a routine. They are mostly used to evaluate the impact of shifts in the LCB and adjustment to C_B, and the impact on wavemaking resistance of form design variations, particularly in the forebody. CFD is useful in assessing the influence of changes to the waterline entrance angle, optimizing the location

Table 2. Influence of the hull form optimization on fuel consumption [7]

Tablica 2. Utjecaj optimizacije forme broda na potrošnju goriva [7]

	Savings	**Applicability**	**Ship Type**
Optimizing the Hull Form	12-16% in resistance by optimizing the ballast waterline together with the full load waterline	Different drafts, trims and speed ranges optimization. Due to high costs, it is justified for multiple ship programs	All New
Forebody Optimization	1-5% in PFC by modifying the bulbous bow	Bulb design, waterline entrance, forward shoulder and transition to the turn of the bilge	All New and existing
Aftbody Optimization	No relevant data	Improvement of flow into the propeller and minimization eddy effects	All New
Appendage Resistance	Compared to the bare hull, no savings are possible, but the increase of appendage resistance can be minimized	Optimization of bilge keels, rudders and bow thruster tunnels	All New and existing

and shape of the fore and aft shoulders, and optimizing the bulbous bow. CFD is to be employed sequentially, for refinement of shape and elimination of less favourable variations.

The optimization of the forebody refers to the bulb design, waterline entrance angle, forward shoulder and transition to the turn of the bilge. Potential flow calculations are widely applied in this part of the optimization process. If designed appropriately, the bulbous bow can reduce wavemaking resistance by producing its own wave system which is out of phase the bow wave from the hull. These two systems interact and cancel each other, and as a consequence, the wavemaking resistance decreases. The issue is that, at a different speed or draft, the shape of the created wave is also altered, so reductions in draft or speed can actually lead to increases in wavemaking resistance. Since not many commercial vessels operate at the design draft only, compromises in the bulb design are necessary to provide an equally good performance over the whole expected range of operating drafts and speeds.

The main objective of the aftbody optimization is the improvement of the stern flow to increase the propulsive efficiency. As in the forebody case, the wavemaking effects through the aft shoulder can be estimated by potential flow calculation. The flow through the propeller and at the wetted transom need to be evaluated by viscous flow calculations. Asymmetrical sterns are under research as a possible solution to propulsive efficiency improvement through pre-rotation of the flow to the propeller.

The typical appendage resistance for cargo vessels in calm water conditions is approximately two to three percent of the overall hull resistance. In terms of optimization, the shape of rudders and bilge keels can be adjusted by CFD analysis in calm water conditions and severe wind/weather conditions. The shape of the bow thruster openings can be adapted to reduce vortices and pressure variations.

4. Devices for efficiency improvement

This section discusses a range of devices which mostly concentrate on the improvement of propeller propulsion effectiveness. Different types of devices have been studied and

Table 3. Influence of the efficiency improvement devices on fuel consumption [9]
Tablica 3. Utjecaj uređaja za povećanje učinkovitosti na potrošnju goriva [9]

	Savings	Applicability	Ship Type
Wake Equalizing and Flow Separation Alleviating Devices	0-5% in PFC	Correction of known hydrodynamic problems	All Medium and lower speed New and existing
Pre-swirl and post-swirl Devices	2-6% in PFC	Design in conjunction with propeller	All New and existing
High-efficiency Propellers	3-10% in PFC	Design considering the ship operational profile and stern shape	All New and existing

developed to either improve the energy performance of a suboptimal ship design and to develop further a nearly-optimal standard design. What is mostly applied in the list of cases in Tables 3 and 4, are some of the physical phenomena, which would be treated as secondary in the normal design process, or which are not yet completely understood. Recent developments are mostly focused on reducing the hull frictional resistance or exploiting readily available natural resources, such as solar and wind energy. Not all of those devices are currently ready for implementation. The most prominent reasons can be the high implementation cost of these technologies, and their difficult integration in the current ship's design and operation setting. As it happens, for most new technologies, the economic risk of their adoption cannot always be readily quantified. For this reason, the utilization of renewable energy is making a rather slow progress.

4.1. Propulsion Improving Devices (PIDs)

Wake Equalizing and Flow Separation Alleviating Devices are features that should improve the flow around the hull. They were developed as a solution to propeller problems and additional resistance caused by suboptimal aft hull forms. As additional devices, they are less effective than a correctly designed ship geometry. The most common wake equalization and flow separation alleviating devices are Grothues spoilers, Schneekluth ducts and stern tunnels.

Pre-swirl devices are hydrodynamic appendages to the hull. Their purpose is to redirect the wake flow in order to impose a rotation opposite to the propeller rotation. In this manner the angle of attack of the flow on the propeller blades over the entire disk can be improved. The most applied types are the pre-swirl fins and stators.

