Biofouling impacts on the environment and ship energy efficiency

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WORLD MARITIME UNIVERSITY

Malmö, Sweden

BIOFOULING IMPACTS ON THE ENVIRONMENT AND SHIP ENERGY EFFICIENCY

By

ADEL ALI DESHER

Iraq

A dissertation submitted to the World Maritime University in partial Fulfilment of the requirements for the award of the degree of

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In

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Declaration

Following the title page, each dissertation must include a formal declaration by the student as follows:

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

Adel Ali Desher
September 2018

Supervised by: Dr. Lawrence P. Hildebrand

Head of Ocean Sustainability, Governance & Management Specialization at World Maritime University
Title of Dissertation:

**BIOFOULING IMPACTS ON THE ENVIRONMENT AND SHIP ENERGY EFFICIENCY**

Degree: Master of Science

Abstract

This dissertation is a study of the role of ship hull biological fouling in the transfer of invasive species. It has been shown on many research that 70-80% of IAS (Invasive Aquatic Species) introductions occur through ship hull biofouling, and new areas are constantly being invaded. Data of case study ship are analyzed before and after maintenance operations of ship’s hull during dry dock. The results obtained have shown that the maintenance of the ship hull during dry-dock and the effectiveness of biofouling management system on board ships are significantly contributing to improve the ship’s speed and to reduce its fuel consumption, which reduces the GHG emission from ships. Furthermore, these methods limit the transfer of invasive species and their negative impacts.

An overview of different stages of fouling formation on the ship’s hull and niche areas is given. The significant threat of aquatic invasive species transfer by ship hulls is assessed with a brief comparison of the contribution of biofouling versus species transferred by ballast water. The growth and development of aquatic species during ship sailing are investigated. The ecological, economic and human health impacts due to the transfer of invasive species by biofouling are examined. Indeed, on the sidelines of local ecosystems, these species can end up without predators and proliferate without control.

Since the success of the “GloBallast” project, various IMO committees and technical subcommittees have been interested in the issue, and a new IMO global project, “GloFouling,” which is based on the success of the “GloBallast” partnership project, has been tasked to protect marine ecosystems from the negative impacts of transfer of invasive aquatic species. On 15 July 2011, IMO has adopted guidelines to regulate the management and control of biofouling to minimize the transfer of aquatic species,
which is still the only regulatory framework for this serious threat from the shipping industry.

Effectively implementing these regulations by successful control and management of the ship’s biofouling results on great economic and environmental benefits coming mainly from reducing the fuel consumption and by extension the CO₂ emissions.

The concluding chapters in this study emphasis on the innovative technologies of antifouling systems to succeed in preventing the invasive aquatic species attachment to the hulls, reduce CO₂ emissions and improve ship’s speed.

**KEYWORDS:** Biofouling, maritime regulatory, chemistry, machinery, CO₂ emissions.
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<td>Ballast Water Management Convention</td>
</tr>
<tr>
<td>CP</td>
<td>Cathodic protection</td>
</tr>
<tr>
<td>EPS</td>
<td>Extracellular Polymeric Substances</td>
</tr>
<tr>
<td>GEF</td>
<td>Global Environment Facility</td>
</tr>
<tr>
<td>HFO</td>
<td>Heavy Fuel Oil</td>
</tr>
<tr>
<td>IAS</td>
<td>Invasive Aquatic Species</td>
</tr>
<tr>
<td>IMO</td>
<td>International Maritime Organization</td>
</tr>
<tr>
<td>RO- RO</td>
<td>Roll On- Roll Off ship</td>
</tr>
<tr>
<td>ROV</td>
<td>Remotely Operated Vehicle</td>
</tr>
<tr>
<td>MEPC</td>
<td>Marine Environment Protect Committee</td>
</tr>
<tr>
<td>MGPS</td>
<td>Marine Growth Prevention System</td>
</tr>
<tr>
<td>MRV</td>
<td>Monitoring, Reporting and Verification</td>
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1. Chapter I:  INTRODUCTION

Invasive aquatic species are now generally recognized as one of the serious threats to global biodiversity. They have severe impacts on the economy, the environment and health; and therefore, they place enormous constraints on the sustainable development (Wangrau, 2017). In aquatic and coastal environments, invasive species have been identified as one of the four greatest risks to the oceans with land-based sources of marine pollution, over-exploitation of living marine resources, and alteration or physical destruction of marine habitats.

The ecological disasters caused by the sinking of the Amoco Cadiz on 16 March 1978 (Hartog & Jacobs, 1980), Tanio on 7 March 1980 (Ganten, 1985), Erika on 12 December 1999 (Poncet, Laruelle, Ragot, & Tintilier, 2003) or Prestige on 13 November 2002 (BBC, 2002) to name only the most famous, are known to be very challenging visible shipping disasters. Pollutants due to ballast water discharge and biofouling of ships are also catastrophic for the maritime ecosystem but less known and more difficult to establish (Lakshmi, 2018). Ballast waters, although indispensable for navigation, constitute a much more important vector of marine pollution than an oil spill (Lakshmi, 2018).

Since its opening in 1869, The Suez Canal has supplied the largest number of successfully established alien marine species in the Mediterranean Sea in terms of vastness, frequency and duration of the transfer. Thereby, the Suez Canal is the preferred path of invasive species from the Red Sea to reach the Mediterranean. Researchers stated that; " nearly 700 known multicellular and non-native species in
the Mediterranean, more than half have been allowed through the Suez Canal” (Otero, Cebrian, Francour, Galil, & Savini, 2013).

Worldwide, shipping traffic has increased significantly since the early 1990s and has experienced unprecedented growth (Ducruet, Roussin, & Jo, 2009). It is in the Indian Ocean that the most massive increase has been recorded: it has exceeded 300% in 20 years. In the North Atlantic, North Pacific and the Mediterranean, the increase is estimated between 100% and 200% (QIU, 2016). With the growth of international trade in recent decades and especially of transoceanic maritime transport, littoral states have been confronted with ecological problems of a new order related to the contribution of living organisms foreign to the local environment. The introduction of these species can have adverse effects on public health, the environment and the local economy. In addition, it can have adverse effects on local ecosystems, which can end up without a predator and proliferate without control (McLean, 2015). The introduction of invasive aquatic species associated with global shipping has been identified as a significant threat to the world’s oceans and coastal ecosystems. Many research suggested that 70-80% of IAS introductions occur through Bio-fouling, and new areas are increasingly affected (Lakshmi, 2018).

Ships can transport alien species in ballast water, as hull fouling or as solid ballast (i.e. with sand, rocks, soil and so on) (IMO, 2017). Hull fouling on ships was recognized as a vector for alien introductions when non-native species were found for the first time in the Mediterranean (Ribera, 2002). As a result, The International Maritime Organization (IMO) adopted, on 15 July 2011, guidelines “Resolution MEPC 207(62)” for the control and management of ship’s Bio-fouling to minimize the transfer of invasive aquatic species (IMO, 2011).

Nowadays, shipping emissions account for 2.5% of the global CO₂ emissions per year, is predicted to increase between 50%-250% by 2050 (EU Commission, 2017), IMO estimates that in 2020 CO₂ emissions from the maritime sector will have increased by 30% (ICS, 2014). Management of ship hull fouling could improve the
performance of the ship; improve the speed of the ship, reduce fuel consumption and thus minimize CO₂ emissions (Hydrex, 2011).
2. Chapter II: SYNOPTIC OF POLLUTION BY SHIP'S HULL FOULING

2.1. Introduction

Shipping activity in coastal waters and ports carries species, not only inside but also attached outside the ship, from virtually any point on the planet to any other, whatever the distance. The number of organisms transported per day over long distances is estimated in billions of individuals (ISSG, 2016). Organisms attach themselves to the hulls of ships, fouling these wetted hull surface areas, or live within the protected nooks and crannies such as sea chests; This is called fouling of the hull or vessel fouling or Biofouling. These organisms then colonize the hull from one port or bioregion to the next. Invasions can occur when these fouling organisms come in contact with structures in a new port or release their larvae into its waters, possibly establishing themselves in the new port and spreading to nearby areas within that bioregion (Yebra, Kiil and Johansen, 2004). This can result in adverse ecological effects in landing areas, as introduced species can aggressively compete with native species, endangering food and habitat as well as introduced viruses and bacteria that can cause disease in local populations (Lakshmi, 2018).
2.2. Biofouling is a major vector of aquatic invasive species transfer:

The Ballast Water Convention was adopted on February 13, 2004, and could have been an Annex VII of MARPOL. It came as a result of the observation and extensive monitoring and research about the living organisms that ballast water contains, which are released during discharging of the water in a new area. These organisms then develop so much that they invade the new waters by eliminating their local species. Ballast water can also allow dangerous bacteria to travel this way. This convention, therefore, focuses on the means to be implemented to limit this serious type of pollution. The IMO Member States made a clear commitment to minimizing the transfer of invasive aquatic species by shipping. When the BWM Convention entered into force in September 2017; however, it may not be enough to minimize the transfer of invasive species.

