# INCREASING OPERATIONAL EFFICIENCY OF HIGH SPEED RO-RO VESSELS VIA NEW HULL COATING TECHNOLOGIES

**HASAN GÖLER**

**PİRİ REİS UNIVERSITY**
**2017**

Hasan GÖLER

M.Sc. THESIS

2017

# INCREASING OPERATIONAL EFFICIENCY OF HIGH SPEED RO-RO VESSELS VIA NEW HULL COATING TECHNOLOGIES

**Hasan GÖLER**
**M.Sc., Maritime Transportation and Management Engineering, Piri Reis University**
**2017**

**Submitted to the Institute for Graduate Studies in**
**Science and Engineering in partial fulfillment of**
**the requirements for the degree of Master of Science**

**Graduate Program in Maritime Transportation and Management Engineering**
**Piri Reis University**
**2017**

**INCREASING OPERATIONAL EFFICIENCY OF HIGH SPEED RO-RO VESSELS VIA NEW HULL COATING TECHNOLOGIES**

APPROVED BY

Prof. Dr. Oral ERDOĞAN ..........................................................................

(Thesis Supervisor)

Prof. Dr. Süleyman ÖZKAYNAK..................................................................

Yrd. Doç. Dr. Kadir ÇİÇEK ..........................................................................

**DATE OF APPROVAL: .../.../ 2017**

***To my father and mother…***

## ACKNOWLEDGMENTS

This thesis was written for my master degree in Maritime Transportation and Management Engineering, at Piri Reis University.

I would like to thank the following people, without whose help and support, this thesis would not have been possible.

I extend my thanks to my thesis advisor Prof. Dr. Oral Erdoğan, Rector of Piri Reis University, for his interest and support during the conduct of this study.

I owe a debt of gratitude to Mr. Kemal Bozkurt, Chief Operating Officer of U.N. RO-RO, who always supported me for my works and studies.

Finally, I owe a debt of gratitude to my wife Gamze Göler, who always supported me.

## ABSTRACT

### INCREASING OPERATIONAL EFFICIENCY OF HIGH SPEED RO-RO VESSELS VIA NEW HULL COATING TECHNOLOGIES

The purpose of this study is to review available data on new hull coating technologies and analyze the potentials to decrease fuel consumption as well as speed loss for high speed RO-RO vessels. Ships' fuel consumption accounts for the important part of operational expenses and it is straight forward that every ship owner would aim to run their fleet as optimum as possible in terms of fuel efficiency. IMO has developed the Energy Efficiency Operational Indicator (EEOI) that provides information concerning the efficiency of the ships in operation where fuel consumption is the main criteria for the calculation. The reduction of fuel consumption through decreased frictional resistance of hull is one of the most known method in maritime industry to increase operational efficiency of ships. Literature needs further studies regarding hull performances with the real-life data even if there will be higher uncertainties compared to laboratory test results. Ship operators are generally making their decisions according to real life experiences. In this report, actual field data of high speed RO-RO vessels has been studied according to ISO 19030 Part 3 for reference and evaluation periods. All vessels are sister vessels and were built in the same shipyard with same characteristics. New technology; self-polishing or foul release coatings are tested against conventional coatings that the vessels had been coated previously. Results indicate that the new technology foul release silicone coatings create significant fuel savings through decreased speed loss.



Keywords – Fuel consumption, Antifouling coating technologies, speed loss, high speed Ro-Ro vessels

# ÖZET

## YÜKSEK HIZLI RO-RO GEMİLERİNİN OPERASYON VERİMLİLİĞİNİN YENİ TEKNOLOJİ KARİNA BOYALARI İLE ARTTIRILMASI

Bu çalışmanın amacı, piyasadaki yeni teknoloji tekne boyalarını ve bu boyaların yüksek hızlı Ro-Ro gemilerinin yakıt tüketimleri ile hız kayıplarının azaltılması üzerindeki etkilerini incelemektir. Gemilerin operasyon giderlerinin önemli bir kısmını yakıt tüketimleri oluşturur ve bilindiği üzere her gemi sahibi gemilerini mümkün olan en düşük yakıt tüketimi ile işletmek ister. IMO gemilerin operasyon verimliliği ile ilgili bilgiler sağlayan ve hesaplanmasında yakıt tüketiminin ana kıstas olduğu Enerji Verimliliği Operasyon İndikatörü 'nü geliştirmiştir. Teknenin sürtünme direncini azaltarak yakıt tüketimini düşürmek denizcilik endüstrisinde gemilerin operasyon verimliliğini arttırmak için kullanılan en bilindik yöntemlerden biridir. Bugüne kadar tekne performansı ile ilgili yapılmış çalışmalar genellikle laboratuvar test sonuçlarına dayanmakta olup her ne kadar gerçek ortam verileri ile yapılan çalışmalarda belirsizlik yüksek olsa da literatürün bu alanda yapılacak çalışmalara ihtiyaç duyduğu açıktır. Gemi operatörleri gemilerinin tekne performansını ve operasyon verimliliğini artırmak için kullanacakları yöntemlerle ilgili kararlarını genellikle gerçek hayat tecrübelerine göre vermektediler. Çalışmada yüksek hızlı Ro-Ro gemilerinin gerçek saha verileri ISO 19030 standardı bölüm 3'te belirtilen referans ve değerlendirme periyodlarına göre incelenmiştir. Gerçek saha verileri kullanılan tüm gemiler aynı tersanede aynı teknik özelliklerle inşa edilmiş kardeş gemilerdir. Yeni teknoloji tekne boyaları gemilerin üzerinde daha önceden var olan konvansiyonel boyalarla karşılaştırılmıştır. Sonuçlar yeni teknoloji Silikon özellikli tekne boyalarının yakıt tüketiminin ve hız kaybının azaltılmasında daha etkili olduğunu göstermiştir.



Anahtar Kelimeler – Yakıt Tüketimi, Antifouling Boya teknolojileri, Hız kaybı, Yüksek hızlı Ro-Ro gemileri

**TABLE OF CONTENTS**

## LIST OF FIGURES

## LIST OF TABLES

## LIST OF SYMBOLS/ABBREVIATIONS

| | |
|---|---|
| RO-RO | Roll on – Roll Off |
| IMO | International Maritime Organization |
| ISO | International Organization for Standardization |
| GHG | Green House Gas |
| EEDI | Energy Efficiency Design Index |
| $CO_2$ | Carbon dioxide |
| MECP | Marine Environment Protection Committee |
| U.S. | United States |
| CAGR | Compound Annual Growth Rate |
| TBT | Tributyltin |
| CFD | Computer Fluid Dynamics |
| SPC | Self-polishing coating |
| FR | Foul Release |
| FFR | Fluoropolymer Foul Release |
| FRC | Foul Release Coating |
| MMT | Million Metric Tones |
| VLCC | Very Large Crude Carriers |
| LNG | Liquid Natural Gas |
| PD | Panos Deligiannis |
| AF | Antifouling |
| CDP | Controlled Depletion Polymer |
| PDMS | Polydimethylsiloxane |
| PVC | Polyvinylchloride |
| SOG | Speed Over Ground (knot) |
| kW | Kilowatt |
| GPS | Global Positioning System |
| $Vd$ | Percentage speed loss |

| | |
|---|---|
| $Vm$ | Measured speed through water (knot) |
| $Ve$ | Expected speed through water (knot) |
| ITTC | International Towing Tank Conference |
| Pb | Brake Power (kW) |
| SFOC | Specific Fuel Oil Consumption (g/kWh) |
| $M_{FOC}$ | Mass of consumed fuel oil by main engine (kg/hour) |
| LCV | Lower calorific value of fuel oil (MJ/kg) |
| $f$ | SFOC reference curve |
| kg | Kilogram |
| kJ | Kilojoule |
| Hz | Hertz |
| PV | Performance Value |
| PI | Performance Indicator |
| LCV | Lower Calorific Value (MJ/kg) |
| DDN | Drydocking |
| FOC | Fuel Oil Consumption |

# 1. INTRODUCTION

In maritime economics, ships' fuel consumption accounts for the important part of operational expenses and it is straight forward that every ship owner would aim to run their fleet as optimum as possible in terms of fuel efficiency. The reduction of fuel consumption through decreased frictional resistance of hull is one of the most known method in maritime industry to increase operational efficiency of ships. The purpose of this study is to review available data on new hull coating technologies for high speed RO-RO vessels and analyze the potentials to decrease fuel consumption as well as speed loss. In this report, actual field data of high speed RO-RO vessels has been studied according to ISO 19030 Part 3 for reference and evaluation periods. All vessels are sister vessels and were built in the same shipyard with same characteristics. New technology; self-polishing or foul release coatings are tested against conventional coatings that the vessels had been coated previously. Results indicate that the new technology foul release silicone coatings create significant fuel savings and decreased speed loss.

Marine industry is having an escalating competition because of stringent environmental regulations are leading to significant higher fuel costs which stands for approximate 35-70% of total operational cost (Wigforss, 2012). Therefore, fuel efficiency measures are vital in order to stay competitive in the future.

Shipping companies of all vessel types are being compelled to evaluate and implement fuel saving initiatives, due to increasing environmental regulations from the IMO (International Maritime Organization), government and port authorities; combined with the relentless rise in bunker prices which is supported the increasing need for energy efficiency to survive in highly competitive and capacity over supplied shipping market.

Energy efficient shipping is a prerequisite for the reduction of the Green House Gas (GHG) emissions to the levels anticipated within the next decades. The continuous growth of the world population and the increase number of developing countries led to the increasing dependence of the world economy on the international trade. According IMO leaflet (Time for international action on $CO_2$ emissions from shipping, 2013), maritime transport emits around 1000 million tons of $CO_2$ annually and is responsible for about

2.5% of global greenhouse gas emissions which is equivalent to more than the total annual emissions of Germany.

European Commission on Climate Actions declared that shipping emissions are predicted to increase between 50% and 250% by 2050 – depending on future economic and energy developments.

These findings alerted the International Maritime Organization (IMO) and led to the implementation of the first maritime energy efficiency regulations that entered force on the 1st of January 2013. The aim of the regulations is to reduce carbon emissions by decreasing the amount of fuel consumed. This can be achieved by optimizing the ship's design, deploying new energy efficient technologies or by improving the ship's operation. 'Energy Efficiency Design Index' (EEDI), which sets minimum energy efficiency requirements for new ships built after 2013 (in terms of $CO_2$ per ton capacity-mile). The target requires stepped efficiency improvements of between 10 and 30 per cent between 2013 and 2025. The EEDI is the first globally binding climate measure and sets energy efficiency parameters for the design of new ships. The full EEDI equation can be summarized as shown below.

$$EEDI = \frac{Power\ installed\ x\ Specific\ fuel\ consumption\ x\ Carbon\ conversion}{Available\ capacity\ x\ Speed} \tag{1.1}$$

The IMO has also developed the Energy Efficiency Operational Indicator (EEOI), an indicator that provides information concerning the efficiency of the ships in operations. The calculation is based on an individual vessel's fuel consumption and data on the achieved transport work (e.g. cargo mass, number of passengers carried, etc.) resulting in a figure of $CO_2$ emissions per ton nautical mile. The full EEOI equation is contained in the circular letter MEPC.1/ Circ.684 and can be summarized as shown below.

$$EEOI = \frac{Fuel\ consumption\ x\ Carbon\ Conversion}{Distance\ sailed\ x\ Cargo\ transported} \tag{1.2}$$

Unlike the EEDI, the EEOI is not limited to new vessels and can be used to measure the 'real' efficiency of a ship in operation and to gauge the effects of any changes, such as hull and propeller cleaning, slow steaming, improved voyage planning, etc. The EEOI can be improved by increasing the amount of cargo transported or by applying any measure aiming at reducing fuel consumption (e.g. hull maintenance, slow steaming, vessel modifications, weather routing, etc.).

The reduction of fuel consumption and fuel costs through keeping ship's hull as smooth as possible is one of the most known method in maritime industry to increase operational efficiency of ships. The fuel consumption of a ship is strongly influenced by her frictional resistance, which is directly affected by the roughness of the hull's surface. Increased hull roughness leads to increased frictional resistance, causing higher fuel consumption and $CO_2$ emissions.

The best method to reduce frictional resistance is to apply a treatment to a ship's hull, to minimize its physical and biological roughness. Physical roughness can be minimized by applying some preventative measures, but biological fouling is more difficult to control.

Fouling is the term generally used to describe the settlement and growth of marine plants and animals on submerged structures. Fouling increases frictional resistance of ships and causes speed loss and increase of fuel consumption. Van Manen (1988) states that frictional resistance meets 80%-85% of total resistance of ships. A fouled hull leads to increased frictional resistance which results in loss of speed and increased fuel consumption. Increased frictional drag caused by hull fouling has both economic and environmental impact on the ship's operations. A clean ship can sail faster and with less energy.

Fouling can be classified into two broad groups as macro-fouling which includes plant and animal fouling and micro-fouling which includes unicellular algae and bacteria. Lejars et al. (2012) state that there are more than 4,000 known fouling species, all of which have the potential to colonize on a submerged surface.

Fouling begins to occur immediately after a ship is immersed in water, and will continue to occur throughout a ship's life at sea until a cleaning process is performed. The level of fouling depends on several factors, including the length of time spent at sea, the water temperature, the geographical location of the ship, surface conditions and the salinity of the sea. The longer ship's immersion time causes greater level of fouling. Such fouling is responsible for a dramatic increase in a ship's frictional resistance. Fouling causes surface roughness, resulting an increase in a ship's frictional resistance and fuel consumption.

Milne (1990) states that the fuel consumption may increase by up to 40% if any precautions have not taken to prevent fouling. Taylan (2010) states that the increase in resistance due to microorganism fouling is around 1–2%, where as an accumulation of hard shelled organisms may cause an increase in resistance of 40%. Schultz (2007) investigated the effect of fouling on the required shaft power for at a speed of 15 knots and found that the presence of slime alone requires a 21% increase in shaft power, and whereas heavy calcareous fouling led to an 86% increase in shaft power requirements. Demirel et al. (2014) declare that marine antifouling coatings is a common method used to smooth hull surfaces to reduce the frictional resistance and fuel consumption of a ship.

Most vessels leave the new build yard or subsequent dry-docking with their hull and propeller in a fairly good condition. Then on account of a combination of bio fouling and mechanical damage, hull and propeller performance begins to deteriorate.

There are technologies and solutions on the market that undertaking to protect the hull and maintain good performance over the full duration of the docking interval.

Antifouling coatings are the most effective solutions to avoid fouling and help to keep hull performance as better as possible. New technology antifouling coatings now aim to not just reduce fouling but make the hull surface as smooth as possible. Most hull coatings today are designed to reduce hydrodynamic drag and to prevent the build-up of marine organisms.

Tripathi (2016) explains the results of latest survey report on the global antifouling paint market, published by Markets & Markets, projects the market to grow from U.S.

$5.61 billion in 2015 to U.S. $9.22 billion by 2021 at a CAGR (Compound Annual Growth Rate) of 8.6 percent between 2016 and 2021. High demand for antifouling coatings from the shipping industry is expected to drive the growth of the market in the near future, the report states.

Demirel et al. (2013) declare that antifouling coatings are the primary protective measure to mitigate marine bio fouling and surface roughness on ship's hulls. $60 billion of fuel saving, 384 million tones reduction in carbon dioxide and 3.6 million tones reduction in sulphur dioxide emissions are estimated to be provided by the use of antifouling coatings.

According to the Clean Shipping Coalition in Marine Environment Protection Committee 63/4/8, poor hull and propeller performance accounts for around 1/10 of world fleet energy cost and GHG emissions. Soyland and Oftedahl (2016) point to a considerable improvement potential; 1/10 of world fleet energy costs and GHG emissions translates into billions of dollars in extra cost per year and around a 0.3% increase in man-made GHG emissions.

Fouling affect ship's hull negatively and increase frictional resistance which results higher fuel consumption and GHG emissions where antifouling coatings are the tools to mitigate this problem and serve to keep ship's hull as smooth as possible. There are technologies and solutions on the market that undertaking to protect the hull and maintain good performance over the full duration of the docking interval. And there is a big competition where all producers of these coatings trying to proof performance of their technologies via different measurement methods and their existing references to sell their products.

So even there are available products and plenty of methods in the market, why then hull and propeller performance is still so poor? Which coating is best for which ship types or under which working conditions? Or is there any coating performs well under all conditions? These questions are still valid and still there isn't any clear reply even plenty of research carried out by producers and academicians. Efforts to develop best antifouling technology started in 1960 with the use of TBT for conventional coatings and still going on.

On the other side, what is the problem and approach of final user, ship operator? Also, problem for them to make decision to select correct antifouling technology for their fleet is going on and repeats again on every dry-docking cycle when new application will be applied. So how ship operator makes the decision?

Ship operators approach this subject from 2 perspectives, price of coating and their experiences. Therefore, most of the operators have an idea about all technologies in the market. They follow performance of the coatings which they applied to their own fleet and what other operators are doing, who is happy from which coating.

According to Soyland and Oftedahl (2016) the problem has been a lack of measurability. You can't manage what you can't measure is an old management adage that is still accurate today. Unless you measure something, you don't know if it is getting better or worse. Now a multitude of measurement methods are being introduced in the market; but there wasn't a specific standard of hull and propeller performance measurement method until draft of ISO 19030 released. This standard is intended for all stakeholders who are struggling to apply a certain and practical way of measuring the changes in hull and propeller performance. It could be ship-owners and operators, companies offering performance monitoring, shipbuilders and companies offering hull and propeller maintenance and coatings. ISO 19030 will make it easier for decision makers to learn from the past and thereby make better informed decisions for tomorrow. It will also provide much needed transparency for buyers and sellers of technologies and services intended to improve hull and propeller performance.

Previous studies have been carried out to determine the impact of antifouling coatings by laboratory tests of coated cylindrical or flat panels, CFD computer modelling tests, coated rotor tests, chemical comparisons or adhesions tests. Some important studies and their aims explained in below paragraphs.

Candries et al. (2001) investigated foul release systems and drag. They tested coated flat plates in a towing tank and found that the total resistance of foul release coatings is lower than biocidal self-polishing coating antifouling systems, when first applied. They also observed result of ships which were in service for 2 months after foul release coating and self-polishing coating application, there was no difference in respect to speed and fuel performance which indicates that slime occurred on the foul release coating surface. But also, they noted that, according to raft panel test and full ship application of foul release system, it does not lead further fouling. Finally, they suggested foul release system for fast and high activity vessels.

Yebra et al. (2003) published an article about "Antifouling technology—past, present and future steps towards efficient and environmentally friendly antifouling coatings". They explained fouling process chemically and mechanically, also explained biological principles of antifouling coatings and how they act on bio fouling.

Townsin (2003) published an article about "The Ship Hull Fouling Penalty" which explains result of fouling technically and economically, also describes fouling types and what is the research direction on this subject. The penalty of fouling is ship speed loss at constant power, or, power increase at constant speed, or, consequentially, an economic penalty due to increased fuel consumption and scheduling penalties and other delays.

Schultz (2004) studied "Frictional Resistance of Antifouling Coating Systems" where he carried out an experimental study to compare the frictional resistance of several ship hull coatings in the unfouled, fouled, and cleaned conditions. Hydrodynamic tests were completed in a towing tank using a flat plate. The results indicate little difference in frictional resistance among the coatings in the unfouled condition. But significant differences were observed after 287 days of marine exposure, with the silicone antifouling coatings showing the largest increases in frictional resistance coefficient.

Mirabedini et al. (2006) carried out an experimental study to evaluate the drag characteristics of different self-polishing co-polymers (SPC) (tin based and tin-free) and a silicone foul release (FR) coating. They performed drag measurements on a smooth aluminum cylinder connected to a rotor device. Drag measurements showed that the frictional resistance of the FR coated cylinders was lower than that of SPC coated samples. Contact angle results showed that the critical surface tension and its polar component for silicone FR coating are less than SPC coatings which prevents firm adhesion of fouling organisms on underwater hulls. They concluded that the drag characteristics of a surface are affected by its free energy and roughness parameters.

Chambers et al. (2006) published an article about “Modern approaches to marine antifouling coatings” which evaluates antifouling coatings from environmental perspective and explain fouling types and recent antifouling technologies.

Schultz (2007) carried out study to evaluate effects of coating roughness and bio fouling on ship resistance and powering. Drag measurements and boundary layer similarity law analysis carried out in laboratory-scale for the mid-sized naval surface combatant at cruising speed and near maximum speed. The results indicate that slime films can lead to significant increases in resistance and powering, and heavy calcareous fouling results in powering penalties up to 86% at cruising speed.

Almeida et al. (2006) reviewed antifouling paints historically and explained in details how they mitigate with different fouling types.

Swain et al. (2007) carried out a study to measure the performance of today’s antifouling coatings. They investigated the hydrodynamic performance of four commercially available antifouling coatings that were subjected to both static and dynamic seawater immersion Static immersion tests were carried out in the Indian River Lagoon, where is an area of high bio-fouling activity. Dynamic immersion was tested with a rotating plate test and a hydrodynamic test was done on the 9-meter boat where test plate attached on the boat’s hull and measurements carried out while speed was up to 17 m/s. The results showed that each coating type developed its own characteristic fouling community and that there were significant differences in drag properties that were further modified by the static or dynamic immersion conditions.

Townsin and Anderson (2009) published an article about “Fouling control coatings using low surface energy, foul release technology” to describe the physics and chemistry of non-biocidal coatings, their smoothness and their effectiveness in preventing adhesion of fouling organisms with the history of development of foul release coatings is and current and future developments, such as the coating of propeller blades and underwater cleaning.

Corbett et al. (2010) study the benefits of fluoropolymer foul release hull coating technology regarding fuel cost savings, Greenhouse Gas Emissions (GHG) reductions and other emissions that may be achieved by this technology. They examined fuel consumption data of three vessel types pre- and post-FFR application. The first vessel type is a tanker represented by a ship called Prem Divya; the second vessel type is a bulk cargo vessel represented by a ship called the Ikuna; the third vessel type is a container vessel where we compare the fuel oil consumption of three new build vessels coated with a tributyltin-free self-polishing copolymer (TBT-free SPC) to two new build vessels coated with FFR; all five container vessels are identical builds. Results indicate that the application of FFR reduced speed-adjusted fuel oil consumption by 10% for the Prem Divya, 22% for the Ikuna, and no change in consumption for container vessels when carrying approximately 10,000 metric tons of extra cargo. If similar fuel efficiency results were realized by all tanker and bulk cargo in the international fleet, annual fuel oil consumption could be reduced by roughly 16 million metric tons (MMT) per year, fuel expenditures could be reduced by \$4.4 to \$8.8 billion per year, and nearly 49 MMT of carbon dioxide ($CO_2$) emissions could be avoided annually. Furthermore, analysis showed that reductions in $CO_2$ emissions are achieved at a negative cost—that is, avoided emissions are coupled with economic benefits to the ship-owner. Additionally, they tried to explore the potential fuel oil consumption reductions for other vessel types including ferries, Roll-on/Roll-off (Ro-Ro) vessels, very-large crude carriers (VLCCs), and liquid natural gas (LNG) vessels. But due to a limited data set for other vessel types that have been coated with FFR which does not allow them for the confident use of statistical analysis methods to compare performance pre- and post-FFR application. They created a table by speed adjusted fuel consumptions for the other type vessels and found 8.1% fuel consumption reduction for Ro-Ro vessels.

Lejars et al. (2012) published a very detailed chemical review with the subject of "Fouling Release Coatings: A Nontoxic Alternative to Biocidal Antifouling Coatings" where they explained fouling organisms, recent antifouling technologies, their chemical background, working mechanism and surface structures.

Demirel et al. (2013) introduced one of the latest investigations on development of marine antifouling coatings and to demonstrate the importance of the type of antifouling coatings on fouling accumulation and ship resistance/powering. They reviewed recent marine bio fouling and fouling prevention methods and then presented a research study (EU FP7 FOUL-X-SPEL Project) concerning a novel and environmentally friendly antifouling coating. Finally, a case study is carried out to assess the effect of fouling on ship resistance and powering. A vessel is selected and the roughness on the hull surface induced by different level of fouling is considered. The increase in frictional resistance and effective power is evaluated for each particular case by using boundary layer similarity law analysis and experimental data. The results emphasize that the type of antifouling coatings has a great importance on the amount of fouling accumulation, hence on ship performance especially in low speeds.

Paik et al. (2014) investigated drag performance of anti-fouling painted flat plates in a cavitation tunnel. The flat plates coated with silicone-type tin–free self-polishing co-polymer (SPC) or the conventional metal-type tin-free SPC is prepared to investigate the drag performance of the anti-fouling SPC. The local skin friction of anti-fouling paints is evaluated by a flat plate model test method in the cavitation tunnel. The properties of the boundary layer and the drag performance are investigated by flow and force measurement techniques. The silicone-type SPC paint shows better drag performance than the metal-type paint in the high-speed regime. The silicone-type SPC paints also show decreasing roughness function with the increase of displacement thickness even in the same silicone-type SPC paints with similar roughness function, drag performance appears differently.

Demirel et al. (2014), carried out a computational fluid dynamics (CFD) model study which enables the prediction of the effect of antifouling coatings on frictional resistance. It also outlines details of CFD simulations of resistance tests on coated plates in a towing tank. They also predicted the effects of antifouling coatings on the frictional resistance of a tanker.

Lindholdt et al. (2015) presents a systematic overview of the literature and described the experimental methods used to quantify the drag of hull coatings. They also summarized the findings of hull coating’s drag performance and identifies the main parameters impacting it. The results determined that drag performance of hull coating technology varies depending on whether the coating condition is newly applied, after dynamic or static seawater exposure.

Trodden et al. (2015) present a methodology to analysis of efficient shipping operations via fuel usage data. Due to results from repeated testing under controlled sea-trial conditions provides high-fidelity data and this approach is prohibitively expensive and requires repeating as the condition of the vessel changes with time, also data monitoring devices are relatively inexpensive, however, the process of analyzing data can be complex, particularly when a ship's activities are diverse, they described a methodology for associating ship activity with corresponding segments of a data-stream from a commercially available monitoring system. Further analysis is then performed to determine the fuel-efficient performance of the ship. The case-study used is a harbor tug, although the approach used is applicable to other ship types, its success on this basis indicates the methodology is robust. To validate the methodology, results from the data analysis are compared to fuel consumption data measured under sea-trial conditions, and are found to be in close agreement.

Meng et al. (2015) carried out a study “Shipping log data based container ship fuel efficiency modeling”. They developed a viable research methodology for modeling the relationship between the fuel consumption rate of a particular container ship and its determinants, including sailing speed, displacement, sea conditions and weather conditions, by using the shipping log data available in practice. The developed methodology consists of an outlier-score-based data preprocessing procedure to tackle the fuzziness, in accuracy and limited information of shipping logs, and two regression models for container ship fuel efficiency.

Aldous et al. (2015) carried out a study to identify the uncertainty in respect to ship performance monitoring analysis where he compared results of continuous monitoring system and noon reports via monte-carlo methods. The results indicate the significant uncertainty benefit of continuous monitoring data over noon report data; this is of the order of 90% decrease in uncertainty, and is especially relevant to shorter term analysis. It has been shown in this analysis that the uncertainty of the 90 days continuous monitoring base line is similar to the uncertainty achievable from a 270-day noon report dataset.