Post-swirl devices are applied for conditioning the flow at the aft end of the hub. The rotational components of the flow created by the propeller are converted to useful axial flow. In some cases the propeller hub vortex is suppressed to improve rudder efficiency, so a smaller rudder can be used. Hence, the appendages resistance can be reduced. The performance of post-swirl devices and rudders is closely linked, so the efficiency of both parts needs to be assured. Currently, rudder thrust fins, post-swirl stators, asymmetric rudders, rudder (costa) bulbs, propeller boss cap fins and divergent propeller caps are being applied to commercial vessels.

Depending on the ship type, various high-efficiency propellers represent different options. This list includes fixed-pitch screw propellers with optimized geometry, controllable pitch propellers, ducted propellers, propellers with end-plates, Kappel propellers, contra-rotating and overlapping propellers, as well as podded and azimuth propulsion [9].

Table 4. Influence of the skin friction reduction on fuel consumption [4]

Tablica 4. Utjecaj smanjenja otpora trenja na potrošnju goriva [4]

	Savings	**Applicability**	**Ship Type**
Air Lubrication	0-10% in PFC	Under research Unknown maintenance costs	All New
Hull Surface Texturing	5-10% in PFC	Under research Unknown maintenance costs	All New and existing

4.2. Skin Friction Reduction

Skin friction is the largest component of viscous resistance. In order to reduce it to some extent, three methods can be applied: reducing the wetted surface (linear reduction), reducing speed (quadratic reduction) or improving the interaction between the wetted surface and the surrounding fluid. The latter approach has been researched through the years, and two types of systems have been developed: systems that change the behaviour of the fluid - through its density, viscosity and boundary layer growth, and systems that improve the wetted surface texture to achieve the best interaction with the fluid. With this aim, air lubrication and hull surface texturing are currently researched.

The idea behind air lubrication is to force air to stay in touch with those parts of the hull that would normally be in contact with water. There are two main types of air lubrication: air cavity systems and micro-bubbles. In air cavity systems, a thin sheet of air is maintained over the flat portions of a ship’s bottom with the aid of pumps and hull appendages. The goal would be to obtain a reduction in the wetted surface at the expense of the power needed to supply the pumps. In the case of micro-bubbles, the density of water in contact with the hull is reduced, and its viscous behaviour is improved by mixing it with air in the form of micro-bubbles.

Hull surface texturing, on the other hand, advocates an alternative form of coating. In general, a smooth hull surface is considered as optimal in terms of performance, especially compared to a fouled hull as a consequence of marine growth. However, it has been demonstrated that some further benefits can be achieved by adopting particular types of surface texturing instead of an entirely smooth hull. Certain shapes and sizes of riblets and semi-spherical microcavities can distort the flow through the boundary layer and thus reduce skin friction. This type of technology is still in its infancy, and it is not known yet how the correct shape and size of texture can be achieved and maintained on a ship’s hull. However, some paints are being developed that might be able to achieve this in the future.

4.3. Renewable Energy

Table 5 provides the wind and solar energies to increase efficiency. The wind has been used to propel ships for thousands of years. Modern propulsion systems have replaced it only in the last 150 years, but the benefits that wind power can provide in terms of fuel savings are seriously considered nowadays. The most researched approaches are towing kites, rotor sails, Flettner rotors, windmills, and turbosails.

There have also been several attempts of powering vessels by solar energy. The issue is that, due to the low electrical output per unit surface, they need to extend on a big surface to be efficient. Therefore, photovoltaic (PV) solar panels are better suited as an additional source of auxiliary power. Another drawback of PV solar power is the high capital cost of these plants that have not yet benefited from large scale economies.

Table 5. Influence of the renewable energy devices on fuel consumption [1]

Tablica 5. Utjecaj uređaja za korištenje obnovljivih izvora energije na potrošnju goriva [1]

	Savings	Applicability	Ship Type
Wind	Up to 30% in PFC	Limited by superstructure and ship's operational profiles	All low-speed New and existing
Solar	Marginal	Limited due to low electrical output per unit surface	All New and existing

5. Fuel efficiency in Ship Operation: Voyage Performance Management

The ship's performance depends on the decisions taken while the ship is on the voyage as much as it depends on the decisions made in design. Speed, weather, routing and loading related choices reflect on the environmental impact. The cases are summarized in Table 6.

5.1. Voyage Speed Optimization

The speed of a vessel affects the fuel consumption directly because it is related to the propulsive power by approximately a third or fourth power relationship. In practice, savings can be achieved by designing the ship for an economically feasible lower speed [10]. Another approach is slow steaming, or sailing slower than the design speed on certain sections of the voyage. The shortcoming of this method is that the main engine and auxiliary systems operate at low loads, sometimes below standard manufacturer recommendations. This low load operation can cause accelerated wear of the engine and auxiliary components if not properly planned and executed. The opportunities for slow steaming can be gained by minimizing the time spent in port, but that time depends on the organization of the terminal and can hardly be counted on.