Marine organisms are transferred by vessels via two main vectors; to ballast water and biofouling, which have process stages. Several factors affect the transfer of species by vessels. Table -1, enumerates factors according to the two transfer vectors. These factors are significant because the quantity and frequency of propagule transfers are considered significant determinants of establishment success, whereas the biogeographical status of organisms determines the conditions of transferred species. The table showed that the majority of factors play a very important role in the transfer of species through biofouling than by ballast water (Davidson, Scianni, Minton, & Ruiz, 2018).
Table -1: Factors affecting species transfers by ship’s (Davidson, Scianni, Minton, & Ruiz, 2018). The relative importance of the factor (from not applicable [no symbol], relevant [+] , important [++] and very important [+++])

Researchers have highlighted how the slowdown in the global economy in 2008 led to the under-employment of merchant ships resulting in long periods of downtime, which have increased the risk of invasion by these vessels. As ships typically accumulate fouling organisms when they are stationary rather than underway, biofouling becomes a very significant driver of invasive aquatic species transfer (Floerl & Coutts, 2009).
2.3. The Phenomenon of attachment of organisms to the surfaces of hard bodies:

2.3.1. Biofouling

Biofouling or biological fouling is the accumulation of aquatic organisms such as plants, algae, or animals on surfaces exposed to the aquatic environment. Biofouling takes into account macrofouling and microfouling (Tortora, Funke, & Case, 2010). Attachment of aquatic organisms to the vessels’ hulls is a very significant problem. Accumulation of these aquatic species can increase the hydrodynamic volume of the ships, which is expressed by an increase of the drag to 60%. This results in a speed reduction of up to 10%, which necessitates an increase in fuel consumption of 40% to compensate, (Steve McElvany, 2009). The increase in fuel consumption due to the roughness of ships' hulls has adverse environmental effects and is expected to increase CO2 and sulfur dioxide emissions by between 38 and 72% by 2020 (Wharton et al., 2010).
2.3.2. Biofilm:

Biofilm includes groups of microorganisms composed of cells that attach to each other and also to a surface. Thus, the cells in a biofilm constitute components; extracellular polymeric substances (EPS), proteins and DNA. By this three-dimensional structure, they represent a community life model for microorganisms (Watnick & Kolter, 2000). Biofilm is a complex polymer that contains several times its dry weight in water and is considered a hydrogel. They are biological systems in which bacteria are organized into a community. Biofilm attaches to surfaces that include a single species or group of microorganisms and share the nutrients with each other. When a bacterium is attached to a surface, it is the birth of a “biofilm” formation (Tortora, Funke, & Case, 2010). Biofilms and the resulting bacterial activity were known for the problems inherent in their ability to cover and corrode the pipes or the vessels' hulls.
2.4. Formation and development of Microbial Biofilm:

According to (Stoodley, Sauer, Davies and Costerton 2002), there are five stages in the mechanism of biofilm formation, as shown in Figure- 2:

1- The phase of transport and attachment of the cells to a substrate, as well as the creation of a so-called conditioning film;
2- Reversible cell adhesion with Extracellular polymeric substances (EPS) production;
3- The beginning of microbial growth and evolution of biofilm architecture with the development of primary micro-colonies;
4- The maturation of the biofilm with the development of colonies; and
5- Microbial detachment or detachment of biofilm colonies in response to hydrodynamic conditions.

Following detachment, the microorganisms (or colonies) are dispersed back into the surrounding environment, where they can colonize other portions of the surface. Many genetic studies carried out on biofilms, have to lead to the same a five-step development model.
After the very fast conditioning of the surface, the bacteria move in the liquid medium thanks to the strength of the flow, the gravitation and/or the movements of their flagella. Then, as the cells divide, the number of bacteria associated with the surface increases and adhesion becomes irreversible; this is the second step. This transition to irreversible adhesion corresponds to the synthesis of structures on the surface of the bacteria, which is accompanied by a profound change in the expression profile of genes. The third stage is characterized by the formation of microcolonies consisting of both the primary bacteria that divide and the bacteria that are associated with the biofilm. Finally, the maturation stage corresponds to the development of microcolonies and the structuring of the biofilm: micro-colonies develop into thick pillars variable within which cells are encompassed in the extracellular matrix. Some bacteria can come off mature biofilm and enter the dissemination phase. This last step allows the colonization of new surfaces (Houdt, 2010). The whole process is illustrated in figure 2.
2.5. Biofouling process:

In the marine environment, biological fouling is highly developed. As shown in figure 3, biofouling is accumulated on the ship’s hull, seawater cooling systems, platforms, buoys, underwater cables, oil installations, offshore structures and underwater acoustics instruments. Several areas outside the vessel with good aeration such as the propeller, bow thruster, steering gear and waterline, experience the greatest amount of fouling (Lebret, 2009). The most common marine foulers are brown algae Ectocarpus and green algae Ulva australis.

![Figure 3: Marine biofouling examples. Areas are susceptible to biofouling on a typical ship (middle) and the common hard-shelled barnacle (Teraclitellapurpurescens), (Bixler & Bhushan, 2012).](image)

The biofouling process can be understood as shown in Figure -4. The First step is short (1 min), and provides a stickier surface that allows microorganisms to adhere. This step consists of a simple physical reaction, a layer of conditioning film composed of organic substances, which are protein, proteoglycan can and polysaccharide, is formed
on the substrate surface. The biofilm then develops as bacteria and microalgae adhere to the surface. Microorganism colonization involves two distinct steps: reversible adsorption, and irreversible adhesion, as described before in section 2-2 formation and development of microbial biofilm (Lebret, 2009).

Figure 4: Temporal settlement of fouling organisms on a substrate surface, (Abarzus, 1995).

After the formation and development of the microbial biofilm, larvae or spores of macrofoulers will attach to the surface. Two or three weeks later, these will finally evolve into a complex biological community. In marine immersion experiments, adhesion of macroorganisms usually occurs after biofilm formation, (Abarzua, 1995). For some biofoulers such as bryozoans and Polychaetes, they adhere before the formation of biofilm. Thus, the process of biofouling forms by both physical reactions and biochemical reactions (Figure 5). The physical reactions factors are water flow and electrostatic interaction and occur in the formation of conditioning biofilm and adsorption of microorganisms. Then, the biochemical reactions include adhesion of microorganisms, the formation of biofilm and adhesion of macrofoulers. Whereas the
physical reactions are usually reversible, the biochemical reactions are effectively irreversible (Abarzua, 1995). It is, therefore easier to prevent biofouling at the physical reaction stage rather than during biochemical reactions.

![Biofouling process](image)

**Figure-5:** Biofouling process (Abarzus, 1995).

### 2.6. Mechanisms of attachment of organisms:

More than 4000 marine biofouling aquatic species have been reported globally, most of which live mainly in two environments: ports that favor a refuge full of nutrients and in shallow waters on the coast (Shan, JiaDao, HaoSheng, & DaRong, 2010). Marine attachment organisms can be isolated into two major categories:

- Microfouling or Biofilm organisms such as bacteria and diatoms.
- Macrofouling organisms, which are algae, barnacles, mussels, polychaete worms, bryozoans and seaweed (Shan, JiaDao, HaoSheng, & DaRong, 2010).

2.6.1. Bacterial adhesion:

The surface-liquid interface such as the one between the ship's hull and water is favors an ideal environment for attachment and growth of micro-organisms. The attachment of microorganisms on the solid surfaces can be obtained according to several factors; the hydrodynamics of the aqueous media, characteristics of the media, the effect of the substratum, conditioning the films that form substratum and, various properties of the cell surface (Dalsin and Messersmith, 2005).

The roughness of the surface is an essential factor for microbial colonization. Studies have shown that the extent of microbial colonization appears to increase as the surface roughness increases. This is because shear forces are diminished, and the surface area is higher on rougher surfaces (Donlan, 2012). The hydrophobicity of the cell surface is important in adhesion because hydrophobic interactions tend to increase with the growth of microbial surfaces and/or the surface of the substratum. Different characteristics of aqueous environments, such as nutrient levels, pH and temperature, play a role in the rate of microbial attachment to surfaces. Researchers have shown in a laboratory study that an increase in nutrients concentration correlated with an increase in the number of attached bacterial cells (Fletcher, 1988).

2.6.2. Microalgae adhesion:

The dominant microalgal organisms are diatoms; their attachment mechanism is as shown in figure-6:

- Secretion of mucilage strands at the central pore, and their attachment to membrane components and substratum;
-Relative backward movement of the membrane components, which leads to forward displacement of the framework itself and the cell as a whole;

- Breaking of the mucilage strands, which forms a short trail.

![Diagram of diatom actions](image)

Figure-6: Actions in diatoms (Shan, JiaDao, HaoSheng, & DaRong, 2010).

According to the published researches, the mechanisms of attachment of microalgae are complicated, and the comprehension always remains primary and still lack theoretical support (Shan, JiaDao, HaoSheng, & DaRong, 2010).

2.6.3. Macro-organism adhesion:

The macro-organisms such as spores of macroalgae, bryozoans, barnacle larvae, molluscs, polychaete, coelenterates and tunicates are the most problematic feature of biofouling. Several experiments have shown that their attachment conditions are determined by surface topography, water streaming conditions and chemical properties (Broberg, Kristensen & Meyer, 2008). Some other specific macro-organisms have different adhesion mechanisms, barnacles as an example have been
studied in great detail, and results indicate that their cyprid antennule consists of four segments that are responsible for crawling, attachment and sensory functions (Shan, JiaDao, HaoSheng, & DaRong, 2010). When an appropriate surface is found, the cyprid will adhere by secretion of granulated cement containing high concentrations of proteins. This cement embeds the antennular attachment organs and hardens because of protein polymerization. After the stable settlement, cyprids metamorphose into juvenile barnacles and finally become adults (Abazrzua, 1995). In the case of Ulva spores, they typically adhere to the surfaces by secreting glycoprotein, and then retract the flagella and form a cell wall.

2.7. The life of organisms on the surfaces of ship’s hull:

2.7.1. Nature of organisms:

The surfaces of the ships may contain aquatic organisms at all stages of life, including; bacteria, Vibrio cholera, fungi, toxic micro-algae, small invertebrates and eggs, spores, seeds, cysts and larvae of aquatic animal and plant species. Some examples of these cycles are shown in figure 7.
Biofouling of vessels has been associated with the introduction of non-native organisms in many parts of the world. For example, more than 65% of the non-native marine species in the waters of New Zealand, Hawaii (United States) and Port Phillip Bay (Australia) have probably been displaced via biofouling. These were mainly unicellular planktonic organisms, diaspores of benthic photosynthetic multicellular organisms, planktonic invertebrates of benthic invertebrate larvae; but eggs, larvae and even adults of teleost could also be present (Bell, 2011).