Swain and Lund (2016) present “Dry-Dock Inspection Methods for Improved Fouling Control Coating Performance”. Royal Caribbean Cruises Ltd. has funded research at the Florida Institute of Technology to develop a strategy to improve the selection, application, and management of ship hull coatings. The purpose of the research was threefold: establish an in-house baseline of performance to improve selection, maintenance, and life cycle costs of the different commercially available coatings; improve quality control of dry-dock procedures to include surface preparation and coating application; and insure that the ships are operating in compliance with both local and international regulations. They presented the methods that are available to measure specific aspects of the dry-dock process and how this data may be used for quality control and coating selection.

Deligiannis (2016) presents a new measure as “Ship Performance Indicator” which is resulted from a formulation related parameters without involving complicate algorithm. There have been several performance indicators in literature that are not completely independent from environmental effects, loading and operational conditions. The novelty of the PD no is shown through its application on a large number of data, collected from quite wide range of hull, propeller and main engine sizes. He presented new indicator which could be used for the framework of an environmental and energy efficiency regulatory policy to provide a shipping indexation, provides the reciprocating interaction between the vessel and the office, and provides a commercial tool for defining the charter-party speed versus fuel oil consumption framework.

Søyland and Oftedahl (2016) present a paper about new standard ISO 19030, its motivation, scope and development. They described the history of ISO 19030 for hull and propeller performance assessment for ships in service. It outlines initial motivation, purpose and implementation of the standard. The standard is intended to serve the wider community as well as support shipping operators and suppliers in better business practice.

It was not easy for analyzers to reach real life data from ships due to most of the ships did not have required measurement tools like torque meters and sensors, any data logging system to keep records, any useful and systematic recorded data to analysis in respect of hull and propeller performance. Also, uncertainty was well high for the data received from ships in respect to human error or equipment errors. On the other side, it was needed to apply first test coating to same ship for a one docking cycle and another one for next docking cycle to compare results and there should not have any major changes for the operation of that ship in order to analysis differences. Or needed completely sister ships under same operational conditions to apply different coatings to each of them and observe results. Also, even some operators have valuable data to support literature but they do not share with a paper unless some person in the company takes interest. To the best of our knowledge, only Corbett (2010) and his friends worked on real data from ships with a subject of "Energy and GHG Emissions Savings Analysis of Fluoropolymer Foul Release Hull Coating". They compared results of self-polishing copolymer coating and fluoropolymer foul release coating which were applied to 7 new built vessels, 1 of them was tanker, one of them was bulker and 5 of them were sister container vessels. Also, Menga, Dub and Wanga (2015) study "Shipping log data based container ship fuel efficiency modeling" with the shipping log data available in practice. This study was not directly for effect of antifouling but due to focus on fuel efficiency, it was also valuable for antifouling studies.

It is clear that, literature needs more studies regarding antifouling coating performances or hull and propeller performances with the real field data even there will be higher uncertainties when compared with laboratory test results. Ship operators are generally making their decisions according to real life experiences. We believe ISO 19030 will led to increase quantity of real life studies.

In order to fill the gap here, we studied a high-speed Ro-Ro fleet which has 11 sister vessels all built in same shipyard in Germany with same technical properties, working under same operational conditions between same ports in Mediterranean Sea since 2000. Only there were some changes with the generations regarding the built date which are explained in the methodology section of this study.

In respect to importance of hull performance on fuel costs, Ro-Ro Company wanted to create efficiency via using new hull coating technologies and to define the best antifouling coating technology for high speed Ro-Ro vessels. In order to obtain this, company decided to apply different type of new hull coating technologies to each sister vessels and measure results of reference and evaluation periods of different applications.

All vessels had been coated with conventional self-polishing antifouling coatings at the beginning then tested with different type of new technology antifouling (self-polishing or foul release) coatings. Then results of reference and evaluation periods compared in respect to speed loss and fuel efficiency according to the methodology described in ISO 19030 part 3. It was not possible fully comply with the ISO 19030 due collected data and collection period was different, but tried to carry out analysis according ISO 19030 as practicable as possible.

The hypothesis of this study is; new technology foul release silicone coatings provides better performance than other hull coating technologies for high-speed Ro-Ro vessels in respect to speed loss, fuel consumption and operational efficiency.

To the best of our knowledge, this is the first study for the high-speed Ro-Ro vessels. We believe result of this study will highlight performance of todays' antifouling technologies even there will be some uncertainty due to analyzed data were collected from arrival, departure and noon reports of test vessels instead of colleting them directly from required sensors and a data logger.

In the following sections of the study; fouling and fouling types will be described, recent antifouling coating technologies will be explained, ISO 19030 will be described, after presenting methodology and the findings, conclusion will take place.

# 2. FOULING AND RECENT ANTIFOULING TECHNOLOGIES

## 2.1 Fouling

Any surface immersed in seawater is subjected to the settlement of marine organisms (bacteria, algae, mollusks), known as fouling or bio fouling. This unwanted colonization has serious impacts for the marine industry, with deterioration of the surfaces, increased roughness, increased fuel consumption, and loss of maneuverability of the vessels. Marine species may also be introduced into non-native environments through ship transport. Lejars et al. (2012) describe marine bio fouling as a worldwide problem, costing billions of dollars per year in transportation.

### 2.1.1. Key Steps of Marine Fouling Growth

The immersion in seawater of a biologically nontoxic material leads to surface colonization by thousands of marine organisms that strive to complete their life-cycle. The process of biological fouling is often grouped into key steps of growth, which include the following figure 2.1.

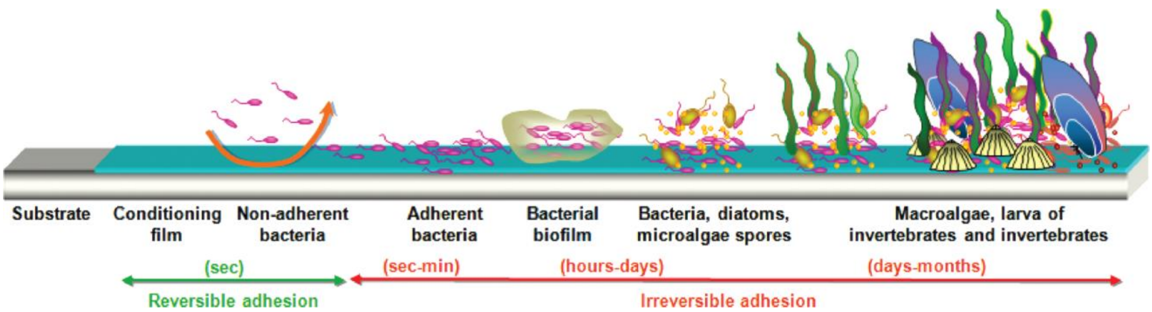


**Figure 2.1.** Development processes of marine fouling.

Source: Chemical Reviews (2012)

• Formation of a conditioning film: by an initial accumulation of physically adsorbed organic molecules (proteins, polysaccharides, glycoproteins).

• Primary colonization: with the settlement and growth of pioneer bacteria creating a biofilm matrix. First, isolated planktonic bacteria become fixed into heaps on a surface. This adhesion is reversible, as only weak and noncovalent bonds, such as Van der Waals, electrostatic, and acid−base forces, form. Then bacteria irreversibly anchor on the surface via a cellular appendix and exopolymers. When the biofilm is mature, it is passed through by liquid currents such as nutrients and can develop at macroscopic scales up to several meters under optimum conditions.

• Secondary colonization: the existence of this microbial film provides sufficient food to allow the fixing of a biofilm of multicellular species (e.g., spores of macro algae), generally called micro fouling (slime).

• Tertiary colonization: which includes the increased capture of particles and organisms, such as larvae of marine macro organisms. Macro foulants include macro algae, sponges, cnidarians, polychaetas, mollusks, barnacles, bryozoans, and tunicates.

### 2.1.2 Main Fouling Organisms

Lejars et al. (2012) declare that more than 4,000 fouling organisms identified worldwide. Bacteria, diatoms, and algae spores are the main micro-organisms that settle on ship hulls (Figure 2.2.a) while barnacles, tubeworms, bryozoans, mussels, and algae are the most common macro-organisms (Figure 2.2b.).

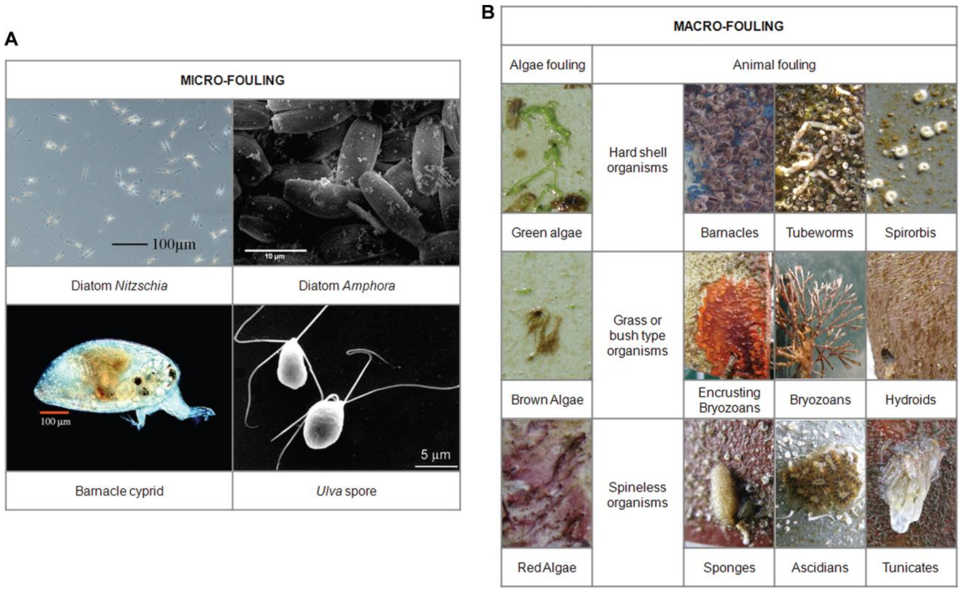


**Figure 2.2a,** Marine micro-organisms currently settled on pristine man-made surfaces immersed in natural seawater.

**Figure 2.2b,** Marine macro-organisms currently settled on pristine man-made surfaces immersed in natural seawater. Diatom Nitzschia.

Source: Chemical Reviews (2012)

Barnacles are the most familiar of the arthropods found on ship bottoms, and all successful AF paints must control barnacle fouling. In their adult form, they are encased in hard calcareous shells and are permanently attached to surfaces which are completely submerged or periodically wetted.

The final larval stage is the cypris larvae or "cyprid", which is approximately 500 μm in length and does not feed but swims around freely in the water prior to settlement. In order to complete the transition to adult life, these cyprids must attach themselves to a hard substrate.

The green alga ulva is the most common macro alga contributing to "soft" fouling of manmade surfaces throughout the world and has been extensively used as a model system for experimental studies of bio fouling and adhesion.

Diatoms are brown pigmented unicellular algae enclosed in a silica wall. Diatom biofilms are of interest because, as well as being highly resistant to biocidal AF paints, they are especially difficult to remove from nontoxic FRCs.

### 2.1.3 Effects of the Environment on Fouling Colonization

Several factors influence the settlement of marine fouling on surfaces, including salinity, PH, temperature, nutrient levels, flow rates, and the intensity of solar radiation. These factors vary seasonally, spatially, and with depth. Colonization and succession of bio fouling communities are highly affected by seasonality in temperate regions, with less fouling development in winter due to the reduction in seawater temperature, the intensity of solar radiation, and the numbers of spores and larvae. From spring to late summer, nutrient levels and seawater temperature increase, leading to a higher fouling pressure. Generally, the same major groups of organisms are responsible for fouling worldwide.

### 2.1.4 Impacts of Marine Fouling

The negative effects of marine fouling can be economic, environmental, or safety-related. Accumulations of micro and macro-organisms generate surface roughness and irregularities which increase the frictional resistance of a ship moving through water and consequently increase fuel consumption and emission of greenhouse gases. Schultz (2007) shows that even slime films can lead to significant increases in resistance and powering as shown in Table 2.1. Heavy calcareous fouling can result increase of frictional resistance up to 86% at service speed.

**Table 2.1,** Predictions of the Change in Total Resistance (ΔRt) and Required Shaft Power (ΔSP) for a Mid-Size Naval Ship with a Range of Representative Coating and Fouling Conditions (with Associated Average Coating Roughness (Rt50)) at Cruising Speed (15 knots)

| hull condition | $Rt_{50}$ ($\mu$m) | ΔRt (%) | ΔSP (%) |
|---|---|---|---|
| hydraulically smooth surface | 0 | | |
| typical as-applied AF coating | 150 | 2 | 2 |
| deteriorated coating or light slime | 300 | 11 | 11 |
| heavy slime | 600 | 20 | 21 |
| small calcareous fouling or weed | 1,000 | 34 | 35 |
| medium calcareous fouling | 3,000 | 52 | 54 |
| heavy calcareous fouling | 10,000 | 80 | 86 |

Source: Chemical Reviews (2012)

European Commission on Climate Actions declared that shipping emissions are predicted to increase between 50% and 250% by 2050. The IMO study about Greenhouse Gas Emissions from Ships (2000), estimated that AF coatings provide the shipping industry with annual fuel savings of $60 billion and reduced emissions of 384 million and 3.6 million tones, respectively, for carbon dioxide and sulfur dioxide per annum.

Another effect of marine fouling is the deterioration of coatings such as favored corrosion, especially in the case of settlement of invertebrates such as barnacles. Settlement of fouling results in an increase of the frequency of dry-docking operations, additional hull cleaning or even costly additional coating replacement or hull repair. On the other hand, it could have economic and societal impacts, including management costs, impact on human health, and costs for eradication and control measures.

### 2.2 Recent Antifouling Technologies

During the late 1970s, the AF research and development efforts were mainly focused on the successful TBT-based self-polishing copolymer systems. However, due to the emergence of environmental issues associated with TBT compounds, tin free coatings were developed in the early 1980s. The increasing number of publications, shown in figure 2.3. shows the intensification of research on new generations of AF technologies.

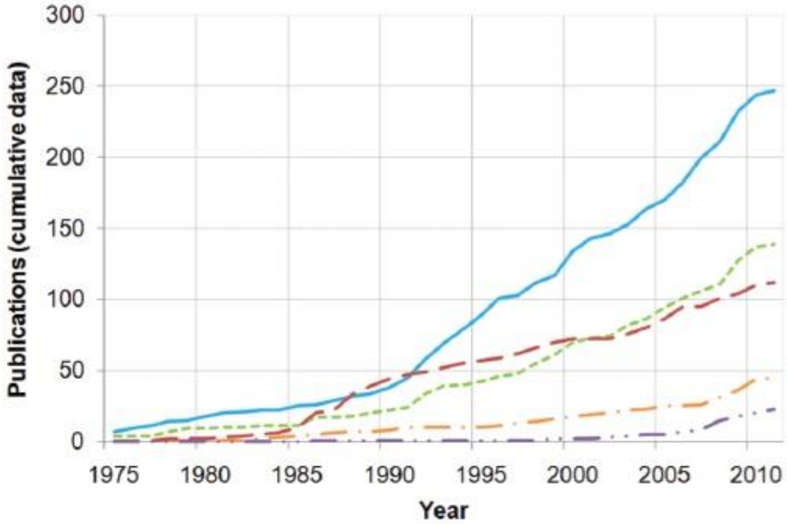


**Figure 2.3.** Total publications, papers, and patents on silicone-based coatings (−), fluoro-based coatings (---), self-polishing coatings (− −), enzyme-based coatings (− · −), and engineered micro topographical coatings (− · · −) from 1975 to 2011, based on a SciFinder search of the terms “marine coating or paint”, “silicone or PDMS”, “fluoro or fluoropolymer”, “self-polishing”, and “enzyme” or “topography”, respectively.

Source: Chemical Reviews (2012)

The current AF strategies can be divided into three main categories:

- Chemically active coatings, which act on the marine organisms by inhibiting or limiting their settlement using chemically active compounds,
- Nontoxic coatings, which inhibit the settlement of organisms or enhance the release of settled organisms without involving chemical reactions.
- Hybrid silicone-based fouling release coatings, which are mixture of FRC and self-polishing coatings where FRC compound consists of chemically active compounds.

During transition period from tin-based coatings to nontoxic AF coatings, the tin-free chemically active self-polishing coatings were claimed as the most efficient coatings in service. Intensive work for foul release coatings has been carried out since the early 1990s related to the development of both silicone and fluoro-based coatings. The number of publications which deal with FRC technology has continuously increased and is currently higher than publications concerning the most efficient chemically active paints.

### 2.2.1 Chemically Active Antifouling Coatings

#### 2.2.1.1 Biocide-Based Coatings

Chemically active AF technologies are based on the release of tin-free active compounds called biocides and can be subdivided into three main categories:

- contact leaching coatings,
- soluble/controlled depletion polymer (CDP) coatings,
- Self-polishing copolymer (SPC) coatings (Figure 2.4.)

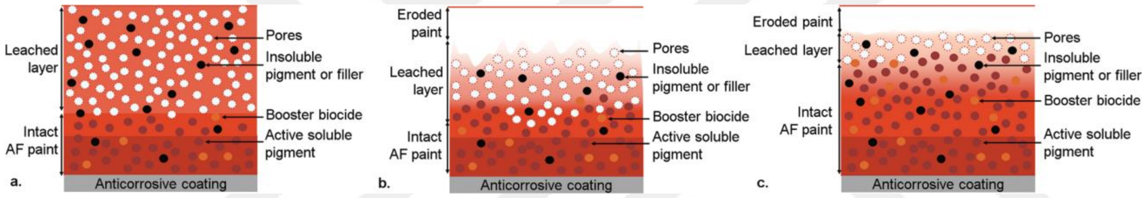


**Figure 2.4.** Schematic illustration of the behavior of a biocide-based antifouling system exposed to seawater.

(a) Contact leaching coatings;

(b) Soluble matrix or Controlled Depletion Polymer coatings;

(c) Self-Polishing Copolymer coatings.

Source: Chemical Review (2012)

These technologies aim the same objective, avoiding fouling with the controlled release of bioactive molecules embedded in a polymer matrix called binder, but act with various mechanisms.

#### 2.2.1.2. Enzyme-Based Coatings

The idea of using enzymes for AF coatings emerged during the 1980s, and the concept has received increased interest in recent years. Enzymes are catalytically active proteins and are omnipresent in nature. They can degrade the fouling organism or its bio adhesive, or produce other biocidal compounds.

### 2.2.2. Nontoxic Coatings

#### 2.2.2.1. Engineered Micro Topographical Surfaces

One of the nontoxic AF strategies is to disrupt physically the adhesion of marine organisms using micro topographical surfaces, as it is employed by natural organisms in their defense against bio adhesion. Micro topography has been shown to deter bio fouling on marine mammal, shark skin, or mollusk shells and affect attachment of barnacles, algae and bacteria. The major difficulties preventing the commercialization of micro topographical surfaces are the price and the impractical use for large vessels.

#### 2.2.2.2. Fouling Release Coatings

Fouling release coatings are biocide-free coatings, and their AF performances rely on a dual mode of action, i.e. nonstick properties and a FR behavior. The general idea of FRCs is to minimize the adhesion between fouling organisms and the surface, so that the fouling can be removed by hydrodynamic stress during navigation or by a simple mechanical cleaning. The self-cleaning properties of FRCs are illustrated in figure 2.5., where an initially fouled FRC-coated surface is able to self-clean at different velocities. Moreover, the smoothness of FRCs enables them to reduce the drag of the vessel and therefore reduce fuel consumption and greenhouse gas emissions. In the patented and scientific literature, FRCs include both silicone- and fluoropolymer based binders, as they are the two major polymeric materials reported to exhibit FR properties.

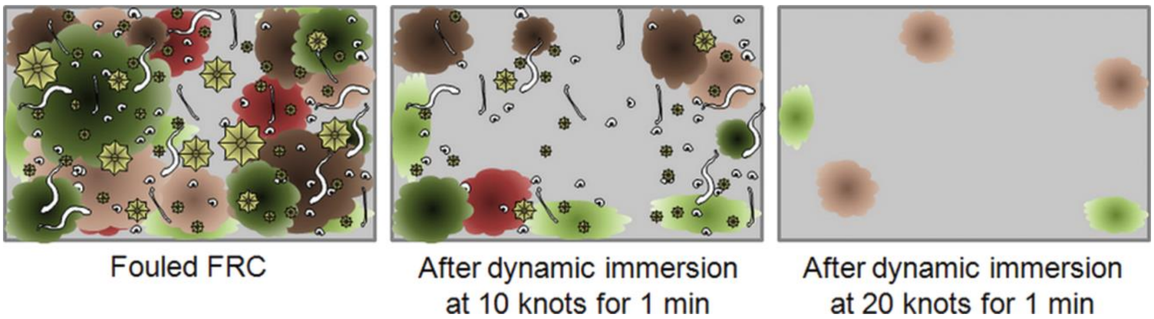


**Figure 2.5.** Schematic illustration of the self-cleaning ability of FRCs

Currently, commercially available FRCs are generally developed as a duplex system composed of a FR top-coat and a tie-coat applied on an anticorrosive epoxy primer. The top-coat is based on cross-linked PDMS elastomers and usually contains additive oils to enhance their slippery nature. The tie coat is required to promote the adhesion between the nonstick FR top-coat and the epoxy primer (Figure 2.6.).

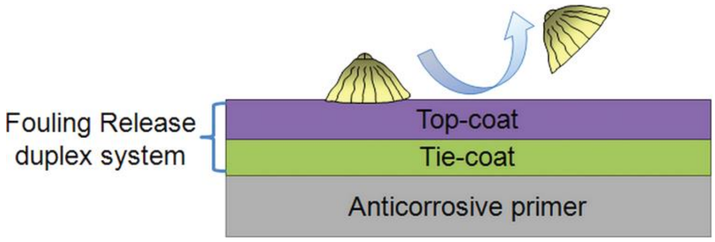


**Figure 2.6.** Schematic illustration of FR systems.

The specific FR properties have traditionally been related to the surface hydrophobicity and low energy but are also influenced by other parameters, including surface roughness, elastic modulus, and thickness of the film coating. The in-service lifetime of FRCs is typically 5 years.

#### 2.2.2.2.1 Silicone Coatings

In 1977, Milne first patented the use of silicone oil within a cured silicone rubber to enhance the AF efficiency of in situ immerged coated panels. Due to the success of TBT-SPC systems, the commercialization of silicone elastomers as FRCs was delayed until the 1980s, when the environmental problems associated with TBT-SPC antifouling were starting to appear.

#### 2.2.2.2.2 Fluorine Based Coatings

Fluoropolymers are well-known for their nonpolar nature, which confers a hydrophobic character to their surfaces and a very low critical surface tension or surface energy. The first use of fluoropolymers as FRCs was patented in 1973, with the use of fluoropolymers such as poly (tetrafluoroethylene) or fluorinated ethylene–propylene copolymers for undersea protection of ship hulls.

### 2.2.3. Hybrid Silicone-Based Fouling Release Coatings

#### 2.2.3.1. Silicone Incorporating Nanofillers

Natural sepiolite nanofibers were incorporated into the hydrolyzation-cured silicone coating to enhance its mechanical properties without weakening its antifouling and FR properties.

#### 2.2.3.2. Silicone Modification with Polyurethane or Epoxy Segments

PDMS-modified polyurethane and epoxy resins have been explored to improve the adhesion and durability of FRCs. These coatings exhibited improved mechanical properties due to the reinforcing effect of the PU domains while retaining the low surface energy of the silicone elastomer.

#### 2.2.3.3. Silicone Coating Incorporating Fluoropolymers

Fluorinated compounds and polymers containing fluorinated moieties are known for their very low surface energy and hydrophobicity, and several approaches have been attempted to improve the FR properties of silicone-based FRCs by the incorporation of fluorinated groups into the elastomeric silicone network. The surface energies of such coatings were reported to be lower than those of pure silicone FRCs and to decrease with increasing amount of fluorine in the network.

#### 2.2.3.4. Hydrogel Silicones

Silicone FRCs are mainly affected by the settlement of diatoms, since hydrophobic surfaces seem to favor the adhesion of such fouling organisms. To overcome this problem, further generation of FRCs developed through a "hydrogel silicone" approach. Hydrogels are cross-linked polymeric structures containing either covalent bonds or physical cross-links from entanglements, association bonds such as hydrogen bonds, or strong van der Waals interactions between chains. These hydrophilic polymer networks are water-insoluble, but they can be swollen and absorb over 99% of their original weight of water. Hydrogels are commonly used in medical applications, as they are well-known to minimize protein and bacterial adhesion.

#### 2.2.3.5. Hybrid Antifouling / Fouling Release Coating

Several studies dealt with the development of marine coatings which involved combining characteristics of a biocidal AF coating with the characteristics of a FRC by incorporating biocides in silicone coatings. There are commercially available Hybrid antifouling/fouling release coatings technologies available in the market which utilizes the added effect of advanced hydrogel silicone and an efficient fouling preventing biocide. This boosts the antifouling barrier and prolongs the fouling free period.

## 2.3. IS0 19030 Ships and Maritime Technology, Measurement of Changes in Hull and Propeller Performance

Hull and propeller performance refers to the relationship between the condition of a ship's underwater hull and propeller and the power required to move the ship through water at given speed. Measurement of changes in ship specific hull and propeller performance over time makes it possible to indicate the impact of hull and propeller maintenance, repair and retrofit activities on the overall energy efficiency of the ship in question.

The aim of this International Standard is to prescribe practical methods for measuring changes in ship specific hull and propeller performance and to define a set of relevant performance indicators for hull and propeller maintenance, repair, retrofit activities. The methods are not intended for comparing the performance of ships of different types and sizes (including sister ships) nor to be used in a regulatory framework.
ISO 19030 consist of three parts:

- The first part outlines general principles for how to measure changes in hull and propeller performance and defines a set of performance indicators for hull and propeller maintenance, repair and retrofit activities;
- The second part defines the default method for measuring changes in hull and propeller performance and for calculating the performance indicators. It also provides guidance on the expected accuracy of each performance indicator;
- The third part outlines alternatives to the default method. Some will result in lower accuracy but increase applicability of the standard. Others may result in same or higher overall accuracy but include elements which are not yet broadly used in commercial shipping.

The default method given in Part 2 of the standard, requires various sensors like torque meter, thrust meter, speed log to measure speed through water, anemometer, gps, gyro compass, draft sensors, echo sounder, rudder angle indicator, thermometer for sea water and ambient air temperature, barometer. And the most important requirement for default method is a system to log all these data continuously not higher then every 15 seconds, store them, back up them and provide when it is required to analysis. It is very well known that most of the commercial ships in service do not have these capabilities. Therefore, Part 3 of the standard which is explaining alternative methods for measuring hull and propeller performance is more useful for most of the ships in service.

### 2.3.1. Data acquisition

Where Part 2 of the international standard, specifies that the data shall be recorded simultaneously at a frequency if 1 signal every 15 seconds (0.07Hz) or collected by a data acquisition system (e.g. data logger), part 3 of the international standard permits the measurements to be recorded less frequently (e.g. noon data) if a system for data collection at this frequency is not available. Part 3 of the standard requires following specifications:

- The data sampling rate shall remain unchanged over the full measurement period (Reference Period and Evaluation Period), except for changes created by time-zone change;
- Primary measurement parameters (speed, power from either shaft torque and rpm or fuel consumption) shall be averaged over the period;
- Secondary measurement parameters shall to the extent possible be collected at the same sampling rate as the primary measurement parameters, or no less frequently than 1 signal per day. With the exception of wind and draught, these values shall be short-term average values (e.g. averages over 1 minute) taken at the point in time the observation is obtained.