5.2. Weather Routing

The weather routing is a service whose fundamental goal is to select a course from the departure port to the destination port, providing the safest passage and reliable on-time arrival while taking into account the actual wind, wave and current conditions expected during the voyage. The climate data is updated at regular intervals for the vessel's predicted position and time, while all the safety limits are checked. Recently the focus shifted from a fast and safe route to a safe and energy efficient route. In the process, the most critical vessel performance prediction is the amount of speed reduction in a seaway. The speed reduction depends on the captain's decision, so it cannot be easily predicted within a simulation. Weather routing is most beneficial on longer voyages (over about 1500 NM) where the route is navigationally unrestricted so that there is a choice of routes, and where weather is a factor on vessel performance.

5.3. Trim/Draft Optimization

Hull forms are traditionally designed and optimized around one or two primary drafts assuming zero trim. The distribution of cargo, ballast and consumables often leads to trims different than that assumed during the design of the hull. For this reason, a vessel in service may sail a significant portion of its voyages at drafts other than the design draft. The traditional approach for determining optimum trim is to rely on model tests in calm water to evaluate the resistance over a full matrix of drafts and trims. In recent years a large number of trim optimization tools have appeared on the market. They are mostly based on CFD methods to evaluate the same matrix of drafts and trim with computation rather than physical tests.

Table 6. Influence of the voyage performance management on fuel consumption [4]
Tablica 6. Utjecaj praćenja plovidbe na potrošnju goriva [4]

	Savings	Applicability	Ship Type
Voyage Speed Optimization	20% in PFC obtained by speed reduction of 10%	Biggest improvement for higher speed ships	All New and existing
Weather Routing	Depending on weather and voyage length	Biggest improvement for long routes in harsh climates	All New and existing
Trim/Draft Optimization	1-2% in PFC	Biggest improvement for long routes	All New and existing
Autopilot Improvements	0-1% in PFC	Biggest improvement for long routes in harsh climates	All New and existing

5.4. Autopilot Improvements

Rudder movements add drag to the hull and increase resistance. This effect can be reduced by minimizing the number of rudder movements and the amount of rudder angle that is applied to maintain course or to perform a change of course. This is true under manual steering as well as when an autopilot is engaged. Conventional autopilots usually rely on linear relationships between rudder angle and rate of change of heading. An adaptive system takes feedback on the rate of response of the ship to a given rudder angle and automatically adjusts the steering control model. A steering model adapted to actual conditions helps prevent excessively frequent or large rudder motions (so called hunting) in course-keeping and course-changing modes. The highest efficiency of the adaptive steering system is obtained if it can be auto-tuned to the weather and load conditions. A voyage routing or performance tool can integrate these options into the overall course prediction.

6. Effect of Hull and Propeller Condition in Energy Efficiency

The frictional resistance is significantly affected by the roughness of the surface exposed to the flow. It is estimated that each 10 μm to 20 μm of additional roughness can increase the total hull resistance by about 1 percent for full form ships and about 0.5 percent for fine-form ships at high speeds. In order to minimize a ship’s frictional resistance, the owner must address both physical and biological roughness of the hull and the propeller. The cases regarding the effect of maintenance and overall management of the vessel are summarized in Table 7 and elaborated below.

6.1. Effects of Hull and Propeller Maintenance

The purpose of in-service, underwater hull cleaning is to remove biological roughness or fouling. Underwater cleaning is accomplished by a diver or a squad with a manually operated scrubber incorporating some type of rotating brushes or pads. This operation is considered cost effective if the proper cleaning technique is used so that the surface roughness is not degraded and the coating material is not removed. For best results, the scheduling of cleaning should be based either on monitoring of performance indicators (such as fuel consumption) or on regular pre-cleaning inspections. In both cases, an economically justified threshold is established. In the planning process some regulatory instruments need to be considered, such as IMO’s MEPC 62/24 [11] that govern the times and locations allowed for the cleaning. These guidelines would greatly diminish the risk of the spread of aquatic species into new areas, especially the so-called niche areas (sea chests, thrust tunnels, etc.).