2.7.2. Survival:

2.7.2.1. In the ship hull:

Some micro-algae are able to acclimate to the severe conditions that prevail on the ship’s hull, different from those of their areas of origin by using their potentiality of heterotrophy or mixotrophic (organisms have been described in sea water) (Adolf, Stoecker, & Harding, 2006). The abundance of some species may drop sharply in the first days of transport, in other species, ship’s hull and niche areas will play the role of the incubator and promote their rapid multiplication. Sea chests have been shown to harbour large communities of biological fouling. Researchers found that 80% of the vessels sampled on the west and east coasts of Canada had biological fouling.
organisms in their marine coffers (Floerl & Coutts, 2009). Twenty-one percent of the identified taxa (groups of organisms identified by taxonomists as a separate unit) sampled in the crates of vessels in British Columbia were non-native or cryptogenic (unknown origin), of which nine were non-native and had not yet settled populations in adjacent waterbodies (Floerl & Coutts, 2009).

2.7.2.2. **In the new habitat:**

The survival rate of the species thus transported by the ship’s hull depends on the conditions of the receiving zone (climatic conditions, brewing conditions, season, light, depth, availability of nutrients, the presence of potential predators, and so on). However, implantation is facilitated when conditions are similar in terms of salinity and temperature. Among the mechanisms that may explain the success of some accidentally introduced species, the absence of parasites was mentioned is when the species introduced free of infestation would have an advantage over one (or more) native species having coevolved with parasites. This theory was tested and verified with the two gastropods; Nassarius reticulatus (native species) and Cyclopeneritea (introduced species) in the Archon Basin, with, for the first time, an attack by five families of trematode Diogenes and prevalences that can reach 18%, and, for the second, a virtual absence of parasites. Similarly, Ruditapes philippinarum clams appeared to be less infested with pests, compared to three other native bivalve species, which may have contributed to the expansion of this introduced species (Bachelet, 2006).
2.8. Impacts of the introduction of IAS:

2.8.1. Ecological impacts:

In any ecosystem, the introduction and spread of exotic species are highly harmful because of the negative and irreversible changes that can result. Exotic species that do not have natural predators can decimate populations of native species by altering their habitat, over-feeding or competing for a particular food source (McLean, 2015). Some species can also alter the dynamics of the ecosystem. For example, zebra mussels (in Great lakes) increase the clarity of water by filtering large amounts of phytoplankton, but the increased penetration of light has caused serious problems for Walleye populations (Stizostedion vitreum) and other organisms adapted to more turbid waters (Stanczak, 2004).

![Figure 8: The quagga mussel (Dreissenabugensis) (bottom photo) a native species threatened by the zebra mussel (Dreissenapopolymorpha).](image)

The increased penetration of light also promotes the proliferation of various species of algae (e.g., Cladophora) at greater depths. The zebra mussel also poses a significant threat to some endangered indigenous species of unionids, such as the quagga mussel.
(Dreissenabugensis), because it competes with these species for food and attaches to their shells, causing their death. Both mussels similar features are shown in figure 8.

2.8.2. Economic impacts:

Biofouling increases production costs of aquaculture operations by an estimated five to ten percent, or equal to 1.5 to 3 billion USD annually (Fitridge, Dempster, Guenther, & De, 2012). As an example, biofouling impacts European finfish aquaculture specifically between five and ten percent of the industry value, or up to 260 million USD/year. These increased costs and negative impacts are due to a variety of general factors (Scianni, Falkner, &DeBruyckere, 2017), including:

- Direct fouling of cultured stock causing physical damage and heavy biofouling can reduce the price of a product by 60% - 90% (Cohen, 2006)
- Disrupting the normal aquaculture operation (e.g., valve obstruction in cultured mussels)
- Fouling of infrastructure
- Competing with cultured stocks for the same resources
- Directly and indirectly affecting the space occupied by the aquaculture operation (e.g., causing the cultured stock to drop from lines due to heavy biofouling)
- Restricting water exchange
- Causing a higher risk of diseases
- Causing deformation of cages and structures.

Global shipping industry costs associated with biofouling prevention, vessel maintenance, and fuel consumption are estimated to be in the billions of dollars annually. Although it is not a direct economic impact, biofouling-induced fuel consumption is also responsible for excessive GHG emissions from ships, which is discussed in the chapters that follow.
2.8.3. Impacts on the human health:

Exotic species can also destroy the environment and threaten the health and safety of human populations. This is the case of the Chinese mitten crab (Eriocheirsinensis), which is able to live both in freshwater and saltwater and which was discovered in the Bas-Saint-Laurent in 2004 (Willemsen P.R. 2005). This crab can travel hundreds of kilometres by inland waterways and has an extremely high reproduction rate. It digs tunnels in the banks of rivers, causing soil erosion and bank subsidence (Willemsen P.R. 2005).

![Crabe chinois à mitaine (Eriocheirsinensis).](image)

Figure 9: Crabe chinois à mitaine (Eriocheirsinensis).

This crab also poses a threat to human health as it hosts an eastern lung fluke (Paragonimuswestermani), a parasite that can cause serious illness in humans and other animals as it crosses the river.

Another example is the zebra mussel that absorbs hazardous compounds such as polychlorinated biphenyls (PCBs). Fish and waterfowl that consume zebra mussels contribute to the transfer of these toxic compounds into the food chain (Forrest and Blakemore, 2006).
2.9. The genesis of the regulations:

Ships' hulls can contain thousands of aquatic species, ranging from bacteria and other microbial organisms to microalgae and plant and animal species at various stages of development. The risk of introduction of this species resulting from the ship’s hull is therefore high. A species (e.g., plant, fish, mammal or microorganism) is described as exotic or non-native if it is not naturally present in a given ecosystem. It is considered invasive if its introduction is likely to have a negative impact on the environment, the economy or the human health. The magnitude of their impacts depends on the origin of the introduced organisms and the location of dissipating. Thus, control and management of biofouling are imperative and necessary.
3. CHAPTER III: REGULATORY REQUIREMENTS FOR THE CONTROL AND MANAGEMENT OF SHIP’S BIOFOULING

3.1. Introduction

Since the invasive species have been recognized as very dangerous for the ecosystem and human health, IMO, the regulatory specialized UN body has adopted in 2011 the guidelines for the Control and Management of Ships’ Biofouling by resolution MEPC.207(62) in order to minimize the transfer of Invasive Aquatic Species. The Guidelines are supplemented by the Guidance for minimizing the transfer of invasive aquatic species as biofouling (hull fouling) for recreational craft circulated as MEPC.1/Circ.792 in November 2012.

Only a few countries such as New Zealand’s have started to develop and implement biofouling regulations as it is fairly new. Biofouling has then started to appear on the international radar. All regulators should communicate with each other, and the whole shipping industry, in order to share their experiences and lessons learned when combatting this serious problem. Although only a few places worldwide hold vessels accountable for hull maintenance, the hope is that more Member States effectively
implement biofouling management requirements and the compliance will also be improved as vessels will have a higher standard (Ministry of New Zealand, 2017).

3.2. Guidelines for the control and management of ship’s biofouling MEPC.207(62)

3.2.1. Guidelines objectives:

The objectives of these guidelines are; the implementation of good practices for the management of antifouling systems on board ships to reduce the development of biofouling and provide advice on measures to reduce the transfer of invasive species from ship biofouling, to states, ship operators, dry docking and classification societies (Res. MEPC.207(62), 2011). It gives the most effective measures to minimize the risk associated with ships’ biofouling.

3.2.2. Biofouling management plan and record book:

3.2.2.1. Biofouling management plan:

It is recommended that each vessel has a biofouling management plan. The objective of the biofouling management plan is to provide effective procedures for biofouling management. It can be integrated into the operational manuals of the ship or even as a stand-alone document. Each vessel must have its biofouling management plan and be updated when necessary. Such a plan should contain the following points; The details of the antifouling and niche areas, their operational practices and the recommended operating conditions suitable for the antifouling systems used on board. Biofouling
management plan should also contain, parts of the hull susceptible to biofouling, the
inspection schedule, maintenance program and the renewal of the antifouling system,
if applicable (IMO, 2011).

3.2.2.2. **Biofouling Record Book:**

Biofouling guidelines contemplate that it is recommended that each vessel should have
a biofouling record book on board. It helps shipowners and operators to evaluate the
effectiveness of antifouling systems. The book should record Biofouling management
measures and details of any inspections. Thus, the register could also help the
authorities concerned to evaluate the risk of biofouling on the ship efficiently and
rapidly and to optimize the ship's travel time. Like the biofouling management plan,
the biofouling record book may be a stand-alone document or integrated with the
operational manuals of the ship. Information that should be recorded in a biofouling
record book are as follows:

1) Details about the anti-fouling systems and operational measures used with dates
   of installation and the coated areas of the ship and their maintenance;

2) The dates and shipyards of dry-dockings, including the date when the vessel was
   re-floated, and if other practices are e; ployed to remove biofouling or to renew or
   maintain the anti-fouling system;

3) The dates and subjects of inspection and maintenance of seawater cooling
   equipment, the outcomes of these inspections, and all the corrective measures taken to
   resolve the observed biofouling problems;

4) The date and location of in-water inspections, the reports subject of the inspections
   and the corrective measures are taken to limit the biofouling; and
5) Details of periods of the ship operation outside its normal operating schedule including any information about periods when the ship was laid-up for long periods of time (IMO, 2011).