If data cannot be automatically collected, data shall be collected manually. This introduces an uncertainty partially due to the increased probability of human error over error probability in automated data collection systems, but also due to the necessity of reducing sampling frequency.

### 2.3.2. Performance Indicators defined in the International Standard

Measurements of ship specific changes in hull and propeller performance can be used in a number of relevant performance indicators to determine the effectiveness of hull and propeller maintenance, repair and retrofit activities.

#### 2.3.2.1. Indicator 1- Dry-docking performance

The change in hull and propeller performance following present out-docking as compared with the average from previous out-dockings (where data/measurements are available) is useful for determining the effectiveness of the dry-docking.

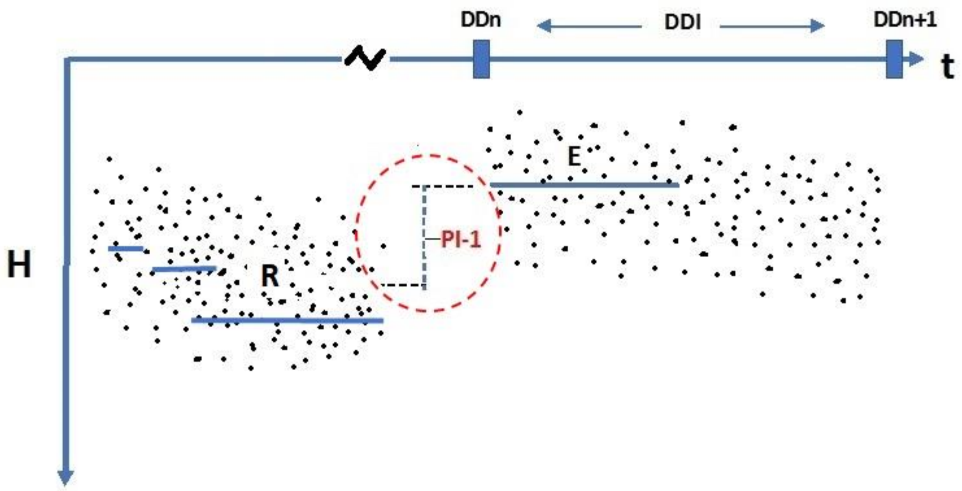


**Figure 2.7.** Dry-docking Performance

Where:

| | |
|---|---|
| H | Hull and propeller performance |
| t | Time |
| DDn | Present dry-docking |
| DDn+1 | Next dry-docking |
| DDI | Dry-docking interval |
| R | Reference period : average hull and propeller performance following previous out-dockings |
| E | Evaluation period : hull and propeller performance following present out-docking |
| PI-1 | Performance Indicator 1: Dry-docking performance |

During a dry-docking the propeller(s) are typically cleaned, polished and/or repaired and the underwater hull is typically cleaned, spot or fully blasted, repaired and re-coated. In addition retrofits may be undertaken to improve the performance of the hull, propeller or both.

It is not possible to accurately isolate individual effects (for example impact of differences in level or quality of pre-treatment, quality of application or surface characteristics of paint). But, if only a sub-set of effects are expected to differ between the dry-dockings and everything else can be reasonably be assumed to be same, the performance indicator can serve as an indicator for this sub-set of effects.

The period following directly after the latest dry-docking is the evaluation period. The period(s) following directly after pervious dry-docking(s) are the reference period(s). All periods are to be of the same length of one year.

#### 2.3.2.2. Indicator 2 – In-service performance

The average change in measured hull and propeller performance over the period from out-docking to the end of the dry-docking interval can be used to determine the effectiveness of the underwater hull and propeller solutions including hull coatings used and any maintenance activities that have occurred over the course of the dry-docking interval.

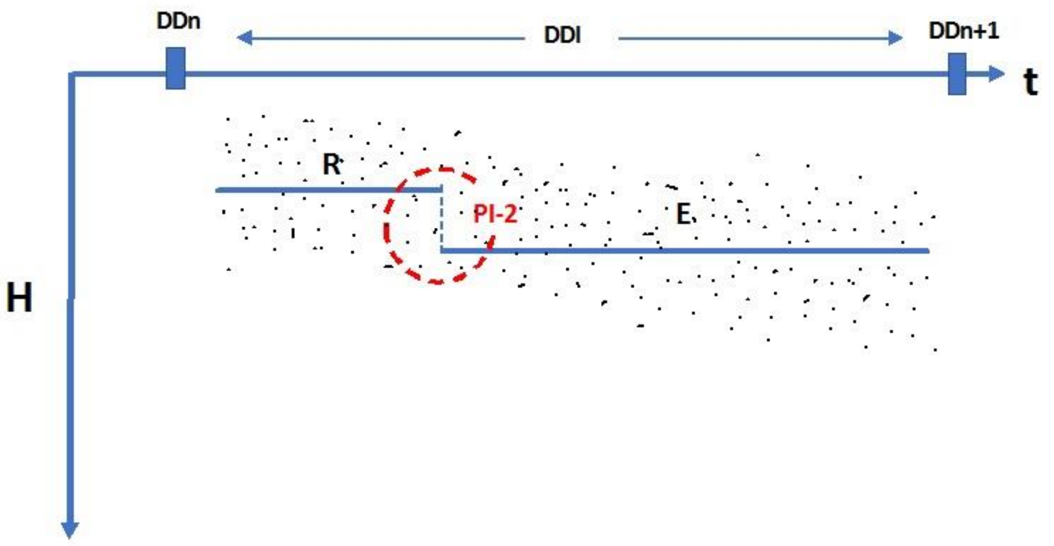


**Figure 2.8.** In-Service Performance

Where:

| | |
|---|---|
| H | Hull and propeller performance |
| t | Time |

| | |
|---|---|
| DDn | Present dry-docking (or in the case of a new ship, date to entry into service) |
| DDn+1 | Next dry-docking |
| DDI | Dry-docking interval |
| R | Reference period : hull and propeller performance following present out-docking |
| E | Evaluation period : avg. hull and propeller performance over remainder of dry-docking interval |
| PI-2 | Performance Indicator 2: In-service performance |

The period following directly after the latest dry-docking is the reference period. The period following the reference period until the end of the same dry-docking period is the evaluation period. The reference period and the evaluation period shall both be of minimum one year.

#### 2.3.2.3. Indicator 3 – Maintenance Trigger

The measured change in hull and propeller performance from the start of the dry-docking interval to a moving average at a chosen time during the same interval can be used as a trigger for underwater hull and propeller maintenance, including propeller and/or hull cleaning.

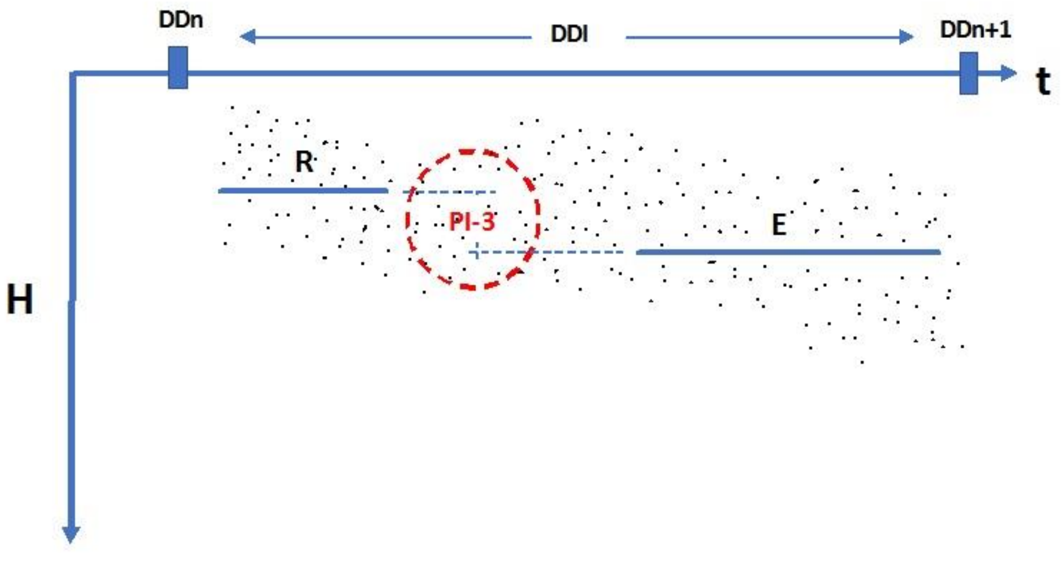


**Figure 2.9.** Maintenance Trigger

Where:

| | |
|---|---|
| H | Hull and propeller performance |
| t | Time |
| DDn | Present dry-docking (or in the case of a new ship, date to entry into service) |
| DDn+1 | Next dry-docking |
| DDI | Dry-docking interval |
| R | Reference period : hull and propeller performance following present out-docking |
| E | Evaluation period : moving average hull and propeller performance at any choosen time |
| PI-3 | Performance Indicator 3: Maintenance trigger |

The period following directly after the latest dry-docking is the reference period. A period after the reference period in the same dry-docking interval is the evaluation period. The reference period and the evaluation period shall both be of minimum three months.

#### 2.3.2.4. Indicator 4 – Maintenance Effect

The change in hull and propeller performance measured before and after a maintenance event can be used to determine the effectiveness of a specific maintenance activity that has taken place in the interval between the measurements, including and propeller and/or hull cleaning.

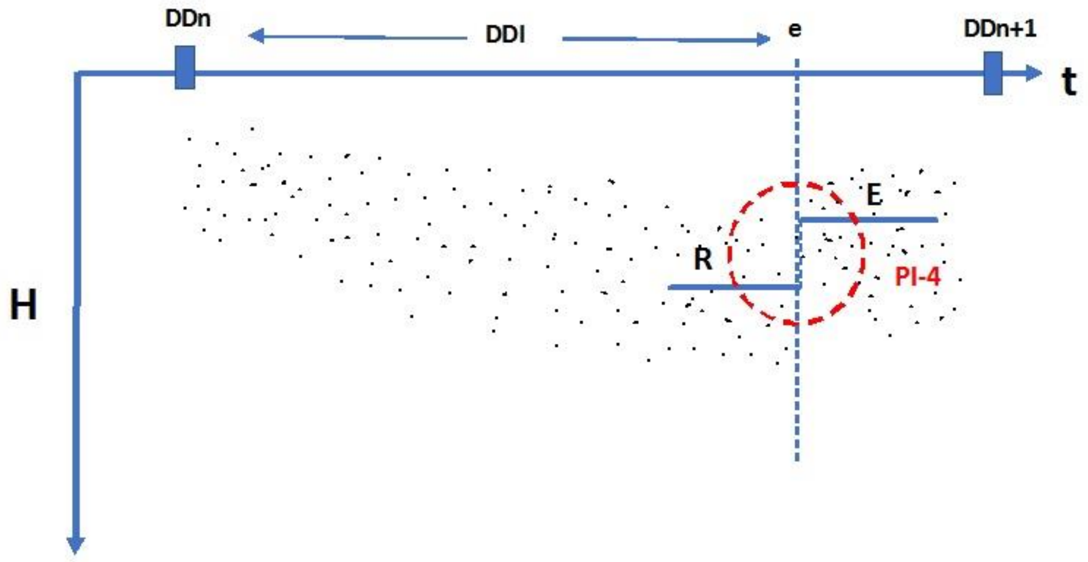


**Figure 2.10.** Maintenance Effect

Where:

| | |
|---|---|
| H | Hull and propeller performance |
| t | Time |
| DDn | Present dry-docking (or in the case of a new ship, date to entry into service) |
| DDn+1 | Next dry-docking |
| DDI | Dry-docking interval |
| E | Maintenance event |
| R | Reference period : hull and propeller performance before maintenance event |
| E | Evaluation period : hull and propeller performance after maintenance event |
| PI-4 | Performance Indicator 4: Maintenance effect |

The period following directly the maintenance event is the evaluation period. The period preceding the event is the reference period. The reference period and the evaluation period shall both be of minimum three months.

### 2.3.3. Performance Values, PVs

A performance value shall be calculated for every data point the corrected data set. The union of the corrected data set and the performance values, PVs, is referred to as the prepared data set.

The performance value, PV, is defined as the percentage speed loss compared to a reference speed-power relation.

### 2.3.4. Determination of reference conditions

The reference conditions are the same for all performance indicators and they are met when, simultaneously:

- Delivered power has to be within the range of power values covered by the available speed-power reference curves,
- Displacement has to be within +-5% of the displacement values for the available speed power reference curves,
- Absolute rudder angle value is smaller than 5 degree,

- In case that delivered power is estimated by the method outlines in Annex C of the standard, the estimated delivered power has to be within the range of power values covered by the available SFOC reference curve.

# 3. DATA AND METHODOLOGY

This study is focused on performance and benefits of new hull coating technologies applied to a high-speed Ro-Ro fleet. In order to carry out analysis, below explained methodology was used which takes ISO 19030 Part 3 as a reference.

Actual field data of 8 sister vessels used in the study where all vessels built in same shipyard with same technical properties and trading on the same route between Turkey to Italy and France. Oldest vessel was built in 2001 and the last one in 2008.

Main idea of this study was to calculate performance indicators defined in ISO 19030 and evaluate results of reference and evaluation periods in order to identify if there is any significant improvement on hull - propeller performance in respect to speed-loss and any reduction on fuel consumption through new hull coating technologies.

Reason of selecting these 8 high-speed sister Ro-Ro vessels listed below:

- All vessels built in same shipyard with same technical properties, only there were some changes with the generations regarding the built date
- All vessels had same technology SPC antifouling coating at the beginning
- All vessels have used same fuel oil from same supplier during test period
- All vessels have been loaded with same type of cargo as trucks and trailers
- All vessels have been operated by same technical management with same planned maintenance system
- All vessels have been maintained with only genuine spare parts during their engine overhauls and routine maintenance activities.
- All test vessels traded between the same routes and same waters in Mediterranean Sea. Example of vessels track have been shown in figure 3.1:


**Figure 3.1.** Test vessel’s tracks in Mediterranean Sea

### 3.1. Limitations and Assumptions

- Methodology explained in the international standard ISO 19030-Measurements of changes in hull and propeller performance, part 3 was taken as a reference and tried to use in this study as practicable as possible.
- Sample fleet operates between Istanbul-Trieste, Istanbul-Toulon and Mersin-Trieste ports since 2000 and it takes a week for each vessel to complete one trip. Therefore, each leg of the trip (e.g. Istanbul to Trieste or Trieste to Istanbul) was used as a sample instead of collecting daily data from noon reports as explained in part 3 of International Standard.
- For the one of the primary measurement parameter speed over ground, average speed over ground calculated for each leg of the trip from distance sailed and duration of the trip relation.
- Sample fleet was not fitted with torque meter, therefore delivered power calculated from fuel consumption, model test result of the ship and engine acceptance test result as explained in Part 3 of the International Standard.
- SFOC curve created in factory acceptance test of the engine was done with a fuel of 42274 kJ/kg. And the actual LCV of the fuel which all vessels in question are consuming is 40200 kJ/kg. Therefore, SFOC curve corrected according to Lower Calorific Value of the fuel which vessels are consuming.

- Due to all vessels were sisters with same technical properties and working under same operational conditions and due to data of high number of voyages has been observed which is covering nearly all seasons of the year, it is assumed that, all vessels had same weather conditions as wind and sea states. Therefore, secondary measurement parameters as wind and water depth were not included in this study.
- Third of secondary measurement parameters, draught data also could not measure due to test vessels were not fitted with draught sensors, also due to displacement for each sampling rate was available from stability reports issued by vessel for each sampling rate. Stability character of test vessels is almost same and they are using same stability software. Stability software on board has online gauging ability from every tank and only cargo weights and positions needs to be entered manually by crew. Cargo weight data provided for each voyage from the port authority.
- Product description explanations given in product data sheet of tested antifouling coatings were used as name/description of the coating.

## 3.2. Methodology

Application and test of new technology hull coatings to specified Ro-Ro fleet started in 2013, 10 vessels docked until July 2014, 8 of them completed their first docking cycle with test application and docked again in 2015 and 2016 which we achieved performance of complete docking cycle on these vessel’s result.

Details and dry-docking history of test vessels listed in below tables:

**Table 3.1.a** Details of Vessels

| VESSEL NO | VESSEL 1 | VESSEL 2 | VESSEL 3 | VESSEL 4 |
|---|---|---|---|---|
| BUILT YEAR | 2001 | 2002 | 2005 | 2005 |
| GROSS TONNAGE | 26469 | 26469 | 29004 | 29004 |
| NET TONNAGE | 7941 | 7941 | 8702 | 8702 |
| DWT SUMMER LOAD | 9865 | 9865 | 11636 | 11636 |
| DWT DESIGN DRAUGHT | 7092 | 7092 | 9481 | 9481 |
| LIGHT SHIP | 8663 | 8663 | 9041 | 9041 |
| BREADTH | 26 mtrs | 26 mtrs | 26 mtrs | 26 mtrs |
| LENGTH OVER ALL | 193 mtrs | 193 mtrs | 193 mtrs | 193 mtrs |
| LENGTH BETWEEN PERP. | 182,39 mtrs | 182,39 mtrs | 182,39 mtrs | 182,39 mtrs |
| DEPTH TO MAIN DECK | 8.6 mtrs | 8.6 mtrs | 8.6 mtrs | 8.6 mtrs |
| DEPTH TO UPPER DECK | 16.7 mtrs | 16.7 mtrs | 16.7 mtrs | 16.7 mtrs |
| DRAUGHT(SUMMER LOAD) | 6.45 mtrs | 6.45 mtrs | 7,00 mtrs | 7,00 mtrs |
| DRAUGHT(DESIGNED) | 5.7 mtrs | 5.7 mtrs | 6,45 mtrs | 6,45 mtrs |
| SERVICE SPEED | 21.6KN | 21.6KN | 21.6KN | 21,5 KN |
| MAIN ENGINES | MCR 16200 KW | MCR 16200 KW | MCR 16200 KW | MCR 16200 KW |
| LANE METERS | 3214 | 3214 | 3735 | 3735 |
| CLASSIFICATION | DNV + 1 A1 GENERAL CARGO CARRIER RO-RO | DNV + 1 A1 GENERAL CARGO CARRIER RO-RO | DNV + 1 A1 GENERAL CARGO CARRIER RO-RO | DNV + 1 A1 GENERAL CARGO CARRIER RO-RO |
| BOW THRUSTER | 1400KW(1900 HP) | 1400KW(1900 HP) | 1400KW(1900 HP) | 1400KW(1900 HP) |

**Table 3.1.b** Details of Vessels

| VESSEL NO | VESSEL 5 | VESSEL 6 | VESSEL 7 | VESSEL 8 |
|---|---|---|---|---|
| BUILT YEAR | 2005 | 2006 | 2008 | 2008 |
| GROSS TONNAGE | 29004 | 29004 | 29004 | 29004 |
| NET TONNAGE | 8702 | 8702 | 8702 | 8702 |
| DWT SUMMER LOAD | 11636 | 11636 | 11523 | 11523 |
| DWT DESIGN DRAUGHT | 9481 | 9481 | 9481 | 9481 |
| LIGHT SHIP | 9041 | 9041 | 9152 | 9152 |
| BREADTH | 26 mtrs | 26 mtrs | 26 mtrs | 26 mtrs |
| LENGTH OVER ALL | 193 mtrs | 193 mtrs | 193 mtrs | 193 mtrs |
| LENGTH BETWEEN PERP. | 182,39 mtrs | 182,39 mtrs | 182,39 mtrs | 182,39 mtrs |
| DEPTH TO MAIN DECK | 8.6 mtrs | 8.6 mtrs | 8.6 mtrs | 8.6 mtrs |
| DEPTH TO UPPER DECK | 16.7 mtrs | 16.7 mtrs | 16.7 mtrs | 16.7 mtrs |
| DRAUGHT(SUMMER LOAD) | 7,00 mtrs | 7,00 mtrs | 7,00 mtrs | 7,00 mtrs |
| DRAUGHT(DESIGNED) | 6,45 mtrs | 6,45 mtrs | 6,45 mtrs | 6,45 mtrs |
| SERVICE SPEED | 21,5 KN | 21,5 KN | 21,5 KN | 21,5 KN |
| MAIN ENGINES | MCR 16200 KW | MCR 16200 KW | MCR 16800 KW | MCR 16800 KW |
| LANE METERS | 3735 | 3735 | 3735 | 3735 |
| CLASSIFICATION | DNV + 1 A1 GENERAL CARGO CARRIER RO-RO | DNV + 1 A1 GENERAL CARGO CARRIER RO-RO | DNV + 1 A1 GENERAL CARGO CARRIER RO-RO | DNV + 1 A1 GENERAL CARGO CARRIER RO-RO |
| BOW THRUSTER | 1400KW(1900 HP) | 1400KW(1900 HP) | 1400KW(1900 HP) | 1400KW(1900 HP) |

**Table 3.2.** Dry-docking History of Test vessels

| | | DDn-1 | DDn | DDn+1 |
|---|---|---|---|---|
| VESSEL 1 | **Date of Drydock** | 4.05.2011 | 11.11.2013 | 13.08.2016 |
| | **Shipyard** | BESIKTAS | BESIKTAS | SEFINE |
| | **Blasting** | SPOT | FULL | %10 sweep blasting |
| | **Hull Coating** | Self Polishing Coating 1 | Foul Release Coating 1 | Foul Release Coating 1 |
| | **Engine Overhaul** | NO | NO | Both Engine 90.000 Hours overhaul Completed |
| VESSEL 2 | **Date of Drydock** | 17.08.2011 | 10.06.2014 | 17.01.2017 |
| | **Shipyard** | BESIKTAS | BESIKTAS | SEFINE |
| | **Blasting** | SPOT | FULL | %10 sweep blasting |
| | **Hull Coating** | Self Polishing Coating 1 | Foul Release Coating 1 | Foul Release Coating 1 |
| | **Engine Overhaul** | NO | NO | Both Engine 90.000 Hours overhaul Completed |
| VESSEL 3 | **Date of Drydock** | 8.04.2010 | 22.01.2013 | 29.03.2015 |
| | **Shipyard** | BESIKTAS | GEMAK | GEMAK |
| | **Blasting** | SPOT | SPOT | FULL |
| | **Hull Coating** | Self Polishing Coating 1 | Self Polishing Coating 1 | Foul Release Coating 2 |
| | **Engine Overhaul** | NO | NO | NO |
| VESSEL 4 | **Date of Drydock** | 29.06.2010 | 5.05.2013 | 16.05.2015 |
| | **Shipyard** | BESIKTAS | GEMAK | BESIKTAS |
| | **Blasting** | SPOT | FULL | FULL |
| | **Hull Coating** | Self Polishing Coating 1 | Self Polishing Coating 2 | Foul Release Coating 1 |
| | **Engine Overhaul** | NO | NO | NO |
| VESSEL 5 | **Date of Drydock** | 30.08.2010 | 27.07.2013 | 2.06.2015 |
| | **Shipyard** | BESIKTAS | BESIKTAS | BESIKTAS |
| | **Blasting** | SPOT | FLAT BOTTOM FULL, VERTICAL SIDES SPOT | FULL |
| | **Hull Coating** | Self Polishing Coating 1 | Self Polishing Coating 3 | Foul Release Coating 2 |
| | **Engine Overhaul** | NO | NO | NO |
| VESSEL 6 | **Date of Drydock** | 22.04.2010 | 8.03.2013 | 9.10.2015 |
| | **Shipyard** | BESIKTAS | GEMAK | BESIKTAS |
| | **Blasting** | SPOT | SPOT | FULL |
| | **Hull Coating** | Self Polishing Coating 1 | Self Polishing Coating 1 | Foul Release Coating 1 |
| | **Engine Overhaul** | NO | NO | NO |
| | **Other** | | | KAPPEL PROPELLER MODIFICATION |
| VESSEL 7 | **Date of Drydock** | 4.02.2012 | 31.05.2013 | 28.04.2016 |
| | **Shipyard** | BESIKTAS | BESIKTAS | SEFINE |
| | **Blasting** | SPOT | SPOT | SPOT |
| | **Hull Coating** | Self Polishing Coating 1 | Self Polishing Coating 1 | Self Polishing Coating 4 |
| | **Engine Overhaul** | NO | NO | NO |
| VESSEL 8 | **Date of Drydock** | 17.08.2011 | 28.08.2013 | 31.03.2016 |
| | **Shipyard** | GEMAK | BESIKTAS | BESIKTAS |
| | **Blasting** | SPOT | SPOT | FULL |
| | **Hull Coating** | Self Polishing Coating 1 | Self Polishing Coating 5 | Foul Release Coating 1 |
| | **Engine Overhaul** | NO | NO | Both Engine 45.000 hours overhaul completed. |
| | **Other** | | | CLT PROPELLER MODIFICATION |

All vessels were coated with the same self-polishing coating technology (self-polishing coating type 1) at the beginning. Then different technology of hull coatings applied and results evaluated.

1st type Foul release coating was first applied in 2013 and 2014 to VESSEL 1 and VESSEL 2. VESSEL 1 completed her dry-docking cycle and dry-docked again in 2016. VESSEL 2 completed her docking cycle in January 2017. Performance of 1st type foul release coating analyzed on these vessels in respect to comparison of reference and evaluation periods defined in ISO 19030 for the dry-docking performance and in-service performance indicators.

VESSEL 3, VESSEL 6 and VESSEL 7 were not tested with any new technology hull coating in 2013 and coated with the same antifouling technology (1st type self-polishing coating) with 25% partly blasting as in previous dry-dock. These vessels were analyzed as a control samples to evaluate what would be the results if the same antifouling coating applied again with only spot blasting.

VESSEL 3 dry-docked again in 2015 and 2nd type foul release coating applied with full blasting. Performance of 2nd type foul release coating technology tested on this vessel.

VESSEL 6 dry-docked again in 2015 and 1st type foul release coating technology applied with full blasting. Also, propeller modification was carried out with Kappel propellers during the same dry-docking. Result of 1st type foul release coating and new propellers evaluated together and compared to other sister vessels which are coated with foul release coating only in order to identify effect of propeller modification.

VESSEL 7 also dry-docked again in 2016 and 4th type self-polishing coating technology hull coating applied with only 15% partly blasting. We tested what would be the result if different technology self-polishing coating applied instead of application of same self-polishing antifouling coating as the previous dry-dock.

VESSEL 4 was dry-docked in 2013 and 2nd type self-polishing coating technology applied with 100% blasting. A performance of 2nd type self-polishing coating tested on this vessel until next dry-dock carried out in 2015 which $1^{st}$ type foul release coating technology applied with full blasting. VESSEL 4 was a good sample which indicated results of self-polishing and foul release coatings with %100 blasting.

VESSEL 5 coated with $3^{rd}$ type self-polishing coating technology in 2013. She was blasted 100% for flat bottom and 5% for vertical sides. VESSEL 5 completed her docking cycle and dry-docked again in 2015 and $2^{nd}$ type foul release coating technology applied with full blasting.

VESSEL 8 coated with $5^{th}$ type self-polishing coating technology in 2013, then she completed her docking cycle and dry-docked again in 2016 and $1^{st}$ type foul release coating technology applied with full blasting. Also, propeller modification had been carried out with CLT blades during the same dry-docking. Result of $1^{st}$ type foul release coating and new propellers evaluated together and compared to other sister vessels which are coated with foul release coating only in order to identify effect of propeller modification.