Table 7. Influence of the hull and propeller conditions maintenance on fuel consumption [4]
Tablica 7. Utjecaj održavanja trupa i brodskog vijka na potrošnju goriva [4]

	Savings	**Applicability**	**Ship Type**
Hull Cleaning	7-9% in PFC by cleaning light slime, 15-18% by cleaning heavy slime and 20-30% by cleaning heavy fouling	Divers and underwater vehicles Yearly and condition-based	All Ships in service
Hull Antifouling Coatings	3-4% in PFC in combination with appropriate cleaning 10-12 % in PFC after recoating a rough hull	Recoating the ships in service at proper intervals, approximately every 3 years	All Ships in service
Propeller Roughness Management	Up to 6% in PFC by propeller cleaning and polishing	Yearly and condition-based	All Ships in service
Condition-based Maintenance	Increase in fuel consumption is monitored	Based on direct regular inspections or on performance monitoring systems (accurate fuel measurements)	All New and existing

There are currently three different hull antifouling coating types in wide usage, and they offer different resistance to fouling. One is the Controlled Depletion Polymer (CDP), a traditional antifouling type based on a water-soluble natural or synthetic pine rosin mixed with a biocide. It requires moving water (or cleaning) to wear off layers of the co-resin “skeleton” and release the next layer of coating and biocide. Another type is the Self-Polishing Copolymer (SPC), an insoluble metallic or organic synthetic that contains a biocide. The polymer becomes soluble through a chemical reaction (hydrolysis). No ship movement is required, and the surface is actually self-smoothing. The third type is the Foul-release Coating, a biocide-free coating that uses non-stick properties to control fouling. It is usually silicone or fluoro-silicone based and designed to shed any micro or macro growth when the vessel is underway. If the vessel is stationary for some time barnacles and other macro-size biota can become attached and it might require cleaning.

Propeller efficiency loss can also be a consequence of increased physical surface roughness. It can be created by corrosion, cavitation erosion, impact, or fouling. To keep the recommended smoothness, regular underwater polishing and reconditioning of the surface of a propeller is necessary.

Finally, the condition-based surface maintenance indicates the optimum intervals for the hull and propeller cleaning. One method involves the measuring of the actual hull and propeller roughness or fouling. The measurements are done by divers while the ship is in port. The results are compared with the threshold values that indicate when cleaning is necessary. The other method involves performance-based systems that track changes in fuel consumption and main engine power. The degrading surface conditions can be identified by collecting records of fuel consumption in controlled or repeatable voyage conditions and isolating the parameters being studied. The use of performance monitoring systems is attractive because all the measurements are obtained while underway, without the need for special arrangements in port.

6.2. Overall Energy Efficiency Management

There are a significant number of energy efficiency measures that can and should be considered by the ship owner or operator in order to minimize fuel consumption, fuel cost and emissions. To effectively coordinate these measures, a ship’s performance monitoring system needs to be adequately designed and well-managed. It should include data collection, analysis, reporting and dissemination to the relevant stakeholders.

The performances of all onboard power consumers should be considered, starting with the engine systems, down to the pumps and lights. Each component can be tuned to perform at the optimum efficiency based on manufacturer’s guidelines. Alternatively, components can be replaced with higher efficiency models or ones that are a better match for the load or service condition.

For proper energy efficiency management, it is necessary to develop an accurate fuel consumption measuring system and reliable reporting process. The data should address both bunker management and energy efficiency measures in a coordinated manner and with acceptable accuracy.

In order to carefully coordinate the efforts made to improve efficiency, it is suggested that a well-managed process is undertaken, such as that defined in the Ship Energy Efficiency Management Plan (SEEMP) regulations. The SEEMP is an amendment to MARPOL Annex VI that makes a SEEMP mandatory for all new and existing ships as of 1 January 2013, adopted in July 2011 by IMO. According to [12], each ship shall keep on board a ship specific SEEMP. The SEEMP implementation consists in four main iterative steps:

1. Planning, which includes the setting of ship-specific, company-specific and human resources goals and procedures
2. Implementation, consisting in the execution of plans and procedures, together with recordkeeping
3. Monitoring requires the appropriate tools and systems without burdening the ships’ crew
4. Self-evaluation and improvement, where effectiveness should be evaluated and feedback should be produced

The scope and detail of the SEEMP can vary, and there are several guidelines already published for owners and operators to reference.

7. Conclusion

Shipping industry currently aims to advance the world trend in greener energy, by producing “green” ships and increasing the efficiency of the modern vessels. Considering the amount of trade on the seaway, the importance of the contribution is apparent. In this regard, an overview of the current practices was presented in this paper.

Initially, the standards that are developed by the IMO were presented. These rules apply to new vessels and to ships that have undergone major conversions after 2011. Optimization of the hull form and the appendages are necessary to match these targets, which were both elaborated. On the other hand, certain devices may apply to new and older vessels. These approaches include propulsion improving devices, skin friction reduction and renewable energy sources, which were described.

It was discussed that the efficiency of a vessel under seaway is not a constant value but a variable. Decisions taken by the captain, the weather, and the loading conditions affect the outcome. They were listed with their expected overall contribution. The state of the ship regarding maintenance was described as the final factor.

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