3.2.3. **Anti-fouling system installation and maintenance:**

3.2.3.1. **Choosing the anti-fouling system:**

The choice of the appropriate antifouling system is a fundamental issue because the antifouling systems are designed according to the operating profile of the vessel. Technical advice is, therefore, necessary to ensure the correct choice of the appropriate system. If the right system is not applied, biofouling accumulation increases. Furthermore, the anti-fouling system chosen should comply with the AFS Convention (IMO, 2001). It is also recommended to install specific antifouling coating systems in distinct areas of the hull such as the bow, seawater cooling system, rudder and internal sea chest to ensure the durability of the coating (IMO, 2011). The factors to consider when choosing the antifouling system are as follows:

1) Ship type and construction;

2) The planning of the ship’s dry dock period;

3) Depending on the speed of the ship, as a choice of an appropriate anti-fouling system can optimize the performance of the vessel speed;

4) Ship’s trade route and periods of inactivity because they influence the rate of biofouling accumulation; and

5) Certification of the antifouling system used;
3.2.3.2. Installing and repairing the anti-fouling system:

During the installation or repair operations of the antifouling coating system, a proper repair of the surface to be treated is required. The preparation of ship’s hull is important to facilitate the adhesion and durability of the antifouling coating system. Precautions must be taken into consideration for the sea chest when installing the antifouling coating system:

1) the internal surfaces of sea chest and the suction grilles should be protected by an antifouling coating adopted to the flow of seawater;

2) Special preparation should be made at the edges and corners of the sea chests, supports and blowing pipes to ensure good adhesion and adequate thickness of the paint; and (IMO, 2011)

3) The installation of the MGPS is necessary to assist the protection of the seawater cooling pipes and the sea chest from foulers, as shown in figure 11. Then, the MGPS installation can offer several advantages; reduces energy consumption and maintains plan and equipment at high efficiency (Dewan, 2015).

Figure 10 The importance of MGPS installation to protect seawater pipes and sea chests from foulers (Dewan, 2015).
Several niche areas other than sea chests and sea water pipes, which are susceptible to biofouling growth, require special management measures:

- **Bow and stern thrusters:** The coating of tunnels and areas around the bow and stern thrusters are susceptible to damage due to the cavitations forces of the propellers. These areas require high-performance coating systems to ensure adequate paint strength and thickness. They should be regularly maintained during the dry dock (Australian Government, 2008).

- **Dry-docking support strips:** These areas should receive a special kind of preparation, and they should be painted at least during alternate docking. It must be ensured that the surfaces under the blocks are covered with antifouling (IMO, 2011).

- **Edges and weld joints:** the weld joints and the exposed edges of the hull are susceptible to be faired and painted suitably to ensure high performance of the coating system.

- **Rudder hinges and stabilizer fin apertures:** Particular attention should be paid when cleaning the hinges of the rudder and behind stabilizers fins for a good preparation of the entire surface. They should also be appropriately lined to withstand wear rates in these areas. In the dry dock, the rudder and fins stabilizers should be free to manoeuvre freely.

- **Propeller and shaft:** The propellers should be covered with an appropriate anti-fouling coating to ensure their effectiveness and to minimize the periodicity of polishing and in-water cleaning (IMO, 2011). Research results have shown that the cleaning and polishing of the propellers can recover significant loss of propulsion efficiency. Besides, these losses can be avoided by applying a suitable paint system
for the propellers. Propeller covered by such a coating is designed as new (Korkut & Altar, 2012).

- **Stern tube sealing system and the internal surfaces of rope guards**; The internal surfaces of the cable guards and the exposed seals of the stern tubes should be carefully covered with coating antifouling.

- **Cathodic protection (CP) anodes**; Some parts of the hull are not painted with antifouling coating for operational reasons, and we should be careful. Such parts include anodes, speed log and echo sounders. The housing should be internally painted with a coating anti-fouling for static conditions. For the anodes flash-fitted in the hull, rubber baking pads are inserted between anodes and hull. If the anode is fixed with bolts, the recess should be caulked to prevent biofouling colonization. Anodes should be regularly inspected and maintained every dry-docking.

- **Sea inlet pipes and overboard discharges**; An adequate antifouling coating should apply the inside of pipes overboard and the accessible internal areas of these pipes. The anti-corrosive or primary coating should be specific to the pipe materials to ensure good adhesion of the paint and good coating thickness (IMO, 2011).

3.2.3.3. **Procedures for ship maintenance and recycling facilities**;

Ship recycling and maintenance facilities should be in accordance with national regulations and laws to ensure the absence of chemical and physical pollutants releases to the marine environment. These measures are as follows:

1) Treat the rejection of the biofouling removed in a manner appropriate for the environment;

2) Make sure not to have negative impacts following the release of organisms captured in the local marine environment, to minimize their risk of survival;
3) Plan ship arrivals/departures at maintenance facilities to minimize the risk of vessel contamination by others and their aquatic environment;
4) When dry docking, eliminate all of the biofouling from the ship’s hull and niches areas; and
5) When dry docking, extending and lowering retractable equipment such as thrusters and fins stabilizers to allow access maintenance equipment to eliminate biofouling (IMO, 2011).

![Figure 11 example of extending fins stabilizer, when dry-docking (Grant, 2015).](image)

3.2.4. **In-water inspection, cleaning and maintenance:**

3.2.4.1. **In-water inspection of ships:**

In-water inspection of the ship’s hull can be a means of routine control performed periodically to assess the state of the biofouling. It is a beneficial inspection process to
have a follow up on the state of antifouling systems and eliminate any high-risk situation. Opportunities that require in-water inspection are:

1) An in-water inspection is required, prior to biofouling cleaning processes, to determine the nature of suspected invasive aquatic species on the hull of the vessel;
2) Before and after an extended stoppage of the vessel, for technical or operational reasons, or before a significant change in the vessel's rotation;
3) An in-water inspection is also necessary, after the discovery of a suspected organism in the seawater cooling system; and
4) Following damage, or deterioration of the antifouling system.

Niche areas on the vessel that may have accumulated biofouling should be identified by the operator of the ship. This procedure makes it possible to target the zones to be inspected and facilitates the work during the inspections. Niche areas may include (Propeller thrusters and propulsion units, sea chests, rudder stock and hinge, fins stabilizer apertures, propeller shafts, rope guards and stern tube seals, cathodic protection anodes, anchor chain and chain lockers, free flood spaces inherent to ship’s design, sea chest and thruster tunnel grades, echo sounders and velocity probes, overboard discharge outlets and sea inlets. In addition to areas prone to antifouling coating system damage or grounding such as areas of the hull damaged by fenders).
3.2.4.2. **Underwater dive inspections using Dive and Remotely Operated Vehicles (ROV):**

Dive and Remotely Operated Vehicle (ROV) can be a very practical means for in-water inspections, but these machines sometimes find it difficult to access some niche areas. These inspections should be carried out by qualified persons, have the necessary experience and knowledge about the IAS and with the risks related to the safety of ROV machines. Figure 14 shows underwater robotic inspections of the ship's hull and niche areas.

Figure: 12 Biofouling on niche areas of the ship (DAR, 2013).
3.2.4.3. **In-water cleaning and maintenance:**

Among the important actions of biological fouling, treatment is underwater cleaning. Cleaning in water can cause environmental hazards, depending on the nature of biofouling, the biocidal content of the antifouling coating system and the amount of leftover released into the local environment of the antifouling coating. Just like the methods of removing macro-fouling, micro-fouling can be carefully removed with gentle techniques that minimize the deterioration of the coating of the antifouling system or the release of antifouling coating biocide. In-water cleaning can reduce the risk of spreading aquatic invasive species by preventing fouling build-up on the hull of the vessel. Cleaning processes in the water can also improve vessel efficiency and speed, reduce fuel consumption and CO₂ emissions. It is therefore recommended to clean the ship’s hull and niche areas when it is possible (IMO, 2011).

It is recommended that states perform a risk assessment of underwater cleaning to minimize the threats to their property and their local environment. Risk assessment factors are; factors that influence the accumulation of biofouling, such as changes in the vessel's operating profile, the biological risk that biological fouling organisms are removed from the ship, if known, the geographical area causing the biological fouling
on the vessel and finally, the toxic effects related to the substances contained in the coating of the antifouling system which could be released following the processes of in-water cleaning and consequently any possible damage to the antifouling system.

3.2.5. Ship construction:

During ship design stages or significant change on the ship construction, the following actions should be highly considered:

1) Small niches and sheltered areas should be avoided from the ship structure when possible, such as flush mounting pipes in sea chests.
2) The design of this equipment should be made so they will be easily accessed during inspections, cleaning and anti-fouling coating applications or maintenance.
3) The corners, gratings and protrusions should be rounded to allow for more effective coverage of anti-fouling coating systems. Granting should be hinged to enable diver access.
4) Blank off the sea chest and similar areas, such as moon pools, floodable docks and other free flood spaces should be possible for cleaning and maintenance (IMO, 2011).

3.3. GloFouling project:

GloFouling project focuses on the effective implementation of the IMO guidelines for the control and management of ships’ biofouling. It was the deep research that further detected the serious need for adopting the guidance on how biofouling should be controlled and managed in order to limit the transfer of IAS. It has shown that IAS is the source of significant environmental and socioeconomic impacts that can affect fisheries, mariculture, coastal infrastructure and other development efforts, ultimately threatening livelihoods in coastal communities (IMO, 2017).
The GloFouling project relies mainly on the success of the UNDP (United Nation Development Panel), the GEF (Global Environment Facility) and the IMO partnership project GloBallast (GEF, 2017). This project has aimed at strengthening the implementation capacity of the IMO Convention on Ballast Water Management (BWM), which treats potentially invasive aquatic species in ballast water.

A successful environmental specialist from the GEF, Chris Severin said: “The implementation of the GloFouling Partnerships will be instrumental in battling aquatic invasive species and will not only lead to healthier more robust marine ecosystems but also positively impact economic opportunities and the livelihoods of millions of people across the globe” (Lakshmi, 2017). He stated; that will be another fingernail between the GEF, UNDP and IMO (Lakshmi, 2017).

3.4. Conclusion:

The guidelines for the Control and Management of Ship’s Biofouling to Minimize the Transfer of Aquatic Invasive Species (Resolution MEPC.207 (62)) is intended to provide a method for the management of biofouling that is uniform worldwide. The BWM Convention that entered into force late in 2017 is indeed a great step to protect the marine ecosystems. However, it may be insufficient to limit the transfer of IAS.