In order to obtain if there is any significant improvement of speed loss and fuel consumption reduction by using new technology hull coatings, following procedure used:

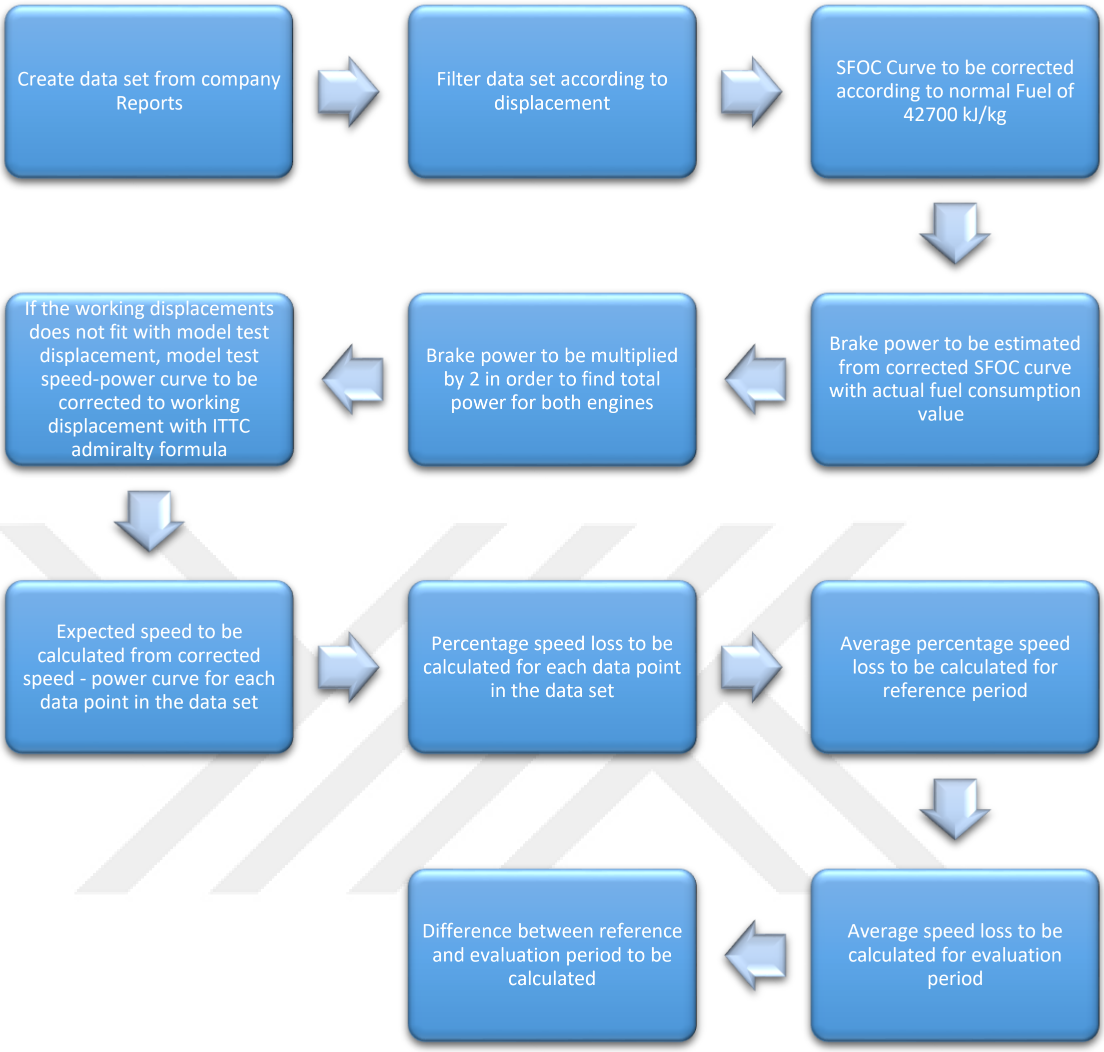


**Figure 3.2.** Methodology overview

1 – Detailed tables created as a raw data for all test vessels from the company's official arrival, departure, and noon and Energy Efficiency Operational Index reports. Only data of the voyages completed in normal conditions included in the analysis. Any voyage which had any engine failure or any unexpected delay on schedule causing abnormal fuel consumptions, were not included.

Raw data was including below information:

- Vessel name
- Voyage number: Each test vessel completes weekly voyages which have 2 legs (e.g. If vessel trading on Pendik – Trieste line, Pendik to Trieste is the first leg, Trieste to Pendik is the second leg of the voyage and data of each leg took as a sample)

- Docking cycle: Identification of voyage data referring to dry-docking period (e.g. DDN refers the drydock which test coating applied, DDN-1 refers to previous drydock and DDN+1 refers to the drydock which is next drydock after test application)
- Voyage between ports: Information of voyage between which ports in order to identify sailed distance.
- Displacement: Actual loaded displacement of vessel for each leg of the voyage
- Total fuel consumption for the voyage: Total fuel consumption for each leg of the voyage
- Total duration of voyage: Total duration of each leg
- Average fuel consumption per hour for the voyage: Calculated average fuel consumption per hour for each leg by dividing total consumption to duration
- Total sailed distance in Nm: Routes of each vessels collected from each test vessel to calculate correctly sailed distance
- Average speed for the voyage (in knots and m/s): Average speed in knot calculated by dividing sailed distance to duration, and average speed in m/s calculated by multiplying knots to 0,5144 as a conversion factor.
- Average fuel consumption per mile for the voyage: Calculated by total consumption to sailed distance in Nm
- Average consumption per engine in kg: All test vessels have 2 main engines and average consumption per hour divided to 2 to find each engine's consumption. Due to company's reporting system for fuel consumption in metric tons, multiplied with 1000 to find consumption in kg. Then corrected to normal fuel of 42700 kJ/kg due to actual fuel's lower calorific value was 40200 kJ/kg.

**2-** Table filtered with +- 5% for displacement of model test or working displacement according actual data of test vessel if model test displacement does not fit with it. Any data for any voyage which is in not limit, not included.

**3-** The SFOC reference curve based on actual shop tests of the specific engine in question, was already corrected in shop test report for environmental factors as per ISO 3046-

1:2002. Then it is also corrected for normal fuel of 42700 kJ/kg with below formulation and new corrected SFOC curve issued.

$$SFOC_{LCV\ corr.} = \left(\frac{SFOC\ x\ LCV_{nor.fuel}}{LCV_{test\ bed}}\right) \quad (3.1)$$

Where;

SFOC(LCV CORRECTED) : Corrected SFOC acc. to Normal fuel of 42700 kJ/kg

SFOC : SFOC value given is shop test report of the relevant engine

LCV (NORMAL FUEL) : 42,7 MJ/kg

LCV (TEST BED) : 42,274 MJ/kg

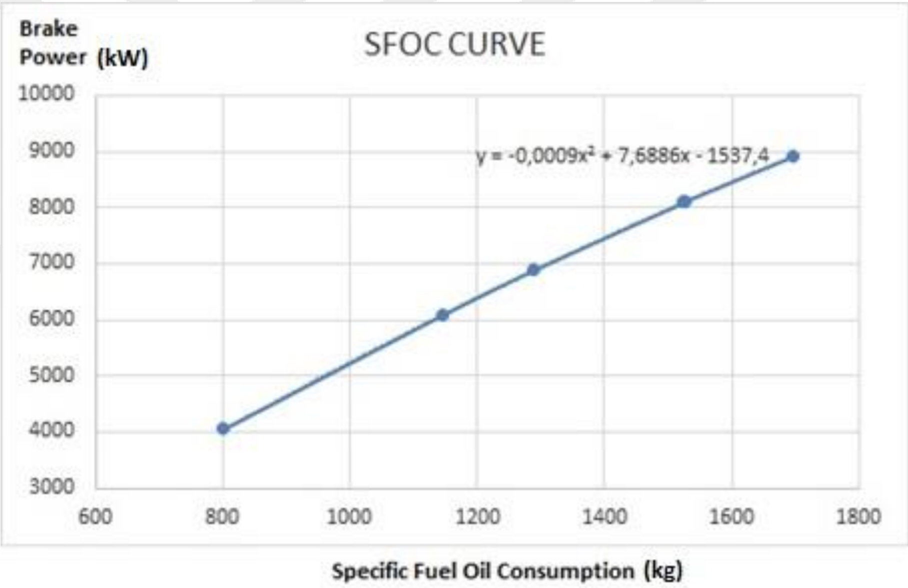


**Figure 3.3.** SFOC Curve of MAK 9M43 engines

**4-** Delivered power of one engine approximated for each data point based on calculations of brake power, $P_B$ from an engine specific SFOC reference curve defined in Annex D of Part 2 of the standard;

$$P_B = f\left(M_{FOC}\ x\ \frac{LCV}{42,4}\right) \quad (3.2)$$

Where:

$M_{FOC}$ : Mass of consumed fuel oil by main engine (kg/hour)

LCV : Lower calorific value of fuel oil (mJ/kg)

f : SFOC reference curve (Corrected with ISO and normal fuel of 42,7 MJ/kg

**5-** Delivered power multiplied by 2 to find total power of both engines

**6-** Model test predictions were available for 18557.6 tons Displacement. For all vessels, a correction factor $(\Delta Voyage/\Delta ModelTest)^{2/3}$ was applied to Speed-Power curve according to ITTC displacement correction methodology.

**7-** Expected speed calculated for each data point from a speed-power reference curve at the corrected delivered power of both engines.

$$V_e = f \text{ x } P_b \tag{3.3.}$$

Where;

$V_e$ : Expected Speed

F : Speed-Power Curve

$P_b$ : Delivered power of both engine

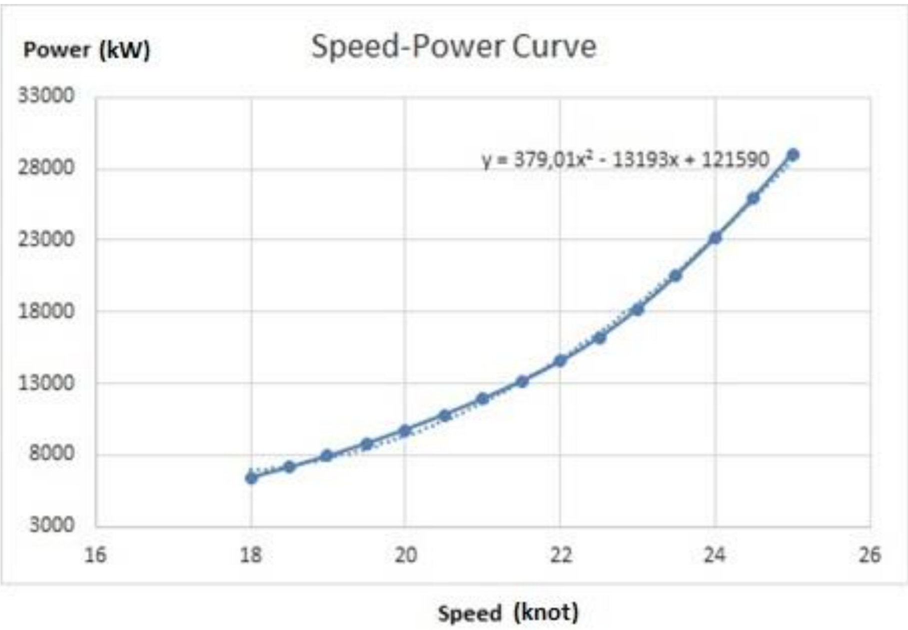


**Figure 3.4.** Speed-Power Curve of test vessels from model test report

**8-** Percentage speed loss which is defined as performance value in the ISO19030 calculated for every data point in the corrected data set.

The percentage speed loss is calculated as the relative difference in percent between the measured speed and expected speed with below formulation:

$$V_{d} = 100 \times \left(\frac{V_m - V_e}{V_e}\right) \qquad (3.4)$$

Where;

$V_d$ : Percentage speed loss

$V_m$ : Measured Speed

$V_e$ : Expected Speed

**9 -** The average percentage speed loss over the reference period(s) calculated as:

$$V_{d,ref} = \frac{1}{k} \sum_{j}^{k} \frac{1}{n} V_{d,j,i} \qquad (3.5)$$

Where

k number of reference periods

j reference period counter

n number of data points in the processed data set under reference conditions in the reference period *j*

i counter of data points in reference period *j*

$V_{d,j,i}$ percentage speed loss for data point i in reference period *j*

$V_{d,ref}$ average percentage speed loss over the reference period(s)

**10 -** Average percentage speed loss over the evaluation period $V_{d,eval}$ calculated as:

$$V_{d,eval} = \frac{1}{k} \sum_{i}^{j} \frac{1}{n} \sum_{i}^{n} V_{d,eval,i} \qquad (3.6)$$

Where

| | |
|---|---|
| n | number of data points in the processed data set under reference conditions of the evaluation period |
| $V_{d,eval,i}$ | percentage speed loss for data point i in a data set of the evaluation period |
| $V_{d,eval}$ | average percentage speed loss in data set of the evaluation period |

**11 -** The change in the average speed loss in the reference period(s) and the average speed loss in the evaluation period is defined as performance indicator, PI, and is calculated according to below equation:

$$k_{HP} = V_{d,eval} - V_{d,ref} \quad (3.7)$$

Where

| | |
|---|---|
| $V_{d,eval}$ | average percentage speed loss in data set of the evaluation period |
| $V_{d,ref}$ | average percentage speed loss over the reference period(s) |
| $k_{HP} = V_{d,eval} - V_{d,ref}$ | Performance indicator, PI |

**12 –** In order to evaluate changes on fuel consumption, average fuel consumption per hour value of reference and evaluation periods calculated from the data set.

**13 –** New table created for each indicator from the data set in order to make fuel consumption comparisons between reference and evaluation period.

**Table 3.3.** Sample result table

| | **Unit** | **Reference** | **Evaluation** |
|---|---|---|---|
| **Sample Size** | **pcs** | 36 | 66 |
| **disp total** | **tons** | 544789,50 | 1000287,30 |
| **disp avr.** | **tons** | 15133,04 | 15155,87 |
| **fuel total** | **tons** | 5128,90 | 9469,72 |
| **fuel avr** | **tons** | 142,47 | 143,48 |
| **mile total** | **miles** | 42806,50 | 84690,80 |
| **hours total** | **hrs** | 2210,40 | 4302,90 |
| **speed avr** | **knots** | 19,38 | 19,71 |
| **Av.cons per hour** | **Tons** | 2,32 | 2,20 |

**14 –** Due to Fuel consumption being effected by speed, fuel consumption of evaluation period normalized based on average speed of reference period. This was achieved by substituting the below equation for the Fuel Oil Consumption(FOC) of evaluation period which was also used by James J. Corbett's study to correct fuel consumption by speed:

$$FOC_{Normalized} = FOC_{\ Evaluation}\ x\ \left(\frac{Average\ \ Speed\ \ Reference\ \ Period}{Average\ \ Speed\ \ Evaluation\ Period}\right)^3 \quad (3.8)$$

Above mentioned equation converts the main engine fuel oil consumption for data entry of evaluation period to a normalized value according the reference period's average speed.

**15 –** Analyze if the difference was significant between the average fuel consumption per hour value of reference period and corrected-normalized average fuel consumption per hour value of evaluation period. Below equation was used to test the difference among 2 means for the samples:

$$t = \frac{(\overline{X}_1 - \overline{X}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \quad (3.9)$$

Results to be displayed at the confidence level of 95%.

# 4. FINDINGS

## 4.1. Results of Vessel 1

First type of foul release coating was first tested on VESSEL 1 in 2013. She completed her dry-docking cycle and dry-docked again in 2016. Performance of 1st type foul release coating analyzed in respect to comparison of reference and evaluation periods defined in ISO 19030. Table 4.1 presents dry-docking history of vessel 1.

**Table 4.1.** Dry-docking History of Vessel 1

| | | DDn-1 | DDn | DDn+1 |
|---|---|---|---|---|
| VESSEL 1 | Date of Drydock | 4.05.2011 | 11.11.2013 | 13.08.2016 |
| | Shipyard | BESIKTAS | BESIKTAS | SEFINE |
| | Blasting | SPOT | FULL | %10 sweep blasting |
| | Hull Coating | Self Polishing Coating 1 | Foul Release Coating 1 | Foul Release Coating 1 |
| | Engine Overhaul | NO | NO | Both Engine 90.000 Hours overhaul Completed |

Vessel 1 was built in 2001. She was previously dry-docked in 2011 and 1st type self-polishing coating technology was applied with spot blasting. Then she dry-docked again in 2013. Due to her hull was not fully blasted at any dry-docking since 2001, hull condition was poor as shown in figures 4.1 and 4.2. Her hull fully blasted and 1st type of foul release coating technology applied. Dry-docking performance indicator could not be calculated due to there weren't available data for the first year after 2011 dry-docking. But her average fuel oil consumption was increased up to 2,32 ton/hour for the last year before entering the dry-dock in 2013. With full blasting and 1st type foul release coating application, her consumption reduced to 2,20 ton/hour according data representing first year after the dry-dock in 2013. Vessel's fuel consumption reduced 5,04 % with the application of 1st type of foul release coating technology. And vessel's speed increased to 19,71 knots from 19,38 knots. If vessel would have kept her speed as 19,38 knots which was the average speed of the last year entering the dry-dock in 2013, her consumption was going to reduce to 2,06 ton/hour which means 11,27 % fuel consumption reduction. According model test results of Vessel 1, her speed loss was calculated as -9,70 % for the last year entering the dry-dock in 2013 and it improved to -7,03% with the application of new coating which represents 2,67 % improvement on ship's speed. Difference between average fuel consumption of last year before dry-dock which was 2,32 ton/hour and first year after dry-dock which was 2,20 ton/hour statistically found significant in the 95 % confidence level. (In order to perform paired samples t test, it is required to compare equal sample sizes for each period. Due to sample sizes of each period was not same, equal quantity of samples taken from each period which resulted minor differences on values e.g. 2,20 ton/hour reduced to 2,1969 ton/hour during statistical calculations. Same condition also valid for other vessels statistical analysis)

According to results of in-service performance indicator, which represents comparing data of the first year after the dry-dock in 2013 and the period after 1 year to next dry-dock, vessel's speed reduced to 19,33 knots from 19,71 knots, but fuel consumption remained same. Average consumptions for the first year (reference period) was 2,20 ton/hour and it occurred as 2,21 ton/hour in the evaluation period. Even vessel's speed reduced during the evaluation period, fuel consumption remained same and vessel did not need to increase load of engine which results significant increase on fuel consumption. If the vessel kept her speed as 19,71 knots also in evaluation period, her fuel consumption would be 2,39 ton/hour which means 8,06 % increase of fuel consumption.

Vessel 1 dry-docked again in 2016, hull and coating condition checked visually, hull was clean and coating condition was very good. Only few slimes observed on vertical side with a 0,5-meter width on the loaded draft area where is open to sunshine. Flat bottom was completely clean and no slime were observed. Representing photos given in figures 4.5 and 4.6. Just one layer of 1$^{st}$ type of foul release coating technology applied again to observe performance of vessel for next 5 years. It was used to dry-dock the vessel every 2,5 year. With the performance of 1$^{st}$ type foul release coating technology, company decided to dry-dock the vessel every 5 years.

**Figure 4.1.** VESSEL 1, 2013 Dry-dock, photo of hull condition, after first wash, condition before 1st type foul release coating application

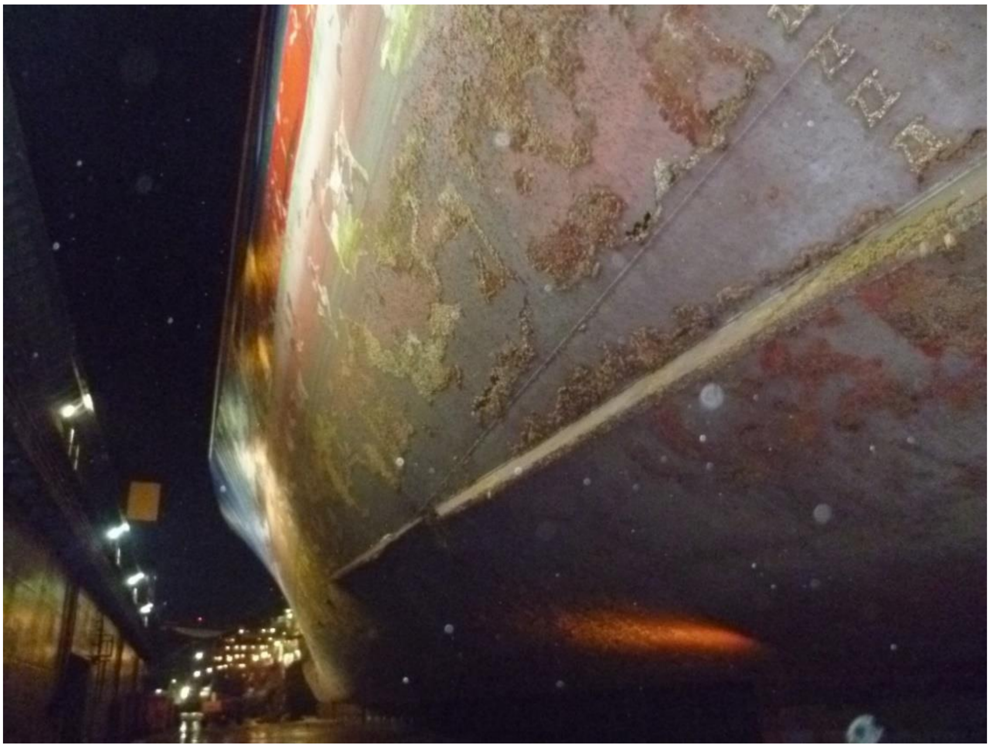

**Figure 4.2.** VESSEL 1, 2013 Dry-dock, photo of hull condition, after first wash, condition before 1st type foul release coating application

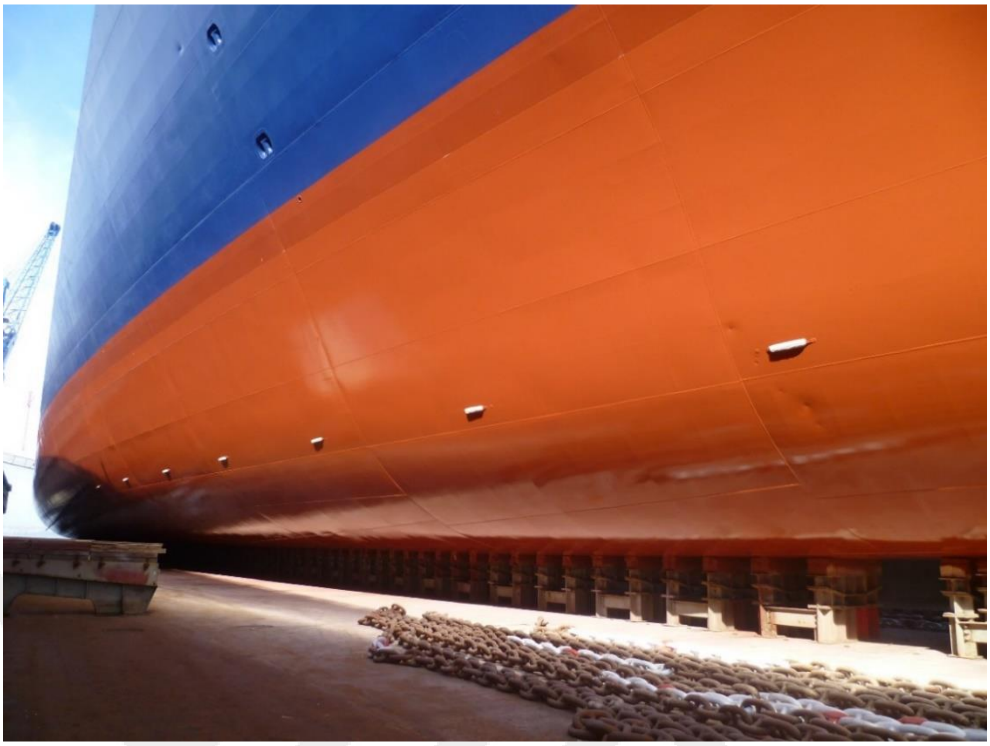

**Figure 4.3.** VESSEL 1, 2013 Dry-dock, photo of hull condition, condition after 1st type foul release coating application

**Figure 4.4.** VESSEL 1, 2013 Dry-dock, photo of hull condition, condition after 1st type foul release coating application

**Figure 4.5.** VESSEL 1, 2016 Dry-dock, photo of hull condition, just after entering the dry-dock

**Figure 4.6.** VESSEL 1, 2016 Dry-dock, photo of hull condition, condition just after entering the dry-dock

**Figure 4.7.** VESSEL 1, 2016 Dry-dock, photo of hull condition, condition after 1 layer of 1st type foul release coating application

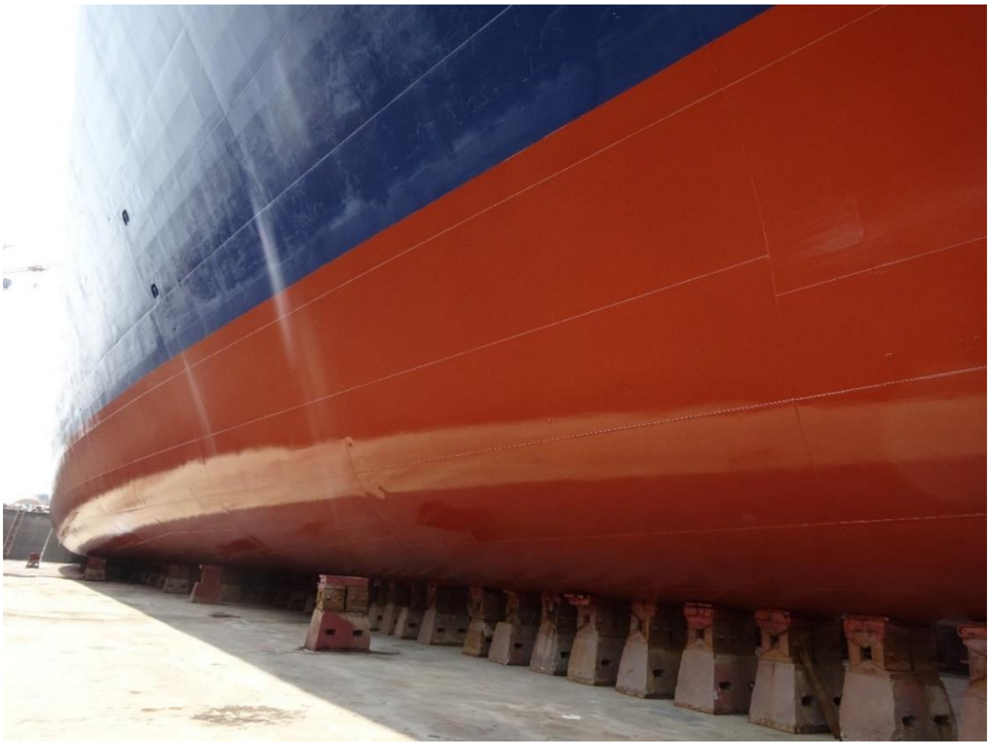

**Figure 4.8.** VESSEL 1, 2016 Dry-dock, photo of hull condition, condition after 1 layer of 1st type foul release coating application

**Table 4.2.** Comparison of last year before and first year after the dry-dock in 2013

| | Unit | Last year before dry-dock | First year after dry-dock | Speed Corrected data of first year after dry-dock |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 36 | 66 | 66 |
| Total Displacement | tons | 544.790 | 1.000.287 | 1.000.287 |
| Average Displacement | tons | 15.133 | 15.156 | 15.156 |
| Total Fuel Oil Consumption | tons | 5.129 | 9.470 | 8.999 |
| Average Fuel Oil Consumption | tons | 142 | 143 | 136 |
| Total Sailed Distance | miles | 42.807 | 84.691 | 84.691 |
| Total Sailed Hours | hrs | 2.210 | 4.303 | 4.370 |
| Average Speed | knots | 19,38 | 19,71 | 19,38 |
| Average Fuel Oil Consumption Per Hour | tons | 2,32 | 2,20 | 2,06 |
| Average Speed Loss | % | -9,71 | -7,04 | |
| Speed loss changes between last year before and first year after the dry-docking | % | | 2,67% | |
| Reduction of Fuel Oil Consumption | % | | -11,27% | |

In-Service performance after Dry-docking in 2013

**Table 4.3.** In service performance of Vessel 1

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 66 | 87 | 87 |
| Total Displacement | tons | 1.000.287 | 1.313.376 | 1.313.376 |
| Average Displacement | tons | 15.156 | 15.096 | 15.096 |
| Total Fuel Oil Consumption | tons | 9.470 | 12.962 | 13.743 |
| Average Fuel Oil Consumption | tons | 143 | 149 | 158 |
| Total Sailed Distance | miles | 84.691 | 113.300 | 113.300 |
| Total Sailed Hours | hrs | 4.303 | 5.871 | 5.748 |
| Average Speed | knots | 19,71 | 19,33 | 19,71 |
| Average Fuel Oil Consumption Per Hour | tons | 2,20 | 2,21 | 2,39 |
| Average Speed Loss | % | -7,04 | -8,81 | |
| In-service Performance according to Decrease of Speed Loss | % | | -1,77% | |
| Reduction of Fuel Oil Consumption | % | | 8,06% | |

Vessel 1, Paired samples statistics for fuel oil consumption and speed changes between last year before and first year after the dry-dock in 2013.