Currently, only some states around the World have merchant fleets accountable for hull maintenance, but the aim is that as more States implement IMO guideline, their ships compliance will also increase as the ships will have an increasingly higher standard. In addition, the hope is that every regulatory body in each State will communicate its experience with the others in order to give the advice for the States on their way to implement the guidelines because biofouling guidelines is still a new and challenging field. That will allow a more and more successful and smooth implementation with possible future improvements in the regulation.
The next chapter will see the importance of biofouling management not only in the context of the transfer of invasive species but also as a strong point to improve the speed of the ship and reduce fuel consumption.
4. CHAPTER IV: Case Study Ship: Data Analyze and Innovative Technologies

4.1. Introduction:

RO-RO passenger ships are known for their very busy and punctual schedules. They need to sail with high speeds to arrive on time and respect the planned timetable for passengers, cars and trucks in order to satisfy their customers. The ship fuel consumption is known to be a cubic function of the ship speed, which makes the Ro-Ro passenger ships high fuel consumers considering their high sailing speeds. In a global context where the fuel price continues to vary considerably, the ship owners have strategically adopted different solutions to reduce their ships’ fuel consumption and consequently their GHG emissions. This can be achieved by improving the ship energy efficiency, which has become a priority for shipping companies given the huge impact of the cost of energy on their financial performance and the environment.

The hull fouling increases the hull roughness, which increases its total water resistance and thereby results in additional fuel usage. The hull maintenance and coating must be well done in order to offer a perfect hydrodynamic so that the ship can sail at maximum speed while maintaining its energy efficiency. Therefore, as the ship speed and the fuel consumption are the main concerns of Ro-Ro passenger ship owners, the hull maintenance is worthy for great consideration when trying to minimize the ship fuel consumption, voyage cost and GHG emission, while maximizing her speed.
In order to further validate the above, this chapter will investigate the speed profile of a case study Ro-Ro passenger ship concerning to her fuel consumption. This will be followed by examining the ship’s hull maintenance techniques during dry dock periods and their effect on the ship speed and fuel consumption profiles. To conclude, the chapter will examine the ways for improvement in the ship hull maintenance.

4.2. Identification of the ship:

The case study ship studied in this research is a Car Ferry passenger ship sailing regularly between Tunis (Tunisia), Marseille (France) and Genova (Italy). The vessel was selected because she is engaged in regular voyages between the different regions North Africa and Europe according to a planned schedule with high speeds. In addition, she is subject to the maintenance of the outer hull annually as a passenger ship and is applying the EU standards for passenger ships in addition to the International standards. These factors make the ship data very valuable to meet the research objectives and give the space for thorough information analysis. It allows making important comparisons of the speed changes and fuel consumptions during similar periods of each year. Another reason is related to the availability of data from the company’s staff, which is an obstacle to many researchers because of the confidentiality of information. The table below gives an overview of the ship particulars.
Average of the Ship's Speed

With a fouled hull the ship requires additional power to maintain the service speeds, which results in an increased fuel consumption. Therefore, marine fouling is behind the degradation of the ship hull performance. Adequate hull condition monitoring and periodical maintenance is a crucial tool to ensure the navigability of a ship in favorable conditions with respect to the fuel consumption and GHG emission.

The ship subject of this study follows a regular schedule throughout the year. This schedule is vivid during the three and a half summer months; June, July, August and the first half of September. Therefore, the yearly dry dock period is always planned to be approximately 20 to 25 days in May to ensure the ship readiness during the peak season. The maintenance of the ship's hull during the drydock period is an important work to carry out in order to eliminate the fouling and treat the hull immersed part again.

### Table 2: The ship particulars

<table>
<thead>
<tr>
<th>Name of the ship</th>
<th>CARTHAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of the shipowner</td>
<td>Compagnie Tunisienne de Navigation, COTUNAV</td>
</tr>
<tr>
<td>Type of the ship</td>
<td>Ro-Ro / Passenger</td>
</tr>
<tr>
<td>Deadweight (in metric tonnes)</td>
<td>4 100</td>
</tr>
<tr>
<td>Gross Tonnage</td>
<td>31 647</td>
</tr>
<tr>
<td>Classification Society (voluntary)</td>
<td>Bureau Veritas</td>
</tr>
</tbody>
</table>

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During 2015, 2016 and 2017 the vessel undergoes periodic maintenance in the dry dock before starting the summer season and the monthly average speeds of the ship during these years are shown in the following figures 11, 12 and 13.

**Figure 14:** Average speed case study ship 2015

**Figure 15:** Average speed case study ship 2016
Figures 11, 12 and 13 show that the vessel reaches its maximum speed during the period between June and September, the three months following the dry dock, in the years: 2015, 2016 and 2017. In other words, the ship speed has improved directly after the cleaning operations of the ship's outer hull, and after eliminating the fouling in the area under the waterline. The graphs further show that the average speed was increased about 1.5 knots, compared with the same duration but from January to April. Noting, that the maximum speed of the vessel during May, before the dry dock, for the same trip and under similar conditions, is 21.6 knots while in June the ship reaches a maximum speed of 24 knots by using same propulsion engines power (24000 kW). It should be mentioned that the ship draft and trim conditions for these comparisons are at the same values with which the ship operates typically at the majority of the time. In addition, it was assumed that the weather encountered by the ship for the same periods had the same conditions, which is correct at a very low difference because the Mediterranean region has the same climate for the same periods in the year. Furthermore, the hull maintenance was conducted with the same techniques “same
paint and hull coating” for these three years. As a result, a significant improvement in the ship speed that has reached 2.4 knots was achieved with the hull maintenance.

Figures 11, 12 and 13 also show a drop in the average ship speed during November and December, which is explained by the low season frequency of voyages where the schedule allowed for these speeds. For this reason, the hull maintenance effect was more valued during sailing periods with high speeds (high season).

It can be then concluded from the speed profile of this Ro-Ro passenger that the periodical hull maintenance makes the ship hull surface smoother, which reduces its water resistance and allows the ship to reach her maximum speed. It is an important factor to improve the hull performance. This will help the shipping company to respect the planned schedule and satisfy its customers. Moreover, in order to reach the same cruising speeds with a fouled ship hull, more power is required resulting in increased fuel consumption. This will be demonstrated in the following parts of this chapter.

4.4. Thorough Review of the Ship’s Fuel Consumption:

Ship’s hulls degradation consists mainly of biofouling or corrosion, despite the application of paint systems specially designed to combat these phenomena. This may be because of the quality of the treatment of the process of application. The surface degradation will then be detected with an increased ship drag because of the increased average hull roughness. As a result, the ship fuel consumption profile experiences a significant augmentation.

Below is an example of average monthly fuel consumption of propulsion engines of the studied ship (Figure 17). The figure shows a significant decrease in the fuel consumption during July, August and September compared to the months before the dry dock, April, March and February. The average fuel saving during these months is about 15kg per mile. In addition, it has been shown in the previous section that the
ship speed during the summer months was much greater than the speed in other months of the year. This should be considered as additional fuel savings because the net gain, in this case, is not only in the fuel consumption but also in the ship speed. The reason is that for the same condition, in order to sail with higher speed, greater fuel usage is needed and therefore the gain on speed could be quantified into further fuel savings.

Figure 17: Monthly consumption of propulsion engines per mile
Figure 15 shows the monthly fuel consumption with the distance travelled for each month. It describes the summary of the data used to evaluate consumption throughout a year.

From the data analyzed in this section, it can be concluded that the maintenance of the ship's hull during annual dry dock periods was effective in improving the ship’s fuel consumption profile. This demonstrates again that the ship hull treatment is a crucial factor when it comes to the fuel consumption minimization. Focusing on the hull maintenance should be highly considered during dry dock periods in order to improve the overall ship speed and fuel consumption performance.
4.5. Review of Hull Maintenance Operations and Possibility of Improvement during Dry Dock:

4.5.1. General maintenance operations of ship’s hull during Dry Dock:

Scheduled dry docks periods are at the heart of a ship's performance management policies. The periodic effective maintenance allows the ship to sail with the optimal operational performance. Dry dock maintenance plans ensure the complete and systematic revision of several ship equipment. For this study, the ship dry dock periods have proceeded annually in the same period of the year in order to ensure that the ship is at her best performance during the three summer months. It is an important event for the annual life of the ship, which consists of 20 to 25 days immobilization period as an average. The ship receives a special care during these days with a great maintenance work and extensive equipment checks.

As already discussed in the second chapter, the passenger ship driven in dry dock annually to allow access to the submerged parts: hull, thrusters, niche areas and others. The maintenance of the hull starts as soon as the ship is deposited on the tin line and the basin is dry and continues for several stages. These are described for the case study ship in the sections below.

4.5.2. Ship’s hull preparation:

As soon as the basin is empty and the hull is dry, an inspection of the hull surfaces is carried out by the site representatives, the painting technician and the ship owner's representatives in order to highlight the areas that need sanding or hydro-blasting treatment, application of paint layers, scraping or degreasing. These different steps in the hull maintenance operations are explained as below.
-Washing with fresh water under high pressure (250 bars), hull and load exponents, seawater intakes, tunnels bow thrusters, fin stabilizers and their housings, rudders, propulsion propellers and main bow thrusters;

-Removal of sea chests grilles; rear scraping chests and grids, cleaning, application of a retouching layer and two layers of paint and reassembly of the grids;

-Scraping off the painting; and

-Degreasing of contaminated areas if necessary.

4.5.3. Hull treatment:

The corroded areas and damaged areas in the ship hull and exponent of the load up to the defence coil are treated first with abrasive blasting or Hydro blasting (grade Sa 2.5). The same treatment is also applied to the seawater intakes, in bow thruster tunnels, fin stabilizers and their housings and on rudders. In addition, all these areas are carefully cleaned from dust and cleaned with fresh-water rinsing.