**Table 4.4.** Statistical results of Vessel 1, Fuel Consumption Changes

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 2,3207 | 36 | 0,09590 | 0,01598 |
| First year after dry-dock | 2,1969 | 36 | 0,07445 | 0,01241 |

| | N | Correlation | Sig. |
|---|---|---|---|
| Last year & First year | 36 | -0,098 | 0,569 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| Last year & First year | 0,12376 | 0,12705 | 0,02117 | 0,08077 | 0,16675 | 5,845 | 35 | 0,000 |

**Table 4.5.** Statistical results of Vessel 1, Speed Changes

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 19,3800 | 36 | 0,51440 | 0,08573 |
| First year after dry-dock | 19,8533 | 36 | 0,51122 | 0,08520 |

| | N | Correlation | Sig. |
|---|---|---|---|
| Lsst year & first year | 36 | 0,173 | 0,312 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| Lsst year & first year | -0,47333 | 0,65943 | 0,10991 | -0,69645 | -0,25021 | -4,307 | 35 | 0,000 |

## 4.2. Results of Vessel 2

Vessel 2 was the 2nd vessel which 1st type foul release coating technology tested. She completed her dry-docking cycle and dry-docked again in 2016. Performance of 1st type foul release coating technology analyzed in respect to comparison of reference and rvaluation periods defined in ISO 19030. Table 4.6 presents dry-docking history of Vessel 2.

**Table 4.6.** Dry-docking History of Vessel 2

| | | DDn-1 | DDn | DDn+1 |
|---|---|---|---|---|
| VESSEL 2 | Date of Drydock | 17.08.2011 | 10.06.2014 | 17.01.2017 |
| | Shipyard | BESIKTAS | BESIKTAS | SEFINE |
| | Blasting | SPOT | FULL | %10 sweep blasting |
| | Hull Coating | Self Polishing Coating 1 | Foul Release Coating 1 | Foul Release Coating 1 |
| | Engine Overhaul | NO | NO | Both Engine 90.000 Hours overhaul Completed |

Vessel 2 was built in 2002. She previously dry-docked in 2011 and 1st type self-polishing coating technology was applied with spot blasting. Then she dry-docked again in 2014. Hull condition was poor as shown in figures 4.9 and 4.10. Her hull fully blasted and 1st type foul release coating technology applied. Dry-docking performance indicator could not be calculated due to there weren't available data for the first year after 2011 dry-docking. But her average fuel oil consumption was increased up to 2,27 ton/hour for the last year before entering the dry-dock in 2013. With full blasting and 1st type foul release coating application, her consumption reduced to 2,11 ton/hour according data representing first year after the dry-dock in 2014. Vessel's fuel consumption reduced 7,04 % with the application of 1st type foul release coating technology. And vessel's speed increased to 19,49 knots from 18,88 knots. If vessel would have kept her speed as 18,88 knots which was the average speed of last year before dry-dock, her consumption was going to reduce to 1,86 ton/hour which means 18,14 % fuel consumption reduction. According model test results of vessel, her speed loss was calculated as -11,57 % for the last year before dry-dock and it improved to -7,09% with the application of new coating which represents 4,48% improvement on ship's speed. Difference between average fuel consumption of last year before dry-dock which was 2,27 ton/hour and first year after dry-dock which was 2,11 ton/hour statistically found significant in the 95 % confidence level. Also, difference between vessel’s speed (18,88 knots and 19,49 knots) found statistically significant in the 95% confidence level.

According to results of in-service performance indicator calculations, vessel’s speed reduced to 19,33 knots from 19,49 knots, but fuel consumption remained same. Average consumptions for the first year (reference period) was 2,11 ton/hour and it occurred as 2,12 ton/hour in the evaluation period. Even vessel’s speed reduced during the evaluation period, fuel consumption remained same and vessel did not need to increase load of engine which results significant increase on fuel consumption. If the vessel kept her speed as 19,49 knots also in evaluation period, her fuel consumption would be 2,19 ton/hour which means 3,60 % increase of fuel consumption.

Vessel 2 dry-docked again in 2017, hull and coating condition checked visually, hull was clean and coating condition was very good. Only few slimes observed on vertical side with a 0,5-meter width on the loaded draft area where is open to sunshine. Flat bottom was completely clean and no slime were observed. Representing photos given in figures 4.15 and 4.16. Just one layer of 1st type foul release coating technology applied again to observe performance of vessel for next 5 years. It was used to dry-dock the vessel every 2,5 year. With the performance of 1st type foul release coating technology, company decided to dry-dock the vessel every 5 years.

**Figure 4.9.** VESSEL 2, 2014 Dry-dock, photo of hull condition, after first wash, condition before 1st type foul release coating application

**Figure 4.10.** VESSEL 2, 2014 Dry-dock, photo of hull condition, after first wash, condition before 1st type foul release coating application

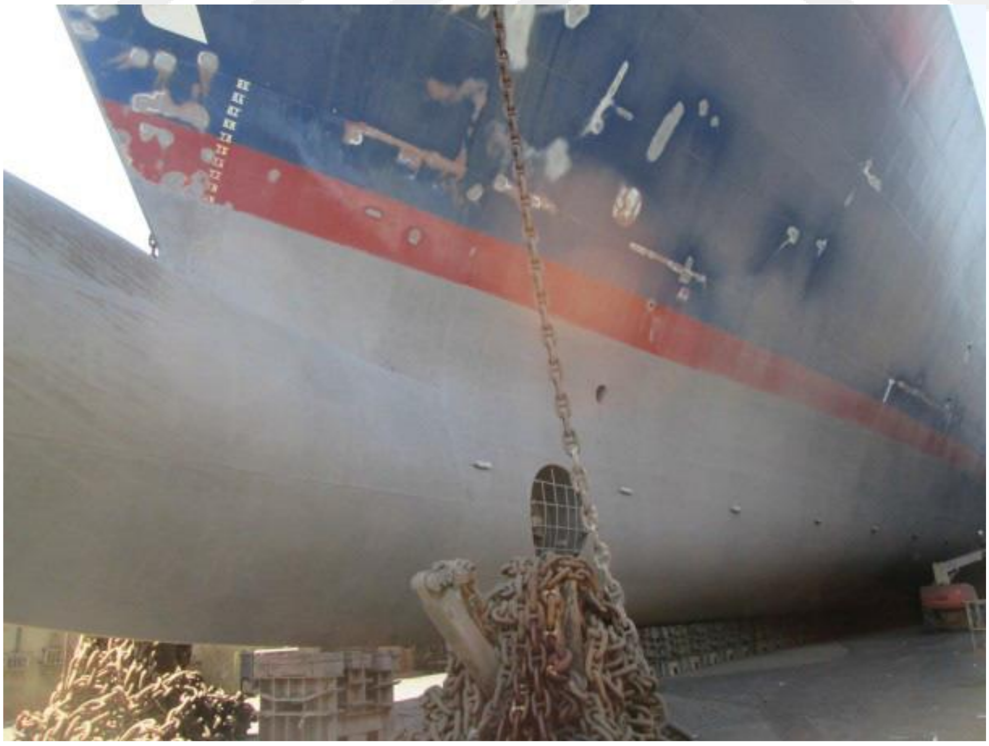

**Figure 4.11.** VESSEL 2, 2014 Dry-dock, photo of hull condition, after full blasting, condition before 1st type foul release coating application

**Figure 4.12.** VESSEL 2, 2014 Dry-dock, photo of hull condition, after full blasting, condition before 1st type foul release coating application

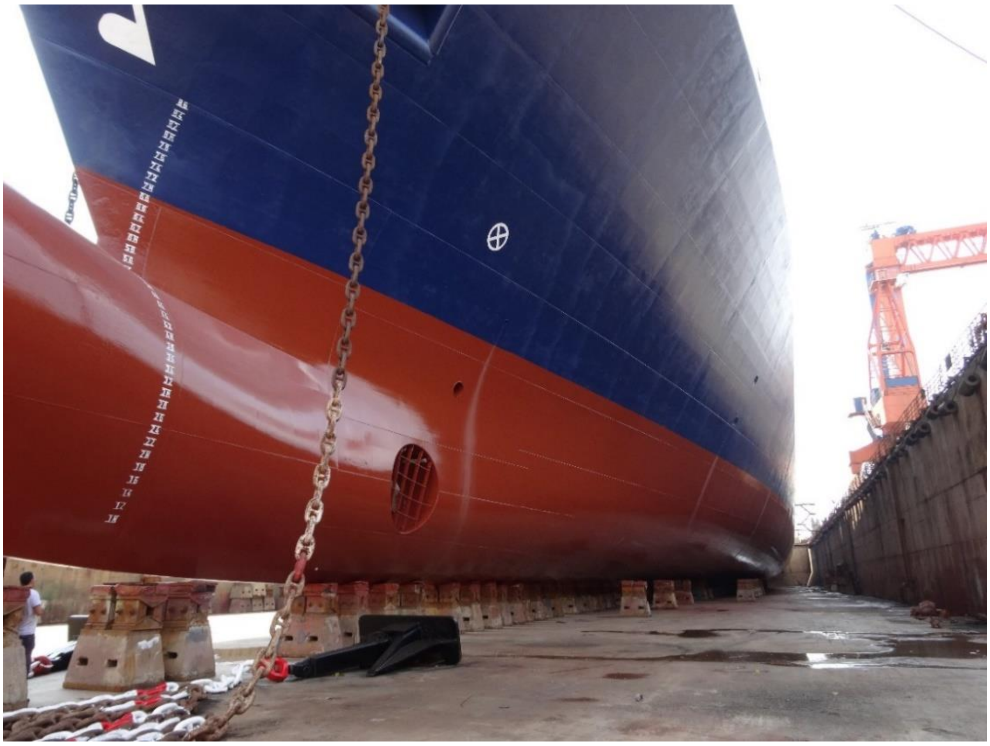

**Figure 4.13.** VESSEL 2, 2014 Dry-dock, photo of hull condition, condition after 1st type foul release coating application

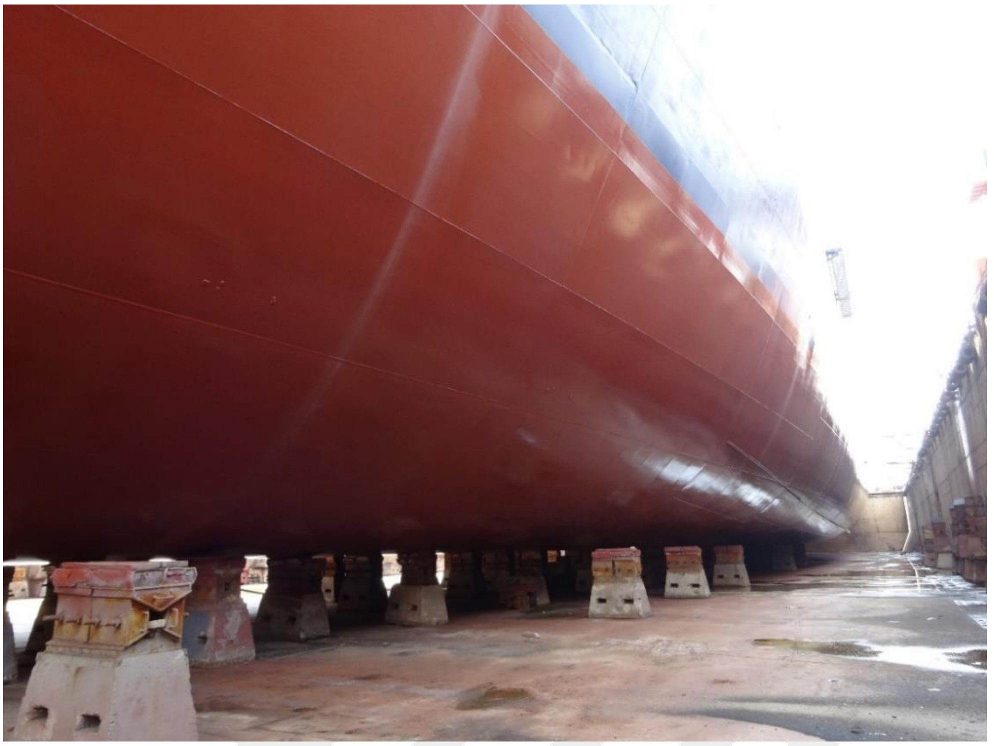

**Figure 4.14.** VESSEL 2, 2014 Dry-dock, photo of hull condition, condition after 1st type foul release coating application

**Figure 4.15.** VESSEL 2, 2017 Dry-dock, photo of hull condition, condition just after entering the dry-dock

**Figure 4.16.** VESSEL 2, 2017 Dry-dock, photo of hull condition, condition just after entering the dry-dock

**Figure 4.17.** VESSEL 2, 2017 Dry-dock, photo of hull condition, condition just after entering the dry-dock

**Table 4.7.** Comparison of last year before and first year after the dry-dock in 2014

| | Unit | Last year before dry-dock | First year after dry-dock | Speed Corrected data of first year after dry-dock |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 48 | 47 | 47 |
| Total Displacement | tons | 722.960 | 705.862 | 705.862 |
| Average Displacement | tons | 15.062 | 15.018 | 15.018 |
| Total Fuel Oil Consumption | tons | 6.888 | 6.728 | 6.118 |
| Average Fuel Oil Consumption | tons | 143 | 143 | 130 |
| Total Sailed Distance | miles | 57.303 | 62.178 | 62.178 |
| Total Sailed Hours | hrs | 3.037 | 3.198 | 3.293 |
| Average Speed | knots | 18,88 | 19,49 | 18,88 |
| Average Fuel Oil Consumption Per Hour | tons | 2,27 | 2,11 | 1,86 |
| Average Speed Loss | % | -11,57 | -7,09 | |
| Speed loss changes between last year before and first year after the dry-docking | % | | 4,48% | |
| Reduction of Fuel Oil Consumption | % | | -18,14% | |

In-Service performance after Dry-docking in 2014

**Table 4.8.** In service performance of Vessel 2

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 47 | 78 | 78 |
| Total Displacement | tons | 705.862 | 1.165.481 | 1.165.481 |
| Average Displacement | tons | 15.018 | 14.942 | 14.942 |
| Total Fuel Oil Consumption | tons | 6.728 | 11.020 | 11.292 |
| Average Fuel Oil Consumption | tons | 143 | 141 | 145 |
| Total Sailed Distance | miles | 62.178 | 100.699 | 100.699 |
| Total Sailed Hours | hrs | 3.198 | 5.219 | 5.166 |
| Average Speed | knots | 19,49 | 19,33 | 19,49 |
| Average Fuel Oil Consumption Per Hour | tons | 2,11 | 2,12 | 2,19 |
| Average Speed Loss | % | -7,09 | -7,91 | |
| In-service Performance according to Decrease of Speed Loss | % | | -0,82% | |
| Reduction of Fuel Oil Consumption | % | | 3,60% | |

Vessel 2, Paired samples statistics for fuel oil consumption and speed changes between last year before and first year after the dry-dock in 2014

**Table 4.9.** Statistical Results of Vessel 2, Fuel Consumption Changes

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 2,2711 | 47 | 0,08148 | 0,01189 |
| First year after dry-dock | 2,1099 | 47 | 0,11045 | 0,01611 |

| | N | Correlation | Sig. |
|---|---|---|---|
| Last year & First year | 47 | -0,324 | 0,026 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| Last year & First year | 0,16125 | 0,15708 | 0,02291 | 0,11513 | 0,20737 | 7,038 | 46 | 0,000 |

**Table 4.10.** Statistical Results of Vessel 2, Speed Changes

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 18,8875 | 47 | 0,40358 | 0,05887 |
| First year after dry-dock | 19,4920 | 47 | 0,82140 | 0,11981 |

| | N | Correlation | Sig. |
|---|---|---|---|
| Last year & First year | 47 | -0,109 | 0,467 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| Last year & First year | -0,60449 | 0,95374 | 0,13912 | -0,88452 | -0,32446 | -4,345 | 46 | 0,000 |

## 4.3. Results of Vessel 3

VESSEL 3 was not tested with any new technology hull coating in 2013 and coated with the same antifouling technology with 25% partly blasting as in previous dry-dock. Vessel 3 analyzed as a control sample to evaluate what would be the results if the same antifouling coating applied again with only spot blasting.

VESSEL 3 dry-docked again in 2015 and 2$^{nd}$ type foul release coating technology applied with full blasting. Table 4.11 presents dry-docking history of Vessel 3.

**Table 4.11.** Dry-docking History of Vessel 3

| | | DDn-1 | DDn | DDn+1 |
|---|---|---|---|---|
| VESSEL 3 | Date of Drydock | 8.04.2010 | 22.01.2013 | 29.03.2015 |
| | Shipyard | BESIKTAS | GEMAK | GEMAK |
| | Blasting | SPOT | SPOT | FULL |
| | Hull Coating | Self Polishing Coating 1 | Self Polishing Coating 1 | Foul Release Coating 2 |
| | Engine Overhaul | NO | NO | NO |

Vessel 3 was built in 2005. She previously dry-docked in 2010 and 1$^{st}$ type self-polishing coating technology was applied with spot blasting. Then she dry-docked again in 2013. Hull condition was poor as shown in figures 4.15 and 4.16. Vessel 3 spot blasted and same technology self-polishing coating applied again. This vessel used as control sample to evaluate results if same self-polishing coating applied with poor spot blasting. Dry-docking performance indicator of 2013 dry-docking could not be calculated due to there weren't available data for the first year after 2010 dry-docking. But her average fuel oil consumption was increased up to 2,44 ton/hour for the last year before entering the dry-dock in 2013 and it reduced to 2,33 ton/hour during the first year after the dry-dock. Vessel's fuel consumption seems reduced 4,09 % however vessel's speed reduced to 18,91 knots from 19,29 knots. This results shows that even speed of the vessel reduced, vessel tried to keep her fuel consumption under control to avoid increase of fuel consumption. If vessel would have kept her speed as 19,29 knots which was the average speed of last year before dry-dock, her consumption was going to increase to 2,53 ton/hour which means 3,57 % fuel consumption increase. According model test results of vessel, her speed loss was calculated as -8,80 % for the reference period and it increased to -9,64 % with the application of same coating which represents -0,84 % decrease on ship's speed. Difference between average fuel consumption of last year before dry-dock which was 2,45 ton/hour and average fuel consumption of first year after dry-dock which was 2,33 ton/hour statistically found significant in the 95 % confidence level. Also, difference between vessel's speed (19,30 knots and 18,91 knots) found statistically significant in the 95% confidence level.

According to results of in-service performance indicator calculations, vessel's speed reduced to 18,19 knots from 18,91 knots, and fuel consumption reduced to 2,27 ton/hour from 2,33 ton/hour. This result shows that, even vessel's speed reduced dramatically, vessel tried to keep fuel consumption under control which results reduced operational efficiency due to increased sailing hours for a scheduled liner vessel. If the vessel kept her speed as 18,91 knots also in evaluation period, her fuel consumption would be 2,65 ton/hour which means 13,80 % increase of fuel consumption.

Vessel 3 dry-docked again in 2015, hull and coating condition checked visually, hull and coating condition was very poor as shown in figures 4,20, 4.21 and 4.22. Hull fully blasted and 2$^{nd}$ type foul release coating technology applied. According to dry-docking performance, vessel's average fuel oil consumption was 2,33 ton/hour for the reference period and 2,30 ton/hour for the evaluation period. Vessel's fuel consumption seems remained same however vessel's speed increased to 19,48 knots from 18,91 knots with the application of 2$^{nd}$ type foul release coating technology. If vessel would have kept her speed as 18,91 knots which was the average speed of reference period, her consumption was going to reduce to 2,04 ton/hour which means 12,4 % fuel consumption reduction. According model test results of vessel, her speed loss was calculated as -9,64 % for the reference period and it improved to -6,64 % with the application of new coating which represents 3% improvement on ship's speed. Difference between average fuel consumption of reference period which was 2,33 ton/hour and average fuel consumption of evaluation period which was 2,30 ton/hour statistically was not found significant in the 95 % confidence level. Difference between vessel's speed (18,91 knots and 19,48 knots) found statistically significant in the 95% confidence level.

According to results of in-service performance indicator calculations, vessel's speed increased to 19,66 knots from 19,48 knots, while fuel consumption also increased to 2,36 ton/hour from 2,30 ton/hour. With the increase of ship speed also fuel consumption increased slightly. If the vessel kept her speed as 19,48 knots also in evaluation period, her fuel consumption would be 2,27 ton/hour which means 1,26 % decrease of fuel consumption.

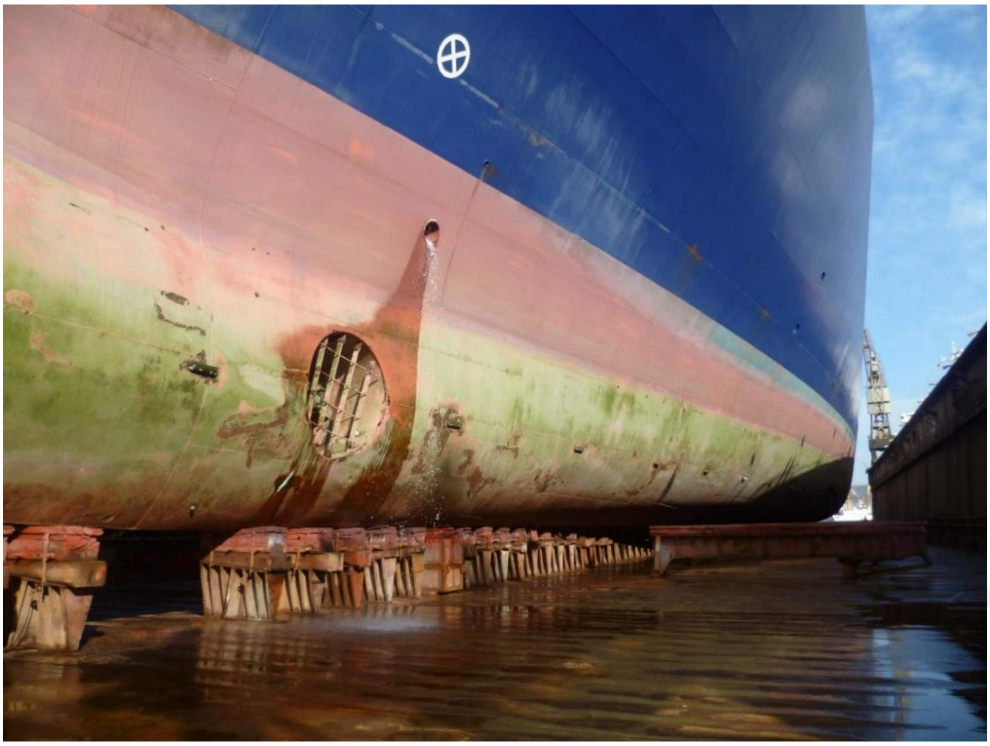

**Figure 4.18.** VESSEL 3, 2013 Dry-dock, photo of hull condition, just after entering the Dry-dock

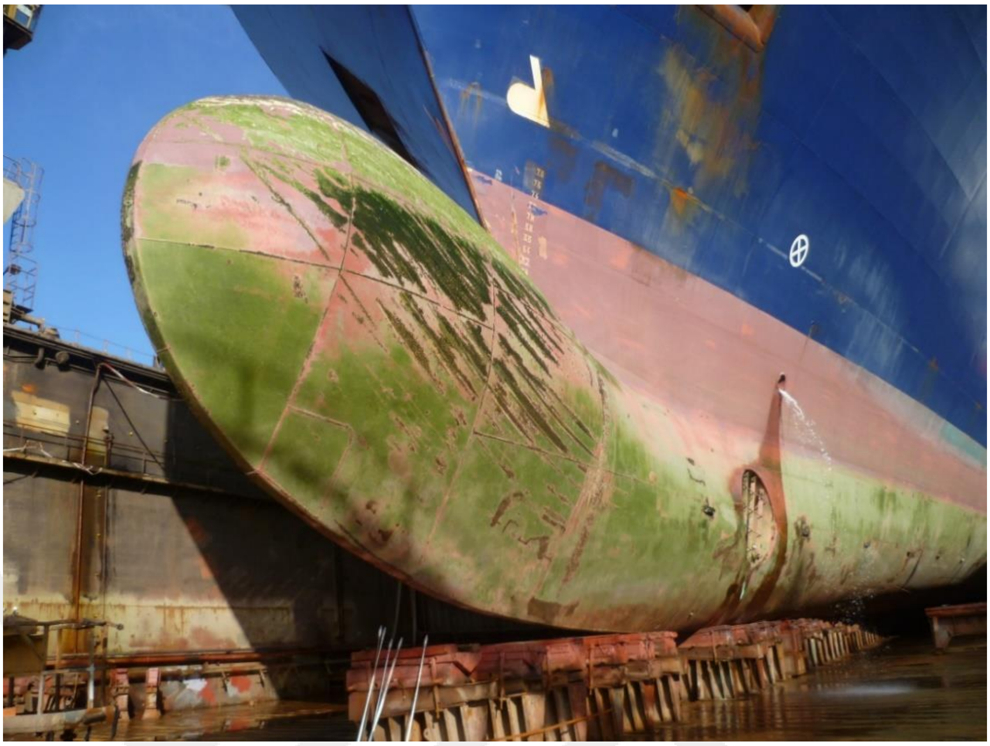

**Figure 4.19.** VESSEL 3, 2013 Dry-dock, photo of hull condition, just after entering the Dry-dock

**Figure 4.20.** VESSEL 3, 2013 Dry-dock, photo of hull condition, condition after 1st type self- polishing coating application with only %25 blasting

**Figure 4.21.** VESSEL 3, 2013 Dry-dock, photo of hull condition, condition after 1st type self-polishing coating application with only %25 blasting

**Figure 4.22.** VESSEL 3, 2013 Dry-dock, photo of hull condition, condition after 1st type self- polishing coating application with only %25 blasting

**Figure 4.23.** VESSEL 3, 2015 Dry-dock, photo of hull condition, just after entering the Dry-dock

**Figure 4.24.** VESSEL 3, 2015 Dry-dock, photo of hull condition, just after entering the Dry-dock

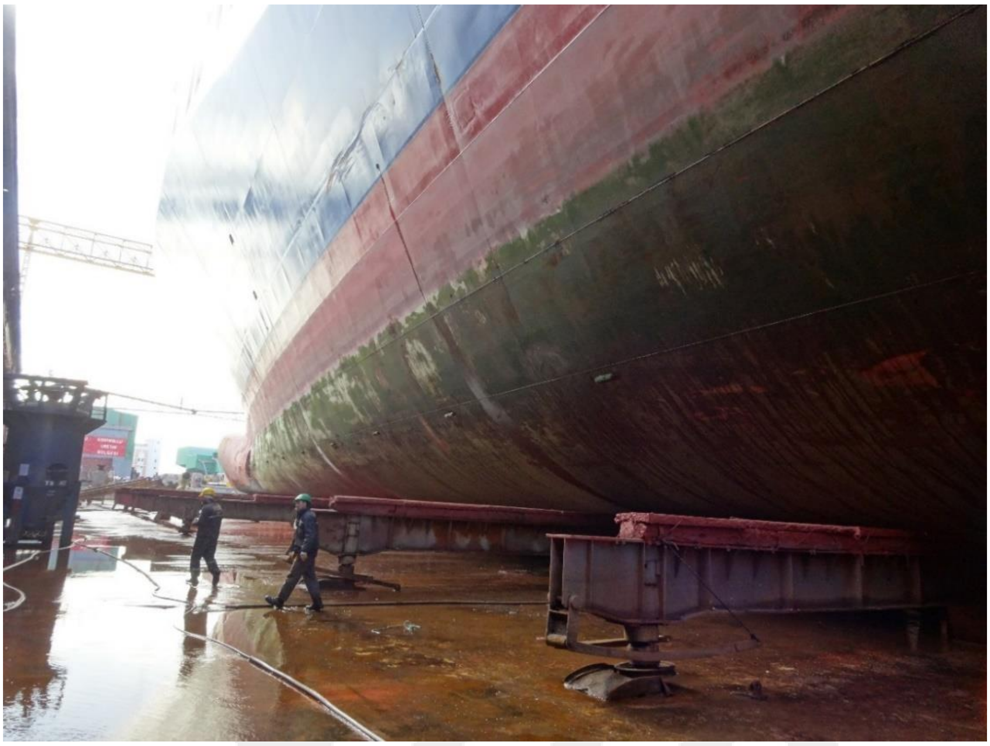

**Figure 4.25.** VESSEL 3, 2015 Dry-dock, photo of hull condition, just after entering the Dry-dock

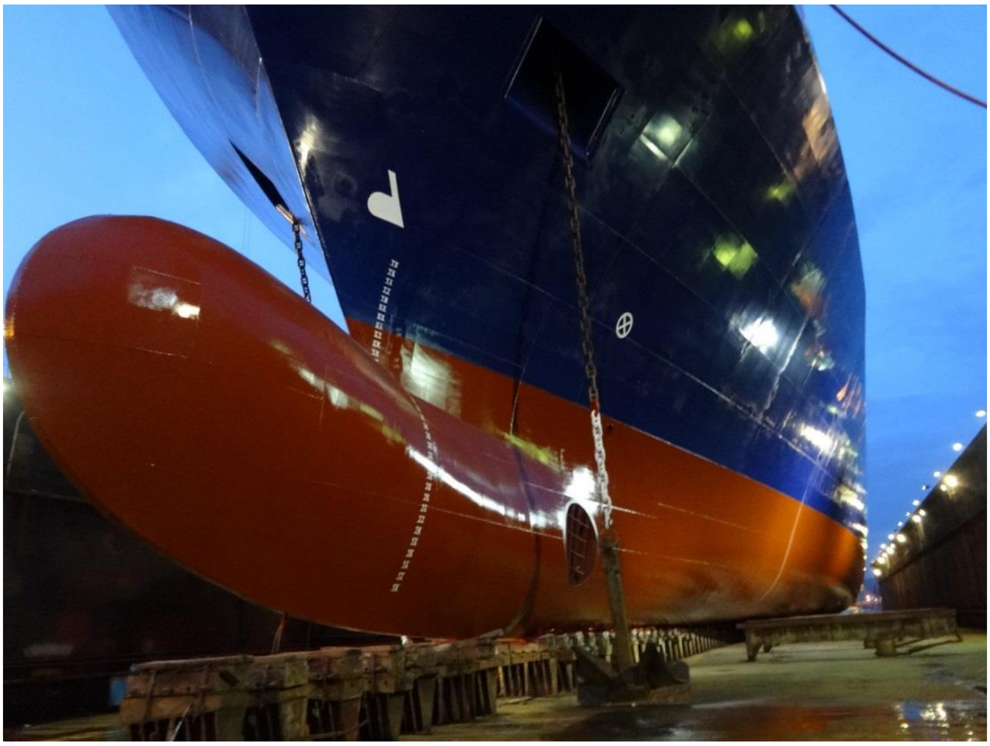

**Figure 4.26.** VESSEL 3, 2015 Dry-dock, photo of hull condition, condition after 2$^{nd}$ type foul release coating application

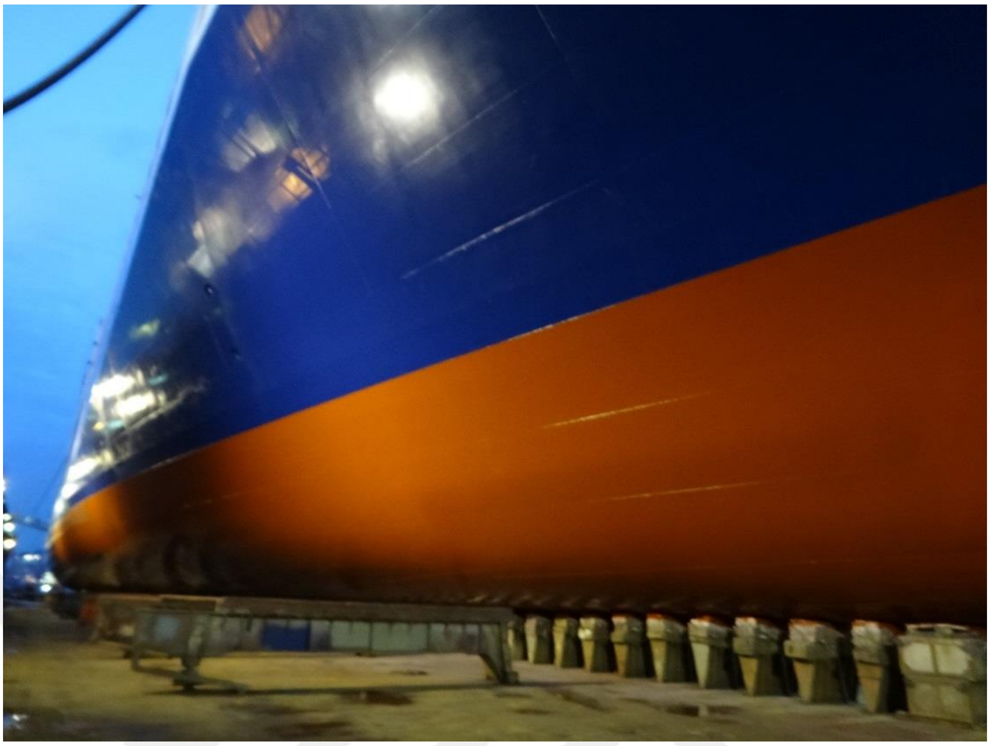

**Figure 4.27.** VESSEL 3, 2015 Dry-dock, photo of hull condition, condition after 2nd type foul release coating application

**Table 4.12.** Comparison of last year before and first year after the dry-dock in 2013

| | Unit | Last year before dry-dock | First year after dry-dock | Speed Corrected data of first year after dry-dock |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 49 | 33 | 47 |
| Total Displacement | tons | 890.507 | 606.457 | 705.862 |
| Average Displacement | tons | 18.174 | 18.377 | 15.018 |
| Total Fuel Oil Consumption | tons | 7.771 | 5.380 | 6.118 |
| Average Fuel Oil Consumption | tons | 159 | 163 | 130 |
| Total Sailed Distance | miles | 61.510 | 43.608 | 62.178 |
| Total Sailed Hours | hrs | 3.190 | 2.308 | 3.293 |
| Average Speed | knots | 19,29 | 18,91 | 18,88 |
| Average Fuel Oil Consumption Per Hour | tons | 2,44 | 2,33 | 1,86 |
| Average Speed Loss | % | -8,81 | -9,64 | |
| Speed loss changes between last year before and first year after the dry-docking | % | -0,84% | | |
| Reduction of Fuel Oil Consumption | % | 3,57% | | |

In-Service performance after Dry-dock in 2013

**Table 4.13.** In service performance of Vessel 3

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 33 | 23 | 23 |
| Total Displacement | tons | 606.457 | 418.195 | 418.195 |
| Average Displacement | tons | 18.377 | 18.182 | 18.182 |
| Total Fuel Oil Consumption | tons | 5.380 | 3.498 | 3.929 |
| Average Fuel Oil Consumption | tons | 163 | 152 | 171 |
| Total Sailed Distance | miles | 43.608 | 27.986 | 27.986 |
| Total Sailed Hours | hrs | 2.308 | 1.541 | 1.480 |
| Average Speed | knots | 18,91 | 18,19 | 18,91 |
| Average Fuel Oil Consumption Per Hour | tons | 2,33 | 2,27 | 2,65 |
| Average Speed Loss | % | -9,64 | -12,51 | |
| In-service Performance according to Decrease of Speed Loss | % | | -2,87% | |
| Reduction of Fuel Oil Consumption | % | | 13,80% | |

Dry-docking Performance of Dry-dock in 2015

**Table 4.14.** Dry-docking performance of Vessel 3

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 33 | 47 | 47 |
| Total Displacement | tons | 606.457 | 844.900 | 844.900 |
| Average Displacement | tons | 18.377 | 17.977 | 17.977 |
| Total Fuel Oil Consumption | tons | 5.380 | 6.777 | 6.205 |
| Average Fuel Oil Consumption | tons | 163 | 144 | 132 |
| Total Sailed Distance | miles | 43.608 | 57.420 | 57.420 |
| Total Sailed Hours | hrs | 2.308 | 2.951 | 3.036 |
| Average Speed | knots | 18,91 | 19,48 | 18,91 |
| Average Fuel Oil Consumption Per Hour | tons | 2,33 | 2,30 | 2,04 |
| Average Speed Loss | % | -9,64 | -6,64 | |
| Dry-docking Performance according to Decrease of Speed Loss | % | | 3,00% | |
| Reduction of Fuel Oil Consumption | % | | 12,40% | |

In service performance after Dry-dock in 2015

**Table 4.15.** 2nd In service performance of Vessel 3

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 47 | 32 | 32 |
| Total Displacement | tons | 844.900 | 572.625 | 572.625 |
| Average Displacement | tons | 17.977 | 17.895 | 17.895 |
| Total Fuel Oil Consumption | tons | 6.777 | 4.927 | 4.788 |
| Average Fuel Oil Consumption | tons | 144 | 154 | 150 |
| Total Sailed Distance | miles | 57.420 | 41.040 | 41.040 |
| Total Sailed Hours | hrs | 2.951 | 2.087 | 2.107 |
| Average Speed | knots | 19,48 | 19,66 | 19,48 |
| Average Fuel Oil Consumption Per Hour | tons | 2,30 | 2,36 | 2,27 |
| Average Speed Loss | % | -6,64 | -6,36 | |
| In-service Performance according to Decrease of Speed Loss | % | 0,28% | | |
| Reduction of Fuel Oil Consumption | % | -1,26% | | |

Vessel 3, Paired samples statistics for fuel oil consumption and speed changes between last year before and first year after the dry-dock in 2013

**Table 4.16.** Statistical Results of Vessel 3, Fuel Consumption Changes, 2013

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 2,4566 | 33 | 0,08510 | 0,01481 |
| First year after dry-dock | 2,3328 | 33 | 0,10978 | 0,01911 |

| | N | Correlation | Sig. |
|---|---|---|---|
| last year & first year | 33 | 0,173 | 0,335 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| last year & first year | 0,12385 | 0,12671 | 0,02206 | 0,07892 | 0,16878 | 5,615 | 32 | 0,000 |

**Table 4.17.** Statistical Results of Vessel 3, Speed Changes, 2013

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 19,3005 | 33 | 0,34720 | 0,06044 |
| First year after dry-dock | 18,9118 | 33 | 0,53910 | 0,09385 |

| | N | Correlation | Sig. |
|---|---|---|---|
| Last year & first year | 33 | 0,269 | 0,131 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| Last year & first year | 0,38869 | 0,55734 | 0,09702 | 0,19106 | 0,58631 | 4,006 | 32 | 0,000 |

Vessel 3, Paired samples statistics for fuel oil consumption and speed changes for the dry-docking performance 2015

**Table 4.18.** Statistical Results of Vessel 3, Fuel Consumption 2015

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 2,3328 | 33 | 0,10978 | 0,01911 |
| evaluation | 2,2972 | 33 | 0,13241 | 0,02305 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 33 | 0,028 | 0,876 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | 0,03557 | 0,16960 | 0,02952 | -0,02456 | 0,09571 | 1,205 | 32 | 0,237 |

**Table 4.19.** Statistical Results of Vessel 3, Speed changes 2015

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 18,9118 | 33 | 0,53910 | 0,09385 |
| evaluation | 19,4993 | 33 | 0,58800 | 0,10236 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 33 | 0,197 | 0,272 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | -0,58745 | 0,71514 | 0,12449 | -0,84103 | -0,33387 | -4,719 | 32 | 0,000 |

## 4.4. Results of Vessel 4

VESSEL 4 was dry-docked in 2013 and 2nd type self-polishing coating technology applied with 100% blasting. Performance of 2nd type self-polishing coating technology tested on this vessel until next dry-dock carried out in 2015 which 1st type foul release coating technology applied with full blasting. VESSEL 4 was a good sample which indicated results of self-polishing and foul release coatings with %100 blasting. Table 4.20 presents dry-docking history of Vessel 4.

**Table 4.20.** Dry-docking History of Vessel 4

| | | DDn-1 | DDn | DDn+1 |
|---|---|---|---|---|
| VESSEL 4 | **Date of Drydock** | 29.06.2010 | 5.05.2013 | 16.05.2015 |
| | **Shipyard** | BESIKTAS | GEMAK | BESIKTAS |
| | **Blasting** | SPOT | FULL | FULL |
| | **Hull Coating** | Self Polishing Coating 1 | Self Polishing Coating 2 | Foul Release Coating 1 |
| | **Engine Overhaul** | NO | NO | NO |

Vessel 4 was built in 2005. She previously dry-docked in 2010. Then she dry-docked again in 2013. Her hull and coating condition was very poor as shown in figures 4.25, 4.26 and 4.27. Her hull completely blasted, 2nd type self-polishing coating technology applied. This vessel was only sample where hull of the vessel completely blasted and different technology but again self-polishing system applied. We had chance to evaluate what would be the difference between spot blasted + self-polishing and fully blasted + self-polishing applied vessels, also what would be the difference if fully blasted + self-polishing and fully blasted + foul release silicone applied vessels.

Dry-docking performance indicator of 2013 dry-docking could not be calculated due to there weren’t available data for the first year after 2010 dry-docking. But her average fuel oil consumption was increased up to 2,48 ton/hour for the last year before entering the dry-dock in 2013 and it reduced to 2,38 ton/hour during the first year after the dry-dock. Vessel’s fuel consumption seems reduced 4,03 % however vessel’s speed remained same. It was 19,14 knots at the reference period and became to 19,16 knots in evaluation period. Difference between average fuel consumption of last year before dry-dock which was 2,48 ton/hour and average fuel consumption of first year after dry-dock which was 2,38 ton/hour statistically found significant in the 95 % confidence level. But difference between vessel's speed (19,14 knot and 19,16 Knot) was not found statistically significant in the 95% confidence level.

According to results of in-service performance indicator calculations, vessel's speed decreased to 18,84 knots from 19,16 knots, while fuel consumption also decreased to 2,29 ton/hour from 2,38 ton/hour. With the decrease of ship speed, vessel tried to keep fuel consumption under control which resulted decreased operational efficiency for a liner Ro-Ro vessel due to increased sailing hours. If the vessel would kept her speed as 19,16 knots also in evaluation period, her fuel consumption would be 2,46 ton/hour which means 2,98 % increase of fuel consumption.

Vessel 4 dry-docked again in 2015. Even her hull was fully blasted in 2013, her hull found completely covered with fouling as shown in figures 4.30 and 4.31. Her hull fully blasted again, then 1st type foul release coating technology applied which was also applied to Vessel 1 and Vessel 2 before. According to dry-docking performance, vessel's average fuel oil consumption was 2,38 ton/hour for the reference period and 2,22 ton/hour for the evaluation period. Vessel's fuel consumption reduced 6,72 % with the application of 1st type foul release coating technology. And vessel's speed increased to 19,29 knots from 19,16 knots. If vessel would have kept her speed as 19,16 knots which was the average speed of reference period, her consumption was going to reduce to 2,16 ton/hour which means 9,42% fuel consumption reduction. According model test results of vessel, her speed loss was calculated as -9,16 % for the reference period and it improved to -6,96 % with the application of new coating which represents 2,21 % improvement on ship's speed. Difference between average fuel consumption of reference period which was 2,38 ton/hour and average fuel consumption of evaluation period which was 2,22 ton/hour statistically found significant in the 95 % confidence level. But difference between vessel's speed (19,29 knots and 19,16 knots) couldn't found statistically significant in the 95% confidence level.

In-service performance indicator calculations couldn't performed due to there weren't available data.

Vessel 4 results indicated benefits of foul release silicone coatings clearly due to self-polishing and foul release coating both applied with full blasting to same vessel and results confirmed that foul release technologies performed better than self-polishing technologies for the high-speed Ro-Ro vessels.

**Figure 4.28.** VESSEL 4, 2013 Dry-dock, photo of hull condition, condition during first wash with fresh water

**Figure 4.29.** VESSEL 4, 2013 Dry-dock, photo of hull condition, condition just after entering the dry-dock

**Figure 4.30.** VESSEL 4, 2013 Dry-dock, photo of hull condition, condition just after entering the dry-dock

**Figure 4.31.** VESSEL 4, 2013 Dry-dock, photo of hull condition, condition after full blasting + 2$^{nd}$ type self-polishing coating application

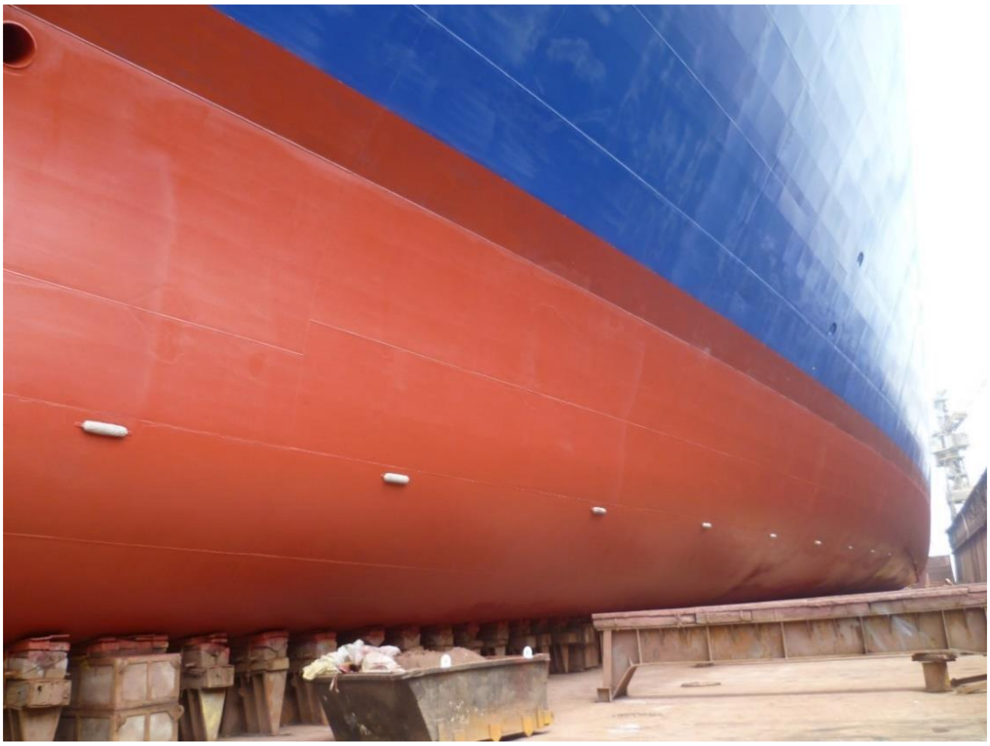

**Figure 4.32.** VESSEL 4, 2013 Dry-dock, photo of hull condition, condition after full blasting + 2$^{nd}$ type self-polishing coating application

**Figure 4.33.** VESSEL 4, 2015 Dry-dock, photo of hull condition, during high pressure wash

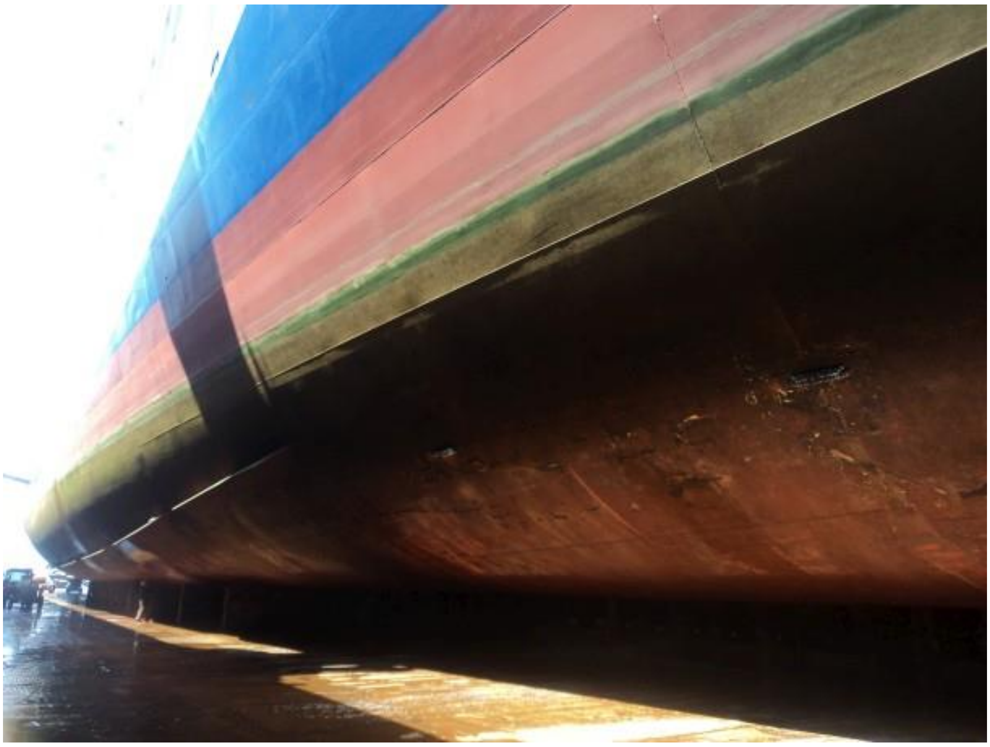

**Figure 4.34.** VESSEL 4, 2015 Dry-dock, photo of hull condition, after entering the dry-dock

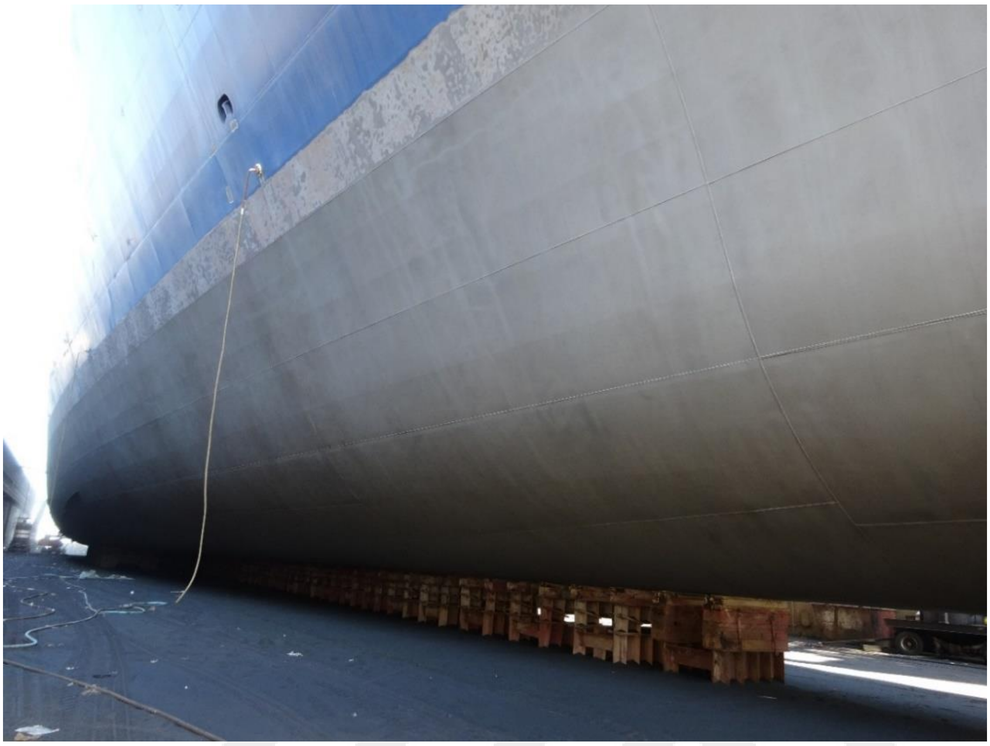

**Figure 4.35.** VESSEL 4, 2015 Dry-dock, photo of hull condition, full blasting completed

**Figure 4.36.** VESSEL 4, 2015 Dry-dock, photo of hull condition, after 1st type foul release coating application

**Figure 4.37.** VESSEL 4, 2015 Dry-dock, photo of hull condition, after 1st type foul release coating application

**Table 4.21.** Comparison of last year before and first year after the dry-dock in 2013

| | Unit | Last year before dry-dock | First year after dry-dock | Speed Corrected data of first year after dry-dock |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 50 | 35 | 35 |
| Total Displacement | tons | 896.688 | 621.938 | 621.938 |
| Average Displacement | tons | 17.934 | 17.770 | 17.770 |
| Total Fuel Oil Consumption | tons | 7.764 | 5.600 | 5.585 |
| Average Fuel Oil Consumption | tons | 155 | 160 | 160 |
| Total Sailed Distance | miles | 59.877 | 44.954 | 44.954 |
| Total Sailed Hours | hrs | 3.130 | 2.348 | 2.348 |
| Average Speed | knots | 19,14 | 19,16 | 19,14 |
| Average Fuel Oil Consumption Per Hour | tons | 2,48 | 2,38 | 2,38 |
| Average Speed Loss | % | -10,09 | -9,16 | |
| Speed loss changes between last year before and first year after the dry-docking | % | 0,93% | | |
| Reduction of Fuel Oil Consumption | % | -4,16% | | |