4.5.4. Painting of the hull:

Having a clean and well treated hull surface, it is time for the application of the paint layers, which is carried out as follows:

-Application of a layer of touch-up of primary paint HEMPADUR 1763/5063 of 150 µm;

-Application of an intermediate paint retouching layer HEMPADUR 4518/2515 of 100 µm;
- Application of a paint retouching layer ANTIFOULING GLOBIC 9000-7895/6000 of 100 µm; and

- Application of a paint retouching layer ANTIFOULING GLOBIC 9000-7895/5111 of 100 µm.

A certificate is issued by HEMPEL certifying that the paint is a TBT-free antifouling paint that complies with the requirements to antifouling systems as stated in the IMO convention on the Control of Harmful Antifouling Systems on ships (AFS/CONF/26), adopted on 5 October 2001 in London.

### 4.5.5. Replacement of sacrificial anodes:

The sacrificial anode is a type of cathodic anti corrosion systems for the metallic surfaces. It is made from a metal with a more negative electrochemical potential than the metal of the surface to protect from corrosion. This difference in potential will put in favour the corrosion of the anode instead of the structure to protect (cathode). Therefore, the sacrificial anode is a wear component in the submerged surfaces with the aim to protect them from corrosion in a highly corrosive environment, the seawater. These anodes will then disappear after a certain period of time and need periodical check and replacement.

Figure 16 shows the sacrificial anode of the fin stabilizers of the case study ship during dry dock, which has almost disappeared as its life cycle is one year. Figure 17 shows the newly mounted sacrificial anode.
During the dry dock, the sacrificial anodes of the hull, rudders, tunnels of bow thrusters, sea chests, fin stabilizers and in their accommodation, are replaced. The anodes used for this ship are of different types along the ship’s hull. Anodes 10 kg for sea chests, fins stabilizers housing and propellers, anode 13 kg for sea chest overboard and anode 1 kg for gear casing thrusters and fins stabilizers.
The anode status should be monitored during the ship operation through the electrical current continuity between the anode and the ship hull with the specific tools and should be replaced during the dry dock. This will avoid the hull corrosion and therefore limits its roughness and by extension, its resistance.

4.5.6. Maintenance of propellers and bow thrusters:

These operations of maintenance of propellers and bow thrusters include;

- Sanding of port and starboard propeller blades;

- Sanding propeller blades of both front and rear thrusters.

Figure 21: Sanding the blades of the propeller after the high pressure washing (Erfan, 2018).
4.5.7. **Suction sea chests maintenance:**

The sea chests are cleaned with 250 bars of high-pressure fresh water, from seawater ballast to the suction valves of seawater pumps. The coolers (seawater/low-temperature cooling water) for generators and main engines cooling systems are dismantled and cleaned.

![Figure 22: Cleaning cooler plates from the fouling (Tempco, "www.tempco.it", 2017).](image)

The figure 19 shows a sample of the fouling resulted from the mud of the accumulation of algae, mussels and bacteria on the plates of refrigerants, which mainly leads to a decreased heat transfer capacity.

The replacement of sacrificial anodes, scratching of corroded areas in the intake ballast tank, painting and application of a general layer (primary paint HEMPADUR 1763/5063 of 150 μm) can improve the flow rate of refrigeration pumps and subsequently improve the efficiency of thermal transfer, which also results on energy savings.
4.6. Innovative technologies to prevent ship’s hull from Biofouling:

4.6.1. Silicone antifouling system:

Silicone and hydrogel-based is the new SILICONE Antifouling system, which gives the coating the properties that prevent organisms from adhering to the shell and facilitate their detachment when the vessel is sailing. It also has the advantage to greatly facilitate the removal of dirt and the application of new layers, hence a long-term reduction in costs. The silicone antifouling system consists of an anti-adhesive paint and a non-biocidal and copper-free process that comes against the accumulation of deposits. The hydrogel is composed of unique and non-reactive polymers that are added to the paint to create an invisible barrier between the ship’s hull and seawater. The polymers responsible for hydrogel formation are uniformly distributed in the painting film. Organisms then perceive the hull as a liquid and adhere to it much less. If the original hydrogel layer fades, a new layer forms instantly when the polymers responsible for forming of hydrogel come into contact with water (HEMPEL, 2017).

Figure 23: Polymers forming a layer between surface and water (HEMPEL, 2017).
The polymers are distributed homogeneously in the paint film. If the original hydrogel film is removed, the component polymers of the hydrogel allow a new layer to reform immediately on contact with water.

4.6.2. Comparison between traditional antifouling and SILICONE antifouling:

Antifouling is based on the controlled release of biocides to prevent the accession of messy organisms on the ship hull. In touch with water, the top layer antifouling is dissolved, and biocides merge to the coating, which is then protected from messy organisms. Unlike antifouling, the SILICONE system does not use biocides. Silicone and hydrogel products give properties to the aqueous coating that prevent organisms to adhere firmly to the hull and to facilitate their detachment when the vessel is sailing underway.

Concerning the cost of both techniques, a brief comparative analysis could be as follow; For the first year of treatment, the costs associated with antifouling are lower than those of the system SILICONE antifouling. However, maintenance costs during the following years become much higher as the removal of the old painting needs time and different technology, while the SILICONE facilitates the application of new
layers. The costs of the SILICONE system are higher the first year, but the associated maintenance costs are lower for the following year. In addition, during the ship operation, the SILICONE system reduces hull friction and thus improves the ship speed and reduces the fuel usage. The SILICONE system can be used on all types of vessels, except wooden boats. On the other hand, for the antifouling, there are different types of antifouling adapted to different types of boats, according to the surface.

4.7. SILICONE antifouling application process:

The application of silicone is initiated by good preparation of the ship’s hull. For the new ship’s hull (untreated), it is necessary at first, to clean it with a suitable detergent and dry G 120 sandpaper. It is essential to clean the surface thoroughly with fresh water and allow drying. For adequate protection, four coats of HEMPEL Light Primer 45551 should be applied. For surfaces previously treated, additional steps must be carried out for better results. It is first necessary to remove all previous layers of antifouling to the epoxy coating and the clean the surface with water and give it the time needed for drying. A coat of HEMPEL Light Primer 45551 will be then necessary (HEMPEL, 2017).

In order to ensure a good adhesion, a layer of TIECOAT UNDERCOAT 27450 must be applied to the entire surface with a wet film thickness of 100 microns. This type of painting has a recovery intervals of four hours and maximum 72 hours after application of Light Primer 45551 at 20 °C. In addition, a special care should be given to the surface uniformity when applying a generous amount of paint. The surpluses of paint should be blurred before the paint dries. The steps for application are as follows;

-First layer: 20 °C: min. 8 hours, max. 48 hours after the application of SILICONE TIECOAT and 10 °C: min. 16 hours, max. 48 hours after the application of SILICONE
TIECOAT. If the recovery interval is exceeded, a new layer of SILICONE TIECOAT 27450 must be applied.

After applying the described hull treatment process, the ship can be launched into the sea 24 hours after applying the last coat while the maximum time of putting to sea is one month. This new SILICONE system has many advantages as already explained and its maintenance is simple with lower costs than those of traditional antifouling systems, which makes it a good solution for hull protection (HEMPEL, 2017).

4.8. Coating propellers:

Many paint companies other than HEMPEL such as AkzoNobel proposed after deep research the coating of the propellers to avoid their deterioration, such as corrosion, cavitation and fouling. This newly proposed method as shown in figure 22, has given satisfactory results when the research was conducted. (AKzoNobel, 2018).

![Figure 25: Foul release coating on propellers (AKzoNobel, 2018).](image)

The experience they made for this research compared the performances of two ships of the same type sailing between USA and Venezuela, the first with propellers treated with a foul release coating and the second with a traditional sand treatment. This
experiment showed a reduction in daily fuel consumption of 7.7% and an increased speed by 1 knot after the dry docking of the ship N° 1 compared to the second ship. Furthermore, the ship N° 1 has maintained her maximum speed after a 15-month navigation period.

### 4.9 Underwater cleaning methods:

During sailing periods the accumulation of fouling on the ship’s hull becomes the reason behind stretched engines and propulsion system with lower ship speed. Underwater cleaning is another method for hull and propellers maintenance that ensure for the ship an extended sailing period without dry dock entry. This method saves time and can be planned easily to be conducted in the port during normal schedule operation. Many cleaning companies provide today high quality underwater hull cleaning services. In addition to the extended period of navigation, this methods save the fuel cost as it is also effective in reducing the ship’s hull resistance. However, this cleaning system cannot totally replace the dry dock periods, which include additional maintenance work that could not be done by underwater cleaning systems. It can rather be included in a comprehensive maintenance program to keep the ship's hull clean and to improve the vessel’s speed while reducing its fuel consumption and GHG emission.

Even though some regulation appeared to prevent underwater cleaning in many places, as well as the restriction on cleaning operations in certain areas of the port, modern methods of underwater cleaning have been developed using methods equipped with a particular system to absorb waste and contaminants. These modern systems are increasingly developing to be faster and more environmentally friendly by preventing any cleaning residues from going into the sea.

Deep trekker remotely operated vehicles (ROV) are the highly advanced solutions for routine ship hull inspections and underwater cleaning. Before docking a ship for
painting, companies will conduct an initial inspection of the hull to get an idea about the workload and the needed budget. Once the vessel is back in the water, the painters send their Deep Trekker ROVs underwater to inspect the hull and conduct a final inspection of their work before sending the ship on her way. Figure 23, below shows an example of high-performance cleaning ROV.

The ROV for underwater cleaning is highly performant with numerous advantages such as;

- No micro scratches found on anti-fouling after cleaning with max cleanings capacities.

- Accessibility; 200 meter long return of seawater mixed with fouling from the cleaning operation.

- Capacity; up to 3000m2 per hour.

- Collection of fouling and organisms; a collection of 100% of residues at full speed.
4.10. **Conclusion:**

Through the study and monitoring of the fuel consumption and sailing speed of the Ro-Ro passenger ship CARTHAGE that has an annual maintenance program for the hull, it can be concluded that the hull condition management has a direct impact on the ship speed and fuel consumption. This is can be translated into a great impact on the ship’s operational energy efficiency.