In-Service performance after Dry-dock in 2013

**Table 4.22.** In service performance of Vessel 4

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 35 | 27 | 27 |
| Total Displacement | tons | 621.938 | 477.197 | 477.197 |
| Average Displacement | tons | 17.770 | 17.674 | 17.674 |
| Total Fuel Oil Consumption | tons | 5.600 | 4.031 | 4.244 |
| Average Fuel Oil Consumption | tons | 160 | 149 | 157 |
| Total Sailed Distance | miles | 44.954 | 33.109 | 33.109 |
| Total Sailed Hours | hrs | 2.348 | 1.759 | 1.728 |
| Average Speed | knots | 19,16 | 18,84 | 19,16 |
| Average Fuel Oil Consumption Per Hour | tons | 2,38 | 2,29 | 2,46 |
| Average Speed Loss | % | -9,16 | -9,87 | |
| In-service Performance according to Decrease of Speed Loss | % | | -0,71% | |
| Reduction of Fuel Oil Consumption | % | | 2,98% | |

Dry-docking Performance of Dry-dock in 2015

**Table 4.23.** Dry-docking performance of Vessel 4

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 35 | 51 | 51 |
| Total Displacement | tons | 621.938 | 908.678 | 908.678 |
| Average Displacement | tons | 17.770 | 17.817 | 17.817 |
| Total Fuel Oil Consumption | tons | 5.600 | 7.741 | 7.595 |
| Average Fuel Oil Consumption | tons | 160 | 152 | 149 |
| Total Sailed Distance | miles | 44.954 | 67.364 | 67.364 |
| Total Sailed Hours | hrs | 2.348 | 3.498 | 3.516 |
| Average Speed | knots | 19,16 | 19,28 | 19,16 |
| Average Fuel Oil Consumption Per Hour | tons | 2,38 | 2,22 | 2,16 |
| Average Speed Loss | % | -9,16 | -6,95 | |
| Dry-docking Performance according to Decrease of Speed Loss | % | | 2,21% | |
| Reduction of Fuel Oil Consumption | % | | 9,42% | |

Vessel 4, Paired samples statistics for fuel oil consumption and speed changes between last year before and first year after the dry-dock in 2013

**Table 4.24.** Statistical Results of Vessel 4, Fuel Consumption Changes, 2013

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 2,4817 | 35 | 0,06060 | 0,01024 |
| First year after dry-dock | 2,3849 | 35 | 0,11023 | 0,01863 |

| | N | Correlation | Sig. |
|---|---|---|---|
| Last year & First year | 35 | 0,289 | 0,092 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| Last year & First year | 0,09673 | 0,10935 | 0,01848 | 0,05917 | 0,13430 | 5,233 | 34 | 0,000 |

**Table 4.25.** Statistical Results of Vessel 4, Speed Changes, 2013

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 19,0799 | 35 | 0,35241 | 0,05957 |
| evaluation | 19,1602 | 35 | 0,52040 | 0,08796 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 35 | 0,306 | 0,074 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | -0,08030 | 0,53186 | 0,08990 | -0,26300 | 0,10240 | -0,893 | 34 | 0,378 |

Vessel 4, Paired samples statistics for fuel oil consumption and speed changes for the dry-docking performance 2015

**Table 4.26.** Statistical Results of Vessel 4, Fuel Consumption Changes, 2015

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 2,3849 | 35 | 0,11023 | 0,01863 |
| evaluation | 2,1743 | 35 | 0,08844 | 0,01495 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 35 | -0,273 | 0,112 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | 0,21061 | 0,15907 | 0,02689 | 0,15597 | 0,26526 | 7,833 | 34 | 0,000 |

**Table 4.27.** Statistical Results of Vessel 4, Speed Changes, 2015

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 19,1602 | 35 | 0,52040 | 0,08796 |
| evaluation | 19,2894 | 35 | 0,53335 | 0,09015 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 35 | -0,151 | 0,388 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | -0,12919 | 0,79932 | 0,13511 | -0,40377 | 0,14539 | -0,956 | 34 | 0,346 |

### 4.5. Results of Test Vessel 5

VESSEL 5 coated with 3rd type self-polishing coating technology in 2013. Her flat bottom was blasted 100% and vertical sides blasted 5%. VESSEL 5 completed her docking cycle and dry-docked again in 2015 and 2nd type foul release coating technology applied with full blasting. Table 4.29 presents dry-docking history of Vessel 5.

**Table 4.28.** Dry-docking History of Vessel 5

| | | DDn-1 | DDn | DDn+1 |
|---|---|---|---|---|
| VESSEL 5 | Date of Drydock | 30.08.2010 | 27.07.2013 | 2.06.2015 |
| | Shipyard | BESIKTAS | BESIKTAS | BESIKTAS |
| | Blasting | SPOT | FLAT BOTTOM FULL, VERTICAL SIDES SPOT | FULL |
| | Hull Coating | Self Polishing Coating 1 | Self Polishing Coating 3 | Foul Release Coating 2 |
| | Engine Overhaul | NO | NO | NO |

Vessel 5 was built in 2005. She previously dry-docked in 2010. Then she dry-docked again in 2013. Her hull and coating condition was very poor as shown in figures 4.35 and 4.36. Her flat bottom fully blasted and vertical sides spot blasted. 3rd type self-polishing coating applied. Dry-docking performance indicator of 2013 dry-docking could not be calculated due to there weren't available data for the first year after 2010 dry-docking. But her average fuel oil consumption was increased up to 2,42 ton/hour for the last year before entering the dry-dock in 2013 and it reduced to 2,28 ton/hour during the first year after the dry-dock. Vessel's fuel consumption seems reduced 5,78 % however vessel's speed reduced to 19,18 knots from 19,44 knots. If vessel would have kept her speed as 19,44 knots which was the average speed of last year before dry-dock, her consumption was going to increase to 2,40 ton/hour which means 0,75 % fuel consumption decrease. According model test results of vessel, her speed loss was calculated as -8,27 % for the last year before dry-dock and it decreased to -8,18 % with the application of new type self-polishing coating. Even vessel's fuel consumption seems 5,78 % decreased, after applying speed correction, result indicated that fuel reduction occurred because of speed reduction. Vessel reduced her speed after dry-dock and this resulted reduction of fuel consumption. Even flat bottom was fully blasted and vessel coated with newer technology self-polishing coating, there was not significant improvement neither for fuel consumption nor speed loss.

According to results of in-service performance indicator calculations, vessel's speed decreased to 18,80 knots from 19,18 knots and fuel consumption slightly increased to 2,33 ton/hour from 2,28 ton/hour. If the vessel kept her speed as 19,18 knots also in evaluation period, her fuel consumption would be 2,52 ton/hour which means 10,70 % increase of fuel consumption. According model test results of vessel, her speed loss was calculated as -8,18 % for the reference period and it increased to -10,43 % during evaluation period which means her vessel's speed decreased 2,25 %.

Vessel 5 dry-docked again in 2015, her hull fully blasted and 2nd type foul release coating technology applied which was also applied to Vessel 3 before. According to dry-docking performance, vessel's average fuel oil consumption was 2,28 ton/hour for the reference period and 2,35 ton/hour for the evaluation period. Vessel's fuel consumption seems increased 3 % however vessel's speed increased to 19,72 knots from 19,18 knots with the application of 2nd type foul release coating. If vessel would have kept her speed as 19,18 knots which was the average speed of reference period, her consumption was going to reduce to 2,10 ton/hour which means 7,93 % fuel consumption reduction. According model test results of vessel, her speed loss was calculated as -8,18 % for the reference period and it improved to -6,23 % with the application of new coating which represents 1,94 % improvement on ship's speed. Difference between average fuel consumption of reference period which was 2,28 ton/hour and average fuel consumption of evaluation period which was 2,35 ton/hour was not significant statistically however difference between vessel's speed (19,18 knots and 19,92 knots) found statistically significant in the 95% confidence level.

According to results of in-service performance indicator calculations, vessel's speed decreased to 19,24 knots from 19,72 knots, while fuel consumption slightly increased to 2,37 ton/hour from 2,35 ton/hour. If the vessel kept her speed as 19,72 knots also in evaluation period, her fuel consumption would be 2,62 ton/hour which means 11,73 % increase of fuel consumption.

2nd type foul release coating performed well during the first year after the dry-dock in 2015, but in-service performance was not good as Vessel 3 which also had applied with same technology coating.

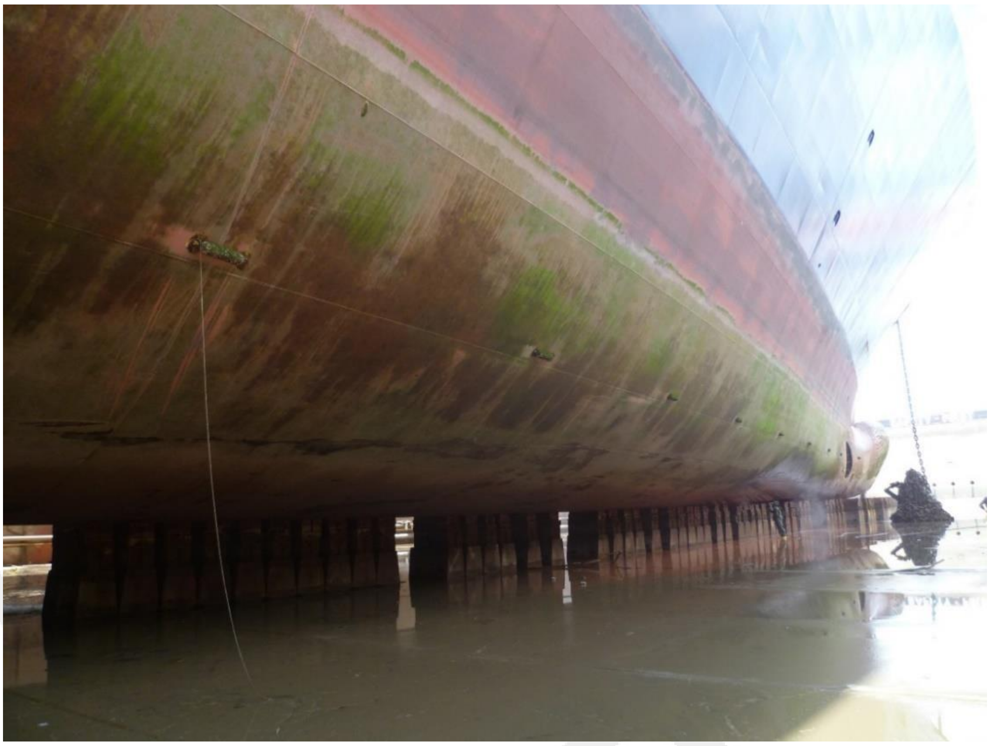

**Figure 4.38.** VESSEL 5, 2013 Dry-dock, photo of hull condition, just after entering the dry-dock

**Figure 4.39.** VESSEL 5, 2013 Dry-dock, photo of hull condition, just after entering the dry-dock

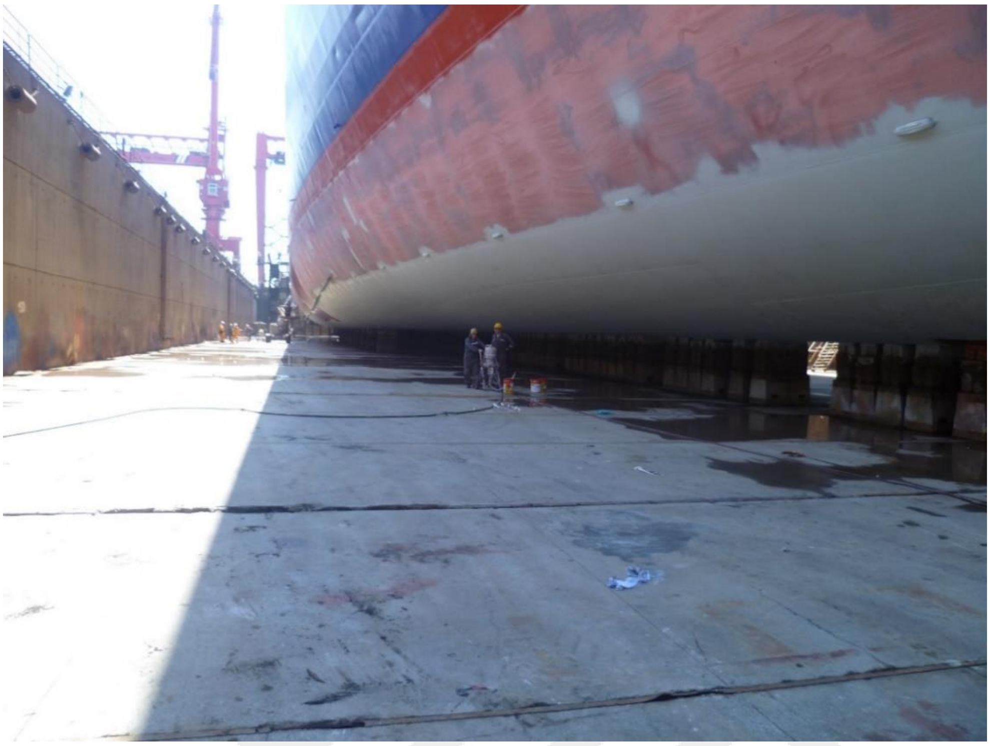

**Figure 4.40.** VESSEL 5, 2013 Dry-dock, photo of hull condition, just after full blasting of flat bottom

**Figure 4.41.** VESSEL 5, 2013 Dry-dock, photo of hull condition, after application of 3rd type self-polishing coating

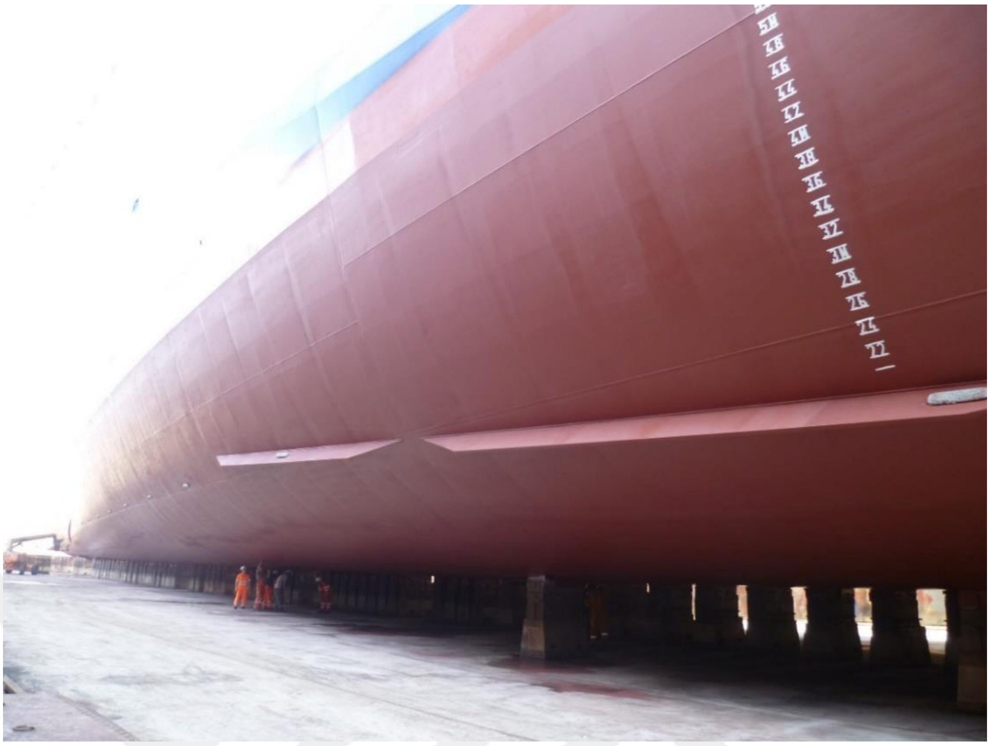

**Figure 4.42.** VESSEL 5, 2013 Dry-dock, photo of hull condition, after application of 3rd self-polishing coating


**Figure 4.43.** VESSEL 5, 2015 Dry-dock, photo of hull condition, during high pressure water washing


**Figure 4.44.** VESSEL 5, 2015 Dry-dock, photo of hull condition, before high pressure water wash

**Figure 4.45.** VESSEL 5, 2015 Dry-dock, photo of hull condition, after 2$^{nd}$ type foul release coating application

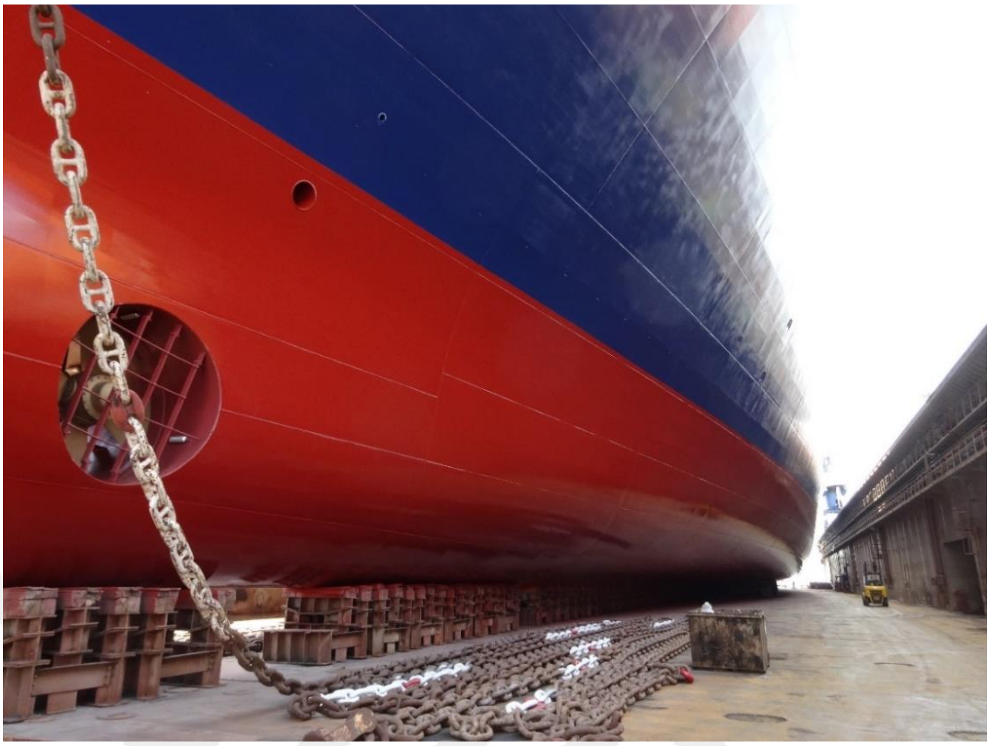

**Figure 4.46.** VESSEL 5, 2015 Dry-dock, photo of hull condition, after 2nd type foul release coating application

**Table 4.29.** Comparison of last year before and first year after the dry-dock in 2013

| | Unit | Last year before dry-dock | First year after dry-dock | Speed Corrected data of first year after dry-dock |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 64 | 34 | 34 |
| Total Displacement | tons | 1.130.430 | 592.797 | 592.797 |
| Average Displacement | tons | 17.663 | 17.435 | 17.435 |
| Total Fuel Oil Consumption | tons | 9.729 | 5.303 | 5.522 |
| Average Fuel Oil Consumption | tons | 152 | 156 | 162 |
| Total Sailed Distance | miles | 78.043 | 44.651 | 44.651 |
| Total Sailed Hours | hrs | 4.018 | 2.329 | 2.296 |
| Average Speed | knots | 19,44 | 19,18 | 19,44 |
| Average Fuel Oil Consumption Per Hour | tons | 2,42 | 2,28 | 2,40 |
| Average Speed Loss | % | -8,28 | -8,18 | |
| Speed loss changes between last year before and first year after the dry-docking | % | 0,10% | | |
| Reduction of Fuel Oil Consumption | % | -0,75% | | |

In-Service performance after Dry-dock in 2013

**Table 4.30.** In service performance of Vessel 5

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 34 | 34 | 34 |
| Total Displacement | tons | 592.797 | 601.565 | 601.565 |
| Average Displacement | tons | 17.435 | 17.693 | 17.693 |
| Total Fuel Oil Consumption | tons | 5.303 | 5.347 | 5.685 |
| Average Fuel Oil Consumption | tons | 156 | 157 | 167 |
| Total Sailed Distance | miles | 44.651 | 43.230 | 43.230 |
| Total Sailed Hours | hrs | 2.329 | 2.300 | 2.253 |
| Average Speed | knots | 19,18 | 18,80 | 19,18 |
| Average Fuel Oil Consumption Per Hour | tons | 2,28 | 2,33 | 2,52 |
| Average Speed Loss | % | -8,18 | -10,43 | |
| In-service Performance according to Decrease of Speed Loss | % | | -2,25% | |
| Reduction of Fuel Oil Consumption | % | | 10,70% | |

Dry-docking Performance of Dry-dock in 2015

**Table 4.31.** Dry-Docking performance of Vessel 5

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 34 | 52 | 52 |
| Total Displacement | tons | 592.797 | 913.203 | 913.203 |
| Average Displacement | tons | 17.435 | 17.562 | 17.562 |
| Total Fuel Oil Consumption | tons | 5.303 | 8.064 | 7.423 |
| Average Fuel Oil Consumption | tons | 156 | 155 | 143 |
| Total Sailed Distance | miles | 44.651 | 67.863 | 67.863 |
| Total Sailed Hours | hrs | 2.329 | 3.441 | 3.537 |
| Average Speed | knots | 19,18 | 19,72 | 19,18 |
| Average Fuel Oil Consumption Per Hour | tons | 2,28 | 2,35 | 2,10 |
| Average Speed Loss | % | -8,18 | -6,23 | |
| Dry-docking Performance according to Decrease of Speed Loss | % | | 1,94% | |
| Reduction of Fuel Oil Consumption | % | | 7,93% | |

In service performance after Dry-dock in 2015

**Table 4.32**. 2nd In service performance of Vessel 5

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 52 | 23 | 23 |
| Total Displacement | tons | 913.203 | 404.213 | 404.213 |
| Average Displacement | tons | 17.562 | 17.574 | 17.574 |
| Total Fuel Oil Consumption | tons | 8.064 | 3.590 | 3.866 |
| Average Fuel Oil Consumption | tons | 155 | 156 | 168 |
| Total Sailed Distance | miles | 67.863 | 29.098 | 29.098 |
| Total Sailed Hours | hrs | 3.441 | 1.513 | 1.476 |
| Average Speed | knots | 19,72 | 19,24 | 19,72 |
| Average Fuel Oil Consumption Per Hour | tons | 2,35 | 2,37 | 2,62 |
| Average Speed Loss | % | -6,24 | -8,78 | |
| In-service Performance according to Decrease of Speed Loss | % | -2,55% | | |
| Reduction of Fuel Oil Consumption | % | 11,73% | | |

Vessel 5, Paired samples statistics for fuel oil consumption and speed changes between last year before and first year after the dry-dock in 2013

**Table 4.33.** Statistical Results of Vessel 5, Fuel Consumption Changes, 2013

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 2,4537 | 33 | 0,08264 | 0,01438 |
| First year after dry-dock | 2,2870 | 33 | 0,09286 | 0,01617 |

| | N | Correlation | Sig. |
|---|---|---|---|
| last year & first year | 33 | -0,073 | 0,686 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| last year & first year | 0,16667 | 0,12875 | 0,02241 | 0,12102 | 0,21233 | 7,437 | 32 | 0,000 |

**Table 4.34.** Statistical Results of Vessel 5, Speed Changes, 2013

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 19,4823 | 34 | 0,50184 | 0,08606 |
| First year after dry-dock | 19,1842 | 34 | 0,61114 | 0,10481 |

| | N | Correlation | Sig. |
|---|---|---|---|
| last year & first year | 34 | -0,161 | 0,364 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| last year & first year | 0,29812 | 0,85077 | 0,14591 | 0,00127 | 0,59496 | 2,043 | 33 | 0,049 |

Vessel 5, Paired samples statistics for fuel oil consumption and speed changes for the dry-docking performance 2015

**Table 4.35.** Statistical Results of Vessel 5, Fuel Consumption, 2015

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 2,2791 | 34 | 0,10231 | 0,01755 |
| evaluation | 2,3609 | 34 | 0,13030 | 0,02235 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 34 | 0,154 | 0,385 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | -0,08172 | 0,15278 | 0,02620 | -0,13503 | -0,02841 | -3,119 | 33 | 0,004 |

**Table 4.36.** Statistical Results of Vessel 5, Speed Changes, 2015

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 19,1939 | 33 | 0,61794 | 0,10757 |
| evaluation | 19,7956 | 33 | 0,59428 | 0,10345 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 33 | 0,580 | 0,000 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | -0,60175 | 0,55584 | 0,09676 | -0,79884 | -0,40466 | -6,219 | 32 | 0,000 |

## 4.6. Results of Vessel 6

VESSEL 6 was not tested with any new technology hull coating in 2013 and coated with the same antifouling technology with 25% partly blasting as in previous dry-dock. Vessel 6 analyzed as a control sample to evaluate what would be the results if the same antifouling coating applied again with only spot blasting.

VESSEL 6 dry-docked again in 2015 and 1st type foul release coating technology applied with full blasting. Also, propeller modification was carried out with Kappel propellers during the same dry-docking. Result of 1st type foul release coating technology and new propellers evaluated together and compared to other sister vessels which are coated only with foul release coating in order to identify effect of propeller modification. Table 4.38 presents dry-docking history of Vessel 6.

**Table 4.37.** Dry-Docking History of Vessel 6

| | | DDn-1 | DDn | DDn+1 |
|---|---|---|---|---|
| VESSEL 6 | **Date of Drydock** | 22.04.2010 | 8.03.2013 | 9.10.2015 |
| | **Shipyard** | BESIKTAS | GEMAK | BESIKTAS |
| | **Blasting** | SPOT | SPOT | FULL |
| | **Hull Coating** | Self Polishing Coating 1 | Self Polishing Coating 1 | Foul Release Coating 1 |
| | **Engine Overhaul** | NO | NO | NO |
| | **Other** | | | KAPPEL PROPELLER MODIFICATION |

Vessel 6 was built in 2006. She previously dry-docked in 2010. Then she dry-docked again in 2013. Her hull was completely covered with heavy fouling as shown in figures 4.44 and 4.45. Her hull spot blasted and same technology self-polishing coating applied again. This vessel used as control sample like vessel 3 to evaluate results if same self-polishing coating applied with poor spot blasting. Dry-docking performance indicator of 2013 dry-docking could not be calculated due to there weren't available data for the first year after 2010 dry-docking. But her average fuel oil consumption was increased up to 2,39 ton/hour for the last year before entering the dry-dock in 2013 and it reduced to 2,31 ton/hour during the first year after the dry-dock. Vessel's fuel consumption seems reduced 3,34 % however vessel's speed increased to 19,31 knots from 19,19 knots. If vessel would have kept her speed as 19,19 knots, her consumption was going to decrease to 2,25 ton/hour which means 5,82 % fuel consumption reduction. According model test results of vessel, her speed loss was calculated as -9,30 % for the last year before dry-dock and it decreased to -7,97 % with the application of same coating which represents 1,33 % increase of ship's speed. Difference between average fuel consumption of last year before dry-dock which was 2,39 ton/hour and average fuel consumption of firs year after dry-dock which was 2,33 ton/hour statistically found significant in the 95 % confidence level. But difference between vessel's speed (19,19 knots and 19,31 knots) was not found statistically significant in the 95% confidence level.