Comparing the current traditional hull treatment system applied to the case study ship with the SILICONE system clarify that the vessel's energy efficiency could be further improved over more extended periods of navigation. Replacing the traditional
antifouling paint with the SILICONE antifouling will help in reducing the hull maintenance cost in the long term, reducing the period of ship immobilization in dry dock, reducing the shop fuel consumption and improving the ship’s speed. As a result and most importantly, the new technology contributes significantly in reducing the CO2 emissions especially in respect with the new European MRV directive since the case study ship is sailing in a regular Africa/Europe route.
5. CHAPTER V: Calculation of CO2 Emissions According to European Directives MRV; Case Study Ship

5.1. Introduction:

In order to reduce the CO2 emission from ships, the EU took the initiative to control the CO2 emission from ships visiting the European ports. Calculation of CO2 emissions is prepared on the basis of Regulation EU 2015/757 of European Parliaments and the Council of 29 April 2015 on the monitoring, reporting and verification of carbon dioxide (CO2) emissions from maritime transport, and amending Directive 2009/16 / EC. The regulation is also called EU MRV Regulation.

MRV stands for monitoring, reporting and verification of fuel consumption, CO2 emissions and transport work of the ship. EU MRV is a Europe Union requirements, applied since 1 July 2015, which requires that ship owners and operators monitor, report and verify the CO2 emission of their ships annually (DNV. GL, 2018). The EU regulation applies to all ships exceeding 5 000 GT calling or trading within EU ports. Under this Regulation, every ship must:

- Develop its monitoring plan (MP) that has to be evaluated by an accredited verifier;
- Monitor and report its emissions and activity data starting from the first of January 2018;
- Have its emissions report independently verified (by another accredited verifier) before submitting to the European Commission and the flag state; and
- Carry on board a Document of Compliance (DOC) from June 2019 (issued by the accredited verifier, which highlights the vessel's licenses to trade and operation.

5.2. Monitoring and reporting:

The monitoring and recording of emissions shall be carried out for every voyage; data are recorded and systematically checked for each voyage:

5.2.1. Monitoring on a per-voyage basis:

Based on the monitoring plan required in accordance with Article 13(1) in the MRV regulation, a ship shall, in accordance with Annex I, Part A, and Annex II, Part A, monitor each voyage bound for or in the departure from a port under the jurisdiction of a European Member State. For each voyage to or from that port, the following parameters have to be recorded:

- Departure and arrival ports, including the date and hour of departure and arrival;
- The amount and the carbon emission factor for each type of fuel consumed in total;
- CO2 emitted;
- Distance travelled;
- Time spent at sea;
- Cargo carried;
- Transport work.

5.2.2. Monitoring on an annual basis:

A ship shall monitor the following parameters, according to the Part A of Annex I and Part B of Annex II in the MRV regulation:

-Amount and carbon emission factor for each type of fuel consumed in total;
-Total aggregated CO2 emitted;

-Aggregated CO2 emissions from all voyages between ports under a European Member State's jurisdiction;

-Aggregated CO2 emissions from all voyages which departed from ports under a European Member State's jurisdiction;

-Aggregated CO2 emissions from all voyages to ports under a European Member State's jurisdiction;

-CO2 emissions which occurred within ports under a European Member State's jurisdiction at berth;

-Total distance travelled;

-Total time spent at sea;

-Total transport work; and

-Average energy efficiency.

An experimental application of the MRV regulation to the case study ship will be executed in the following part.

5.3. Basic data of the ship case study:

The ship Chief Engineer is responsible for the implementation of the MRV plan aboard the ship. He collects all the required information and makes the needed calculations and interpretations in order to prepare the data for submission in the requested format.
### 5.3.1. Emission sources and fuel types used:

The table below (table 3) shows the fuel consumers onboard the ship and their characteristics. In addition, the characteristics of the fuel oil used on board this ship are illustrated in the same table.

<table>
<thead>
<tr>
<th>No. ref.</th>
<th>Emission source (name, type)</th>
<th>Technical description of emission source (performance/power, specific fuel oil consumption (SFOC), year of installation, identification number in case of multiple identical emission sources, and so on.)</th>
<th>Fuel types used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main engine N°1</td>
<td>Diesel SULZER 12 ZAV 40 S 4T, P 8640 KW, 510 rpm sn 21 86</td>
<td>ME N°1 HFO 380 Cst</td>
</tr>
<tr>
<td>2</td>
<td>Main engine N°2</td>
<td>Diesel SULZER 12 ZAV 40 S 4T, P 8640 KW, 510 rpm sn 21 87</td>
<td>ME N°2 HFO 380 Cst</td>
</tr>
<tr>
<td>3</td>
<td>Main engine N°3</td>
<td>Diesel SULZER 12 ZAV 40 S 4T, P 8640 KW, 510 rpm sn 21 88</td>
<td>ME N°3 HFO 380 Cst</td>
</tr>
<tr>
<td>4</td>
<td>Main engine N°4</td>
<td>Diesel SULZER 12 ZAV 40 S 4T, P 8640 KW, 510 rpm sn 21 89</td>
<td>ME N°4 HFO 380 Cst</td>
</tr>
<tr>
<td>5</td>
<td>Diesel Generator N°1</td>
<td>Moteur diesel VASA 6R32 P 2460 RPM 750 4t S/N :8534</td>
<td>AE N°1 HFO/MDO/ MGO</td>
</tr>
<tr>
<td>6</td>
<td>Diesel Generator N°2</td>
<td>Moteur diesel VASA 6R32 P 2460 RPM 750 4t S/N :8535</td>
<td>AE N°2 HFO/MDO/ MGO</td>
</tr>
<tr>
<td>7</td>
<td>Diesel Generator N°3</td>
<td>Moteur diesel VASA 6R32 P 2460 RPM 750 4t S/N :8536</td>
<td>AE N°1 HFO/MDO/ MGO</td>
</tr>
<tr>
<td>8</td>
<td>Diesel Generator N°4</td>
<td>Moteur diesel VASA 6R32 P 2460 RPM 750 4t S/N :8537</td>
<td>AE N°2 HFO/MDO/ MGO</td>
</tr>
<tr>
<td>9</td>
<td>Boiler N°1</td>
<td>Chaudière aalborg? OIL BURNER TPE MS 8 Z/2. BOILER TYPE AB-2 2000KG/H 7 BAR 98-34268</td>
<td>MB 1 HFO/MDO/ MGO</td>
</tr>
<tr>
<td>10</td>
<td>Boiler N°2</td>
<td>Chaudière aalborg? OIL BURNER TPE MS 8 Z/2. BOILER TYPE AB-2 2000KG/H 7 BAR 98-34269</td>
<td>MB 2 HFO/MDO/ MGO</td>
</tr>
</tbody>
</table>

Table 3: Emission sources and fuel types.
The fuels used and their emission factors are in conformity to ISO 8217 and mentioned on the following table.

### 5.3.2. Fuel emission factors:

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>IMO emission factors (in tonnes of CO2/tonne fuel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Fuel Oil (Reference: ISO 8217 Grades RME through RMK)</td>
<td>3.114</td>
</tr>
<tr>
<td>Light Fuel Oil (Reference: ISO 8217 Grades RMA through RMD)</td>
<td>3.151</td>
</tr>
<tr>
<td>Diesel/Gas Oil (Reference: ISO 8217 Grades DMX through DMB)</td>
<td>3.206</td>
</tr>
<tr>
<td>Liquefied Petroleum Gas (Propane)</td>
<td>3.000</td>
</tr>
<tr>
<td>Liquefied Petroleum Gas (Butane)</td>
<td>3.030</td>
</tr>
<tr>
<td>Liquefied Natural Gas</td>
<td>2.750</td>
</tr>
<tr>
<td>Methanol</td>
<td>1.375</td>
</tr>
<tr>
<td>Éthanol</td>
<td>1.913</td>
</tr>
<tr>
<td>Other fuel with non-standard emission factor</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Emission factors
5.4. Monitoring of fuel consumption:

The methods chosen by COTUNAV to monitor the fuel consumption for the management of the emission CO2 are shown in table 5, where method C consists on;

Method C: Flow meters for applicable combustion processes. This method is based on measured fuel flows onboard. The data from all flow meters linked to relevant CO2 emission sources shall be combined to determine all fuel consumption for a specific period. The period means the time between two port calls or time within a port. For the fuel used during a period, the fuel type and the sulphur content need to be monitored.

The calibration of the flow meters used is done every five years. The uncertainties associated with the flow meters depend on the uncertainties of calibrations, circuit leaks, fuel returns, fuel water content, concentration rate of sediments, zander and others separated by the purifiers is set at 10%. Where the amount of fuel consumed is determined in units of volume, expressed in litres, the company shall convert that amount from volume to mass by using actual density values.

<table>
<thead>
<tr>
<th>Emission source</th>
<th>Chosen methods for fuel consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main engine N°1</td>
<td>Method C: Flow meters for applicable combustion processes</td>
</tr>
<tr>
<td>Main engine N°2</td>
<td>Method C: Flow meters for applicable combustion processes</td>
</tr>
<tr>
<td>Main engine N°3</td>
<td>Method C: Flow meters for applicable combustion processes</td>
</tr>
<tr>
<td>Main engine N°4</td>
<td>Method C: Flow meters for applicable combustion processes</td>
</tr>
<tr>
<td>Diesel Generator N°1</td>
<td>Method C: Flow meters for applicable combustion processes</td>
</tr>
<tr>
<td>Diesel Generator N°2</td>
<td>Method C: Flow meters for applicable combustion processes</td>
</tr>
<tr>
<td>Diesel Generator N°3</td>
<td>Method C: Flow meters for applicable combustion processes</td>
</tr>
<tr>
<td>Diesel Generator N°4</td>
<td>Method C: Flow meters for applicable combustion processes</td>
</tr>
<tr>
<td>Boiler N°1</td>
<td>Method C: Flow meters for applicable combustion processes</td>
</tr>
<tr>
<td>Boiler N°2</td>
<td>Method C: Flow meters for applicable combustion processes</td>
</tr>
</tbody>
</table>

Table 5: Monitoring of fuel consumption.
Onboard; Chief Engineer calculate the real density from the density measured by the fuel supplier during bunkering and given in the delivery documents. The actual density is expressed in kg / l is determined for the applicable temperature for the specific measurement.

5.5. Heavy fuel oil density:

MARPOL Annex VI and Annex V require fuel suppliers to report fuel density (tested according to ISO 3675: 1998, "Crude petroleum and liquid petroleum products - Laboratory determination of density- Hydrometer method" or ISO 12185: 1996). The on-board density measurements are made in accordance with ISO 650: 1977, "Relative density 60/60 degrees F (15 ° C) of general purpose hydrometers" or ISO 12185: 1996, "Crude petroleum and petroleum products-Determination of density Oscillating method in U-tube". There are standard oil measurement tables for reference temperatures of 15 ° C and 20 ° C. When the quality of the fuel oil changes to residual fuel, the standard density tables require an overhaul. The mixed fuel density is the weighted average density of each fuel in the capacity One conversion method is to use volume correction factors (VCFs) according to ASTM D1250 as below;

\[
M = VT \times \text{VCF} \times D_{15°C}\left(\frac{\text{Tonnes}}{\text{m}^3}\right)
\]

The measurement of the density of the embedded product is at 15 ° C as stipulated in the bulletin of delivery. The measurement of the actual volume must be corrected to 15 ° before the conversion of the mass. The measured density is corrected according to the temperature of the HFO as below;
Actual HFO Fuel Density at Temperature (t1) = HFO Fuel Density at 15 degrees Celsius * [1 - ((t1-15) * 0.00064)]

- t1 represents the temperature of the HFO in the bunker capacities in degrees Celsius,
- 0.00064 is the temperature correction factor of the product,
- The volume of HFO fuel expressed in m3 (actual sounded volume of the capacity), this value is calculated from the probe tables of the fuel capacities and corrected according to the conditions of attitude and possible lodging of the ship.
- In addition, taking into account the fuel impurities, the declared mass correction of the fuel on board must take into account the volume correction factor namely:
- The quantities of fuel must be corrected for the masses associated with impurities (ash and metals, water).
- ISO 8217 specifies the maximum content of impurities for four different classes of distillate and six different levels of residual fuels.
- The quantity of fuel is corrected by multiplying the quantity of fuel (in tonnes) by the determined correction factor (CF):
  - CF = (100 - W [%] - A [%]) / 100
  - W: water content in the fuel
  - A: inert material in the fuel such as ashes and metals

5.6. Procedures for quality assurance of measuring equipment:

The fuel tanks must be monitored during loading on board using manual sounding and/or ullages. If in the design of the ship, the builder has identified the pipe hoses by Ullage of the fuel capacities, it is always necessary to use the pipes with reference tables to the ullages. The appropriate tables delivered from the shipyard have to be followed, otherwise, significant errors in the calculation of the fuel quantity could
occur and consequently wrong CO2 emission results in the report (GUIDANCE ON FUEL MONITORING, 2017).

5.6.1. Level indicators for fuel tanks

Onboard ships, the fuel tanks are equipped with level indicators mounted directly on the enclosure, those indicators must be checked and calibrated each time the vessel is in dry-dock to ensure that they are fully operational and accurate. The date of the last check must be visible in order to facilitate monitoring the indicators calibration schedule. The level mount can be in the form of the pressure gauge, U-tube with direct indicator strip or stainless-steel tube containing the fuel with an external viewfinder using magnetic indicators. For its good functioning, the level indicator should be free from any damage and cracks.

5.6.2. Flow meters

The flow meters provide an uncertainty level of 0.1-2% flow impact. It must be tested and calibrated by a manufacturer-authorized company that follows the procedures for checking and verifying the accuracy recommended in the flow meter. In addition, the results of the recalibration must be within the limits of the manufacturer's tolerances. Generally, the verification period is 60 months. These flow meters must be maintained and checked according to the same manufacturers’ recommendations as below:

• Verification of electrical connections and terminal blocks, visual inspection of meter status with the thorough cleaning to detect leaks, deterioration of equipment conditions and accessories

• Occasional inspection of interconnected cables and junction boxes of the meter signal transitions system,

• Check of the direction of fuel flow in the meter,
• Periodically, the service greaser must inspect the service storytellers for corrosion, seal leaks; and alterations of cables and junction boxes that can of the effect of vibration, leakage, elevation of the temperature of the operating medium

• Periodically removal of the flow element for:

* The inspection based on the historical evidence of debris (preventive maintenance that depends on flow sewers as a function of its diameter),

* Elimination of any impurities from the fuel and operating conditions of the meter

* Replacement of seals and gaskets

* Replacement of bearings

* Resume the verification of the direction of circulation of the fuel with the possible replacement of the magnet

* Control of the functional clearances of the rotor (s)

* Clean the drain element, if necessary, with a soft brush and available solvents (compatible with stainless steel)

* Calibration of the meter

* And other instructions according to the recommendation of each type of meter manufacturer.
5.6.3. **Manual gauging rod (manual sounding equipment)**

The fuel tanks probe must be designed especially for tanks control; before using the manual gauging rod in the fuel tank, the oiler must ensure the good condition of this equipment as follows:

- No trace of impurities on the gauging ribbon and the numbers are clearly visible
- The absence of excessive distortions of the gauging ribbon may influence the measurement of the quantity and increase the errors of the readings.
- After the sounding strips are used, they must be cleaned and stored.
- In case of large distortions where the ribbon numbers are difficult to read or wear, the ribbon must be replaced with a new one and should be available on board.

5.7. **CO2 emissions: case study ship:**

Figure 24 shows the CO2 emissions per tonne-mile of the vessel after calculating the fuel consumption, distance travelled as the MRV regulation cited at the beginning of the chapter. In 2018, the ship has conducted the dry dock between 18 March and 10 April. It can be shown in figure 24 that the CO2 emission reported from this Ro-Ro ship has significantly decreased between February and April. In April, the vessel was sailing after the annual dry dock that included the hull maintenance. Therefore, this figure further confirms the results obtained in the previous chapters, where the ship fuel consumption profile was improved following the interventions to treat the ship's hull. The four values represented in the graphs are drawn under the same conditions and distance of trips in order to show the effect of the work to eliminate the hull fouling and treat it adequately. CO2 emissions are almost 50% lower after hull maintenance.
It has been demonstrated that the contribution of hull treatment is a crucial measure to reduce the ship CO2 emission with the possibility of improvement if of the new technology of the Silicone paint are introduced.

**5.8. Conclusion**

To conclude, the management of biofouling is an important vector that has a great potential to reduce the ships’ fuel consumption and thereby their CO2 emissions. It is, therefore, necessary to strengthen this area by the different stakeholders in the maritime industry starting from with the IMO Member States and their leaders. Currently, there is no doubt about the influence of GHGs on global warming and its negative impact on the environment and the world sustainability. GHGs are then a very serious issue that needs urgent actions on all levels. imperative to act on all the plans.
6. CHAPTER VI: Conclusion

Managing biofouling is an important measure to improve the ships energy efficiency. Moreover, biofouling treatment is important for ship safety, as seawater cooling systems and intakes when clogged with organisms operate less efficiently. Vessels with dirty hulls spend far more on fuel than clean ones and these additional fuel costs quite often far exceed the costs associated with hull maintenance activities.

Continual hull maintenance using best practice is the best way for vessels owners to comply with the IMO guidelines. Managing biofouling is, as shown in this dissertation, a beneficial vector on many levels. It protects the marine environment by minimizing the transfer of aquatic invasive species. In addition, it mitigates the global warming impacts by reducing CO2 emissions from ships. Furthermore, it allows the ship operators to save money since the fouling increases the energy needed to move the vessel forward so more fuel consumption and with the rising fuel prices anything that can lead to overconsumption of fuel is targeted by ships owners. Managing biofouling helps also to improve the ship’s speed, which is highly needed for Ro-Ro passengers to meet their schedules.

According to the example of the case study ship, although the ship follows a regular maintenance program of the hull, it has been shown that it is possible to further improve the ship operational performance by applying new technologies and antifouling systems.
For vessels other than passenger ships the new technologies could be very useful as the cargo ships are required to go to the dry dock every five years instead of one year. Therefore, the accumulation of hull fouling becomes very embarrassing for the ship’s speed and the SILICONE treatment would prevent the increased hull fouling for a longer period of time.

Furthermore, in the second IMO greenhouse study, it has been presented demonstrated that the operational energy efficiency still has a great potential to reduce emission from ships (IMO, 2009). Therefore, the prospects for shipping are hardly encouraging. However, in order to limit the global warming in 2100 well below 1 ° C compared to today, and 2 ° C compared to the pre-industrial period. As a result, if the trend is not reversed, the share of shipping in global GHG emissions could move from 3% today to 17% in 2050 (IMO, 2014). In the context of combating CO2 emissions from ships, it is therefore clear that the management of biofouling is a very important factor acting on the reduction of ships emissions that must be addressed seriously.

The preservation of the marine environment, the development of services and ecological solutions are major challenges for the future development of the maritime industry. This can only be achieved through an adapted and effective management of biofouling which needs all the know-how of maritime technology in this area, its capacity for innovation and its constant concern for the protection of the environment in adequacy with the regulatory requirements. Now that a few countries and states have begun to develop and implement biofouling regulations, biofouling has started to appear on the international actions and more discussion on the topic are to come at future MEPC sessions.

The anticipation of future regulation about biofouling management, civic and responsible attitude are the main environmental issues facing the maritime industry.
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