According to results of in-service performance indicator calculations, vessel's speed reduced to 18,53 knots from 19,31 knots, and fuel consumption remained same as 2,31 ton/hour. This results shows that, even vessel's speed reduced dramatically, vessel tried to keep fuel consumption under control which results reduced operational efficiency due to increased sailing hours for a scheduled liner vessel. If the vessel would kept her speed as 19,31 knots also in evaluation period, her fuel consumption would be 2,72 ton/hour which means 17,88 % increase of fuel consumption. According model test results of vessel, her speed loss was calculated as -7,97 % for the reference period and it increased to -11,67 % during the evaluation period which means vessel's speed reduced 3,70 %.

Applying same self-polishing coating with spot blasting seems to be working maximum for a year, sometimes less and hull performance becomes worst after first year and vessel's speed decreases dramatically where photos of heavily fouled hulls which were taken just after entering the each dry-docks explains reason of speed reduction clearly.

Vessel 6 dry-docked again in 2015, her hull condition was very poor. Hull fully blasted and 1st type foul release coating applied. Also, propeller blades of the vessel changed with Kappel propellers to improve propeller efficiency. With comparing to vessel 4, which vessel was only same type of foul release coating applied but propellers were not modified, we had chance to evaluate efficiency of new propeller blades. According to dry-docking performance, vessel's average fuel oil consumption was 2,31 ton/hour for the reference period and 2,33 ton/hour for the evaluation period. Vessel's speed increased to 19,46 knots from 19,31 knots. If vessel would have kept her speed as 19,31 knots which was the average speed of reference period, her consumption was going to reduce to 2,26 ton/hour which means 2,01 % fuel consumption reduction. With good experience of foul release coatings from other sister vessels, this result was unexpected and we thought that propeller had negative effect on ship performance and deleted the effect of full blasting and foul release coating.

In-service performance calculations couldn’t perform due to there was not enough data after the dry-dock in 2015.

**Figure 4.47.** VESSEL 6, 2013 Dry-dock, photo of hull condition, just after entering the dry-dock

**Figure 4.48.** VESSEL 6, 2013 Dry-dock, photo of hull condition, just after entering the dry-dock

**Figure 4.49.** VESSEL 6, 2013 Dry-dock, photo of hull condition, after 1st type self-polishing coating application

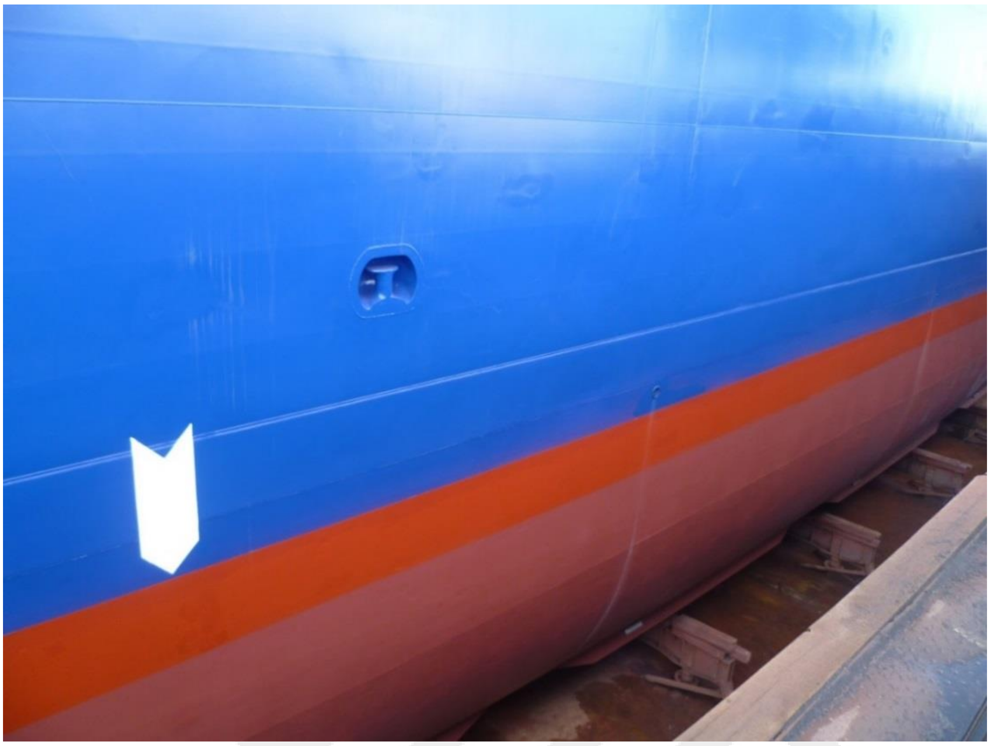

**Figure 4.50.** VESSEL 6, 2013 Dry-dock, photo of hull condition, after 1st type self-polishing coating application

**Figure 4.51.** VESSEL 6, 2015 Dry-dock, photo of hull condition, after high pressure water wash

**Figure 4.52.** VESSEL 6, 2015 Dry-dock, photo of hull condition, after high pressure water wash

**Figure 4.53.** VESSEL 6, 2015 Dry-dock, photo of hull condition, after full blasting

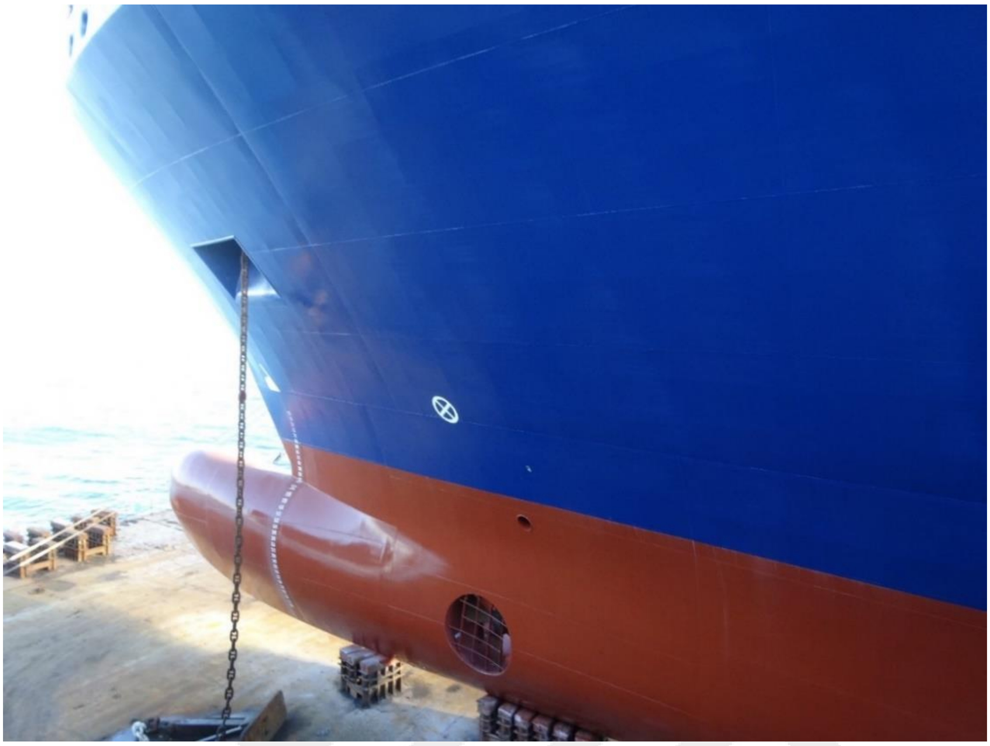

**Figure 4.54.** VESSEL 6, 2015 Dry-dock, photo of hull condition, after 1st type foul release coating application

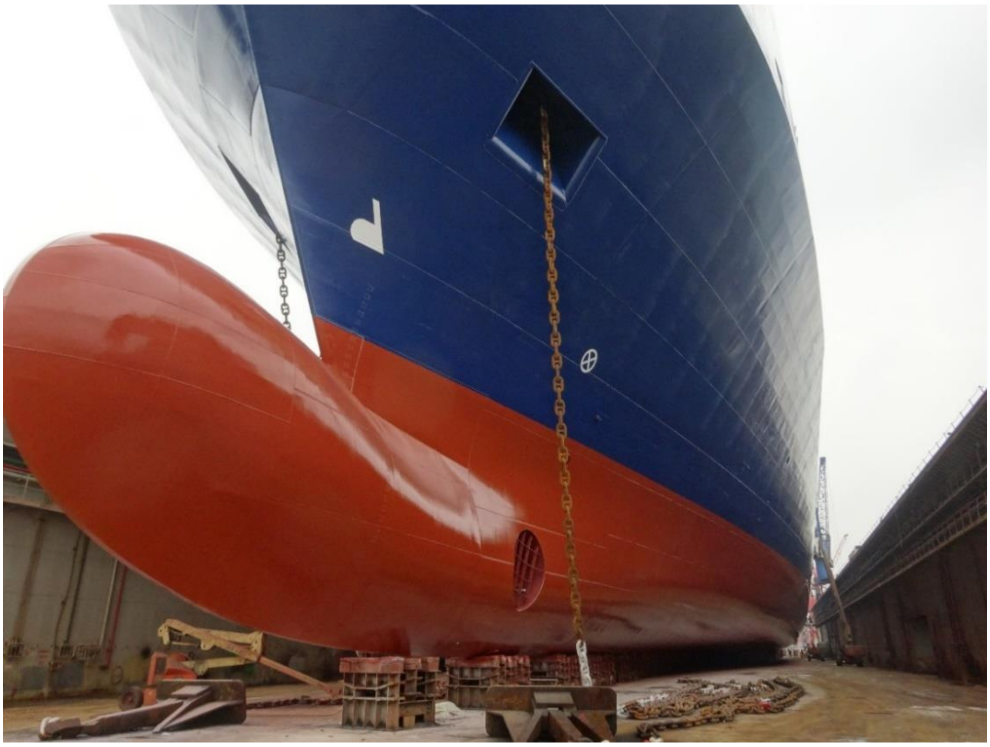

**Figure 4.55.** VESSEL 6, 2015 Dry-dock, photo of hull condition, after 1st type foul release coating application

**Table 4.38.** Comparison of last year before and first year after the dry-dock in 2013

| | Unit | Last year before dry-dock | First year after dry-dock | Speed Corrected data of first year after dry-dock |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 28 | 37 | 37 |
| Total Displacement | tons | 493.557 | 650.485 | 650.485 |
| Average Displacement | tons | 17.627 | 17.581 | 17.581 |
| Total Fuel Oil Consumption | tons | 4.300 | 5.621 | 5.521 |
| Average Fuel Oil Consumption | tons | 154 | 152 | 149 |
| Total Sailed Distance | miles | 34.540 | 47.043 | 47.043 |
| Total Sailed Hours | hrs | 1.801 | 2.439 | 2.451 |
| Average Speed | knots | 19,19 | 19,31 | 19,19 |
| Average Fuel Oil Consumption Per Hour | tons | 2,39 | 2,31 | 2,25 |
| Average Speed Loss | % | -9,30 | -7,97 | |
| Speed loss changes between last year before and first year after the dry-docking | % | | 1,33% | |
| Reduction of Fuel Oil Consumption | % | | -5,82% | |

In-Service performance after Dry-dock in 2013

**Table 4.39.** In service performance of Vessel 6

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 37 | 58 | 58 |
| Total Displacement | tons | 650.485 | 1.004.971 | 1.004.971 |
| Average Displacement | tons | 17.581 | 17.327 | 17.327 |
| Total Fuel Oil Consumption | tons | 5.621 | 9.156 | 10.351 |
| Average Fuel Oil Consumption | tons | 152 | 158 | 178 |
| Total Sailed Distance | miles | 47.043 | 73.529 | 73.529 |
| Total Sailed Hours | hrs | 2.439 | 3.969 | 3.808 |
| Average Speed | knots | 19,31 | 18,53 | 19,31 |
| Average Fuel Oil Consumption Per Hour | tons | 2,31 | 2,31 | 2,72 |
| Average Speed Loss | % | -7,97 | -11,68 | |
| In-service Performance according to Decrease of Speed Loss | % | | -3,70% | |
| Reduction of Fuel Oil Consumption | % | | 17,88% | |

Dry-docking Performance of Dry-docking in 2015

**Table 4.40.** Dry-docking performance of Vessel 6

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 37 | 44 | 44 |
| Total Displacement | tons | 650.485 | 770.837 | 770.837 |
| Average Displacement | tons | 17.581 | 17.519 | 17.519 |
| Total Fuel Oil Consumption | tons | 5.621 | 6.422 | 6.267 |
| Average Fuel Oil Consumption | tons | 152 | 146 | 142 |
| Total Sailed Distance | miles | 47.043 | 53.556 | 53.556 |
| Total Sailed Hours | hrs | 2.439 | 2.753 | 2.774 |
| Average Speed | knots | 19,31 | 19,46 | 19,31 |
| Average Fuel Oil Consumption Per Hour | tons | 2,31 | 2,33 | 2,26 |
| Average Speed Loss | % | -7,97 | -7,48 | |
| Dry-docking Performance according to Decrease of Speed Loss | % | | **0,49%** | |
| Reduction of Fuel Oil Consumption | % | | **2,01%** | |

Vessel 6, Paired samples statistics for fuel oil consumption and speed changes between last year before and first year after the dry-dock in 2013

**Table 4.41.** Statistical Results of Vessel 6, Fuel Consumption Changes, 2013

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 2,3915 | 28 | 0,10595 | 0,02002 |
| first year after dry-dock | 2,3310 | 28 | 0,08701 | 0,01644 |

| | N | Correlation | Sig. |
|---|---|---|---|
| last year & first year | 28 | -0,159 | 0,420 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| last year & first year | 0,06045 | 0,14738 | 0,02785 | 0,00330 | 0,11760 | 2,170 | 27 | 0,039 |

**Table 4.42.** Statistical Results of Vessel 6, Speed Changes, 2013

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 19,1911 | 28 | 0,49288 | 0,09314 |
| first year after dry-dock | 19,3500 | 28 | 0,47423 | 0,08962 |

| | N | Correlation | Sig. |
|---|---|---|---|
| last year & first year | 28 | -0,318 | 0,099 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| last year & first year | -0,15893 | 0,78511 | 0,14837 | -0,46336 | 0,14551 | -1,071 | 27 | 0,294 |

Vessel 6, Paired samples statistics for fuel oil consumption and speed changes for the dry-docking performance 2015

**Table 4.43.** Statistical Results of Vessel 6, Fuel Consumption, 2015

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 2,3059 | 37 | 0,08836 | 0,01453 |
| evaluation | 2,3524 | 37 | 0,10751 | 0,01767 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 37 | -0,196 | 0,244 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | -0,04649 | 0,15197 | 0,02498 | -0,09716 | 0,00418 | -1,861 | 36 | 0,071 |

**Table 4.44.** Statistical Results of Vessel 6, Speed Changes, 2015

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 19,3065 | 37 | 0,44632 | 0,07337 |
| evaluation | 19,4716 | 37 | 0,66603 | 0,10949 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 37 | 0,051 | 0,762 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | -0,16514 | 0,78243 | 0,12863 | -0,42601 | 0,09574 | -1,284 | 36 | 0,207 |

## 4.7. Results of Vessel 7

VESSEL 7 was not tested with any new technology hull coating in 2013 and coated with the same antifouling technology with 25% partly blasting as in previous dry-dock. Vessel 7 analyzed as a control sample to evaluate what would be the results if the same antifouling coating applied again with only spot blasting.

VESSEL 7 also dry-docked again in 2016 and 4$^{th}$ type self-polishing coating technology hull coating applied with only 15% partly blasting. We tested what would be the result if different technology self-polishing coating applied instead of application of same self-polishing antifouling coating as the previous dry-dock. Table 4.46 presents dry-docking history of Vessel 7.

**Table 4.45.** Dry-docking History of Vessel 7

| | | DDn-1 | DDn | DDn+1 |
|---|---|---|---|---|
| VESSEL 7 | Date of Drydock | 4.02.2012 | 31.05.2013 | 28.04.2016 |
| | Shipyard | BESIKTAS | BESIKTAS | SEFINE |
| | Blasting | SPOT | SPOT | SPOT |
| | Hull Coating | Self Polishing Coating 1 | Self Polishing Coating 1 | Self Polishing Coating 4 |
| | Engine Overhaul | NO | NO | NO |

Vessel 7 was built in 2008. She previously dry-docked in 2012. After applying spot blasting, 1$^{st}$ type self-polishing coating technology applied. Then dry-docked again in 2013. Spot blasting and same technology self-polishing coating applied again. Finally, vessel dry-docked again in 2016. After spot blasting, different type of 4$^{th}$ type self-polishing coating technology applied. This vessel was not tested with any foul release technology since she delivered from shipyard. So, it was a good sample to evaluate what happens if self-polishing technologies applied to same vessel with only spot blasting.

When she dry-docked in 2013, her hull found completely covered with fouling, especially vertical sides were heavily fouled as shown in 4.53 and 4.54. Dry-docking performance indicator of 2013 dry-docking could not be calculated due to there weren't available data for the first year after 2012 dry-docking. But her average fuel oil consumption was increased up to 2,26 ton/hour for the last year before entering the dry-dock in 2013 and it reduced to 2,19 ton/hour during the first year after the dry-dock.

Vessel's fuel consumption seems reduced 3,09 % however vessel's speed decreased to 19,25 knots from 19,37 knots. If vessel would have kept her speed as 19,37 knots, her consumption was going to remain same as 2,25 ton/hour.

According to results of in-service performance indicator calculations, vessel's speed reduced to 18,95 knots from 19,25 knots, and fuel consumption increased to 2,37 ton/hour. If the vessel kept her speed as 19,25 knots also in evaluation period, her fuel consumption would be 2,52 ton/hour which means 15,13 % increase of fuel consumption. According model test results of vessel, her speed loss was calculated as -6,83 % for the reference period and it increased to -9,94 % during the evaluation period which means vessel's speed reduced 3,10 %. Result of vessel 7 also indicated that applying same self-polishing coating with spot blasting causes increased speed loss and fuel consumption during the time.

Vessel 7 dry-docked again in 2016, her hull spot blasted, 4$^{th}$ type self-polishing coating technology applied. According to dry-docking performance, vessel's average fuel oil consumption was 2,19 ton/hour for the reference period and 2,36 ton/hour for the evaluation period. Vessel's fuel consumption seems increased 7,76 %. Vessel's speed decreased to 19,07 knots from 19,25 knots. If vessel would have kept her speed as 19,25 knots which was the average speed of reference period, her consumption was going to decrease to 2,45 ton/hour which means 11,90 % fuel consumption increase. According model test results of vessel, her speed loss was calculated as -6,83 % for the reference period and it decreased to -9,35 % with the application of same coating which represents 2,52 % decrease of ship's speed. Difference between average fuel consumption of reference period which was 2,19 ton/hour and average fuel consumption of evaluation period which was 2,36 ton/hour statistically found significant in the 95 % confidence level. But difference between vessel's speed (19,25 knots and 19,07 knots) was not found statistically significant in the 95% confidence level.

In-service performance calculations couldn't perform due to there was not enough data after the dry-dock in 2016. Results of vessel 7 confirmed that without full blasting, hull performance goes worst even any kind of self-polishing coating applied to the hull. It is not possible to get benefits of new coating without hull blasting.

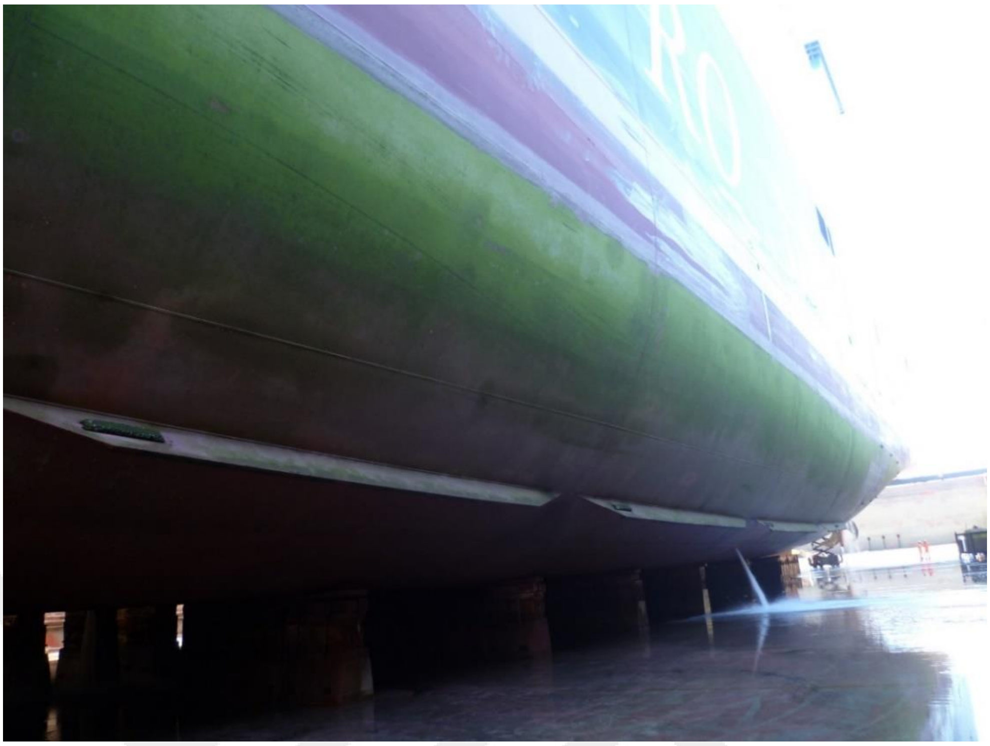

**Figure 4.56.** VESSEL 7, 2013 Dry-dock, photo of hull condition, just after entering the dry-dock

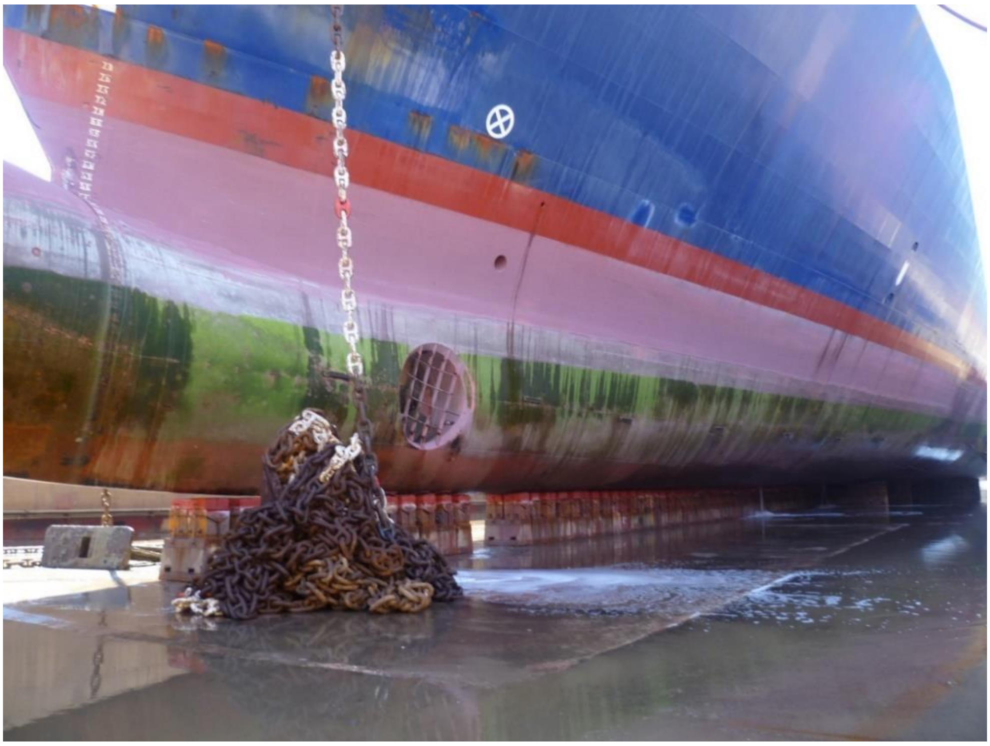

**Figure 4.57.** VESSEL 7, 2013 Dry-dock, photo of hull condition, just after entering the dry-dock

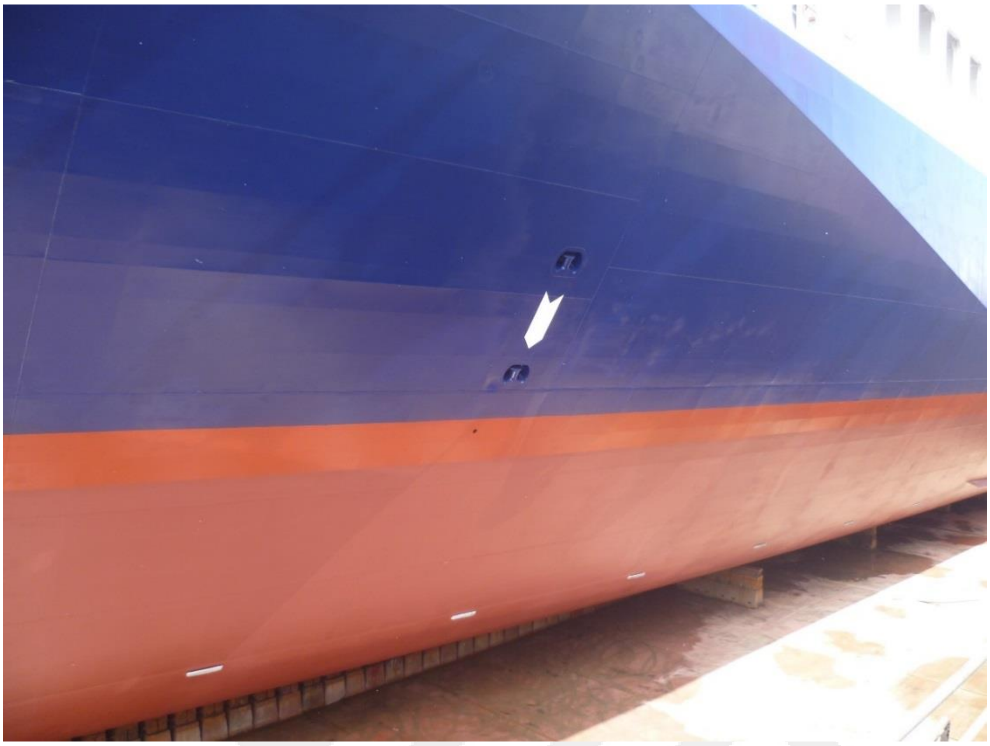

**Figure 4.58.** VESSEL 7, 2013 Dry-dock, photo of hull condition, after 1st type self-polishing coating application

**Figure 4.59.** VESSEL 7, 2013 Dry-dock, photo of hull condition, after 1st type self-polishing coating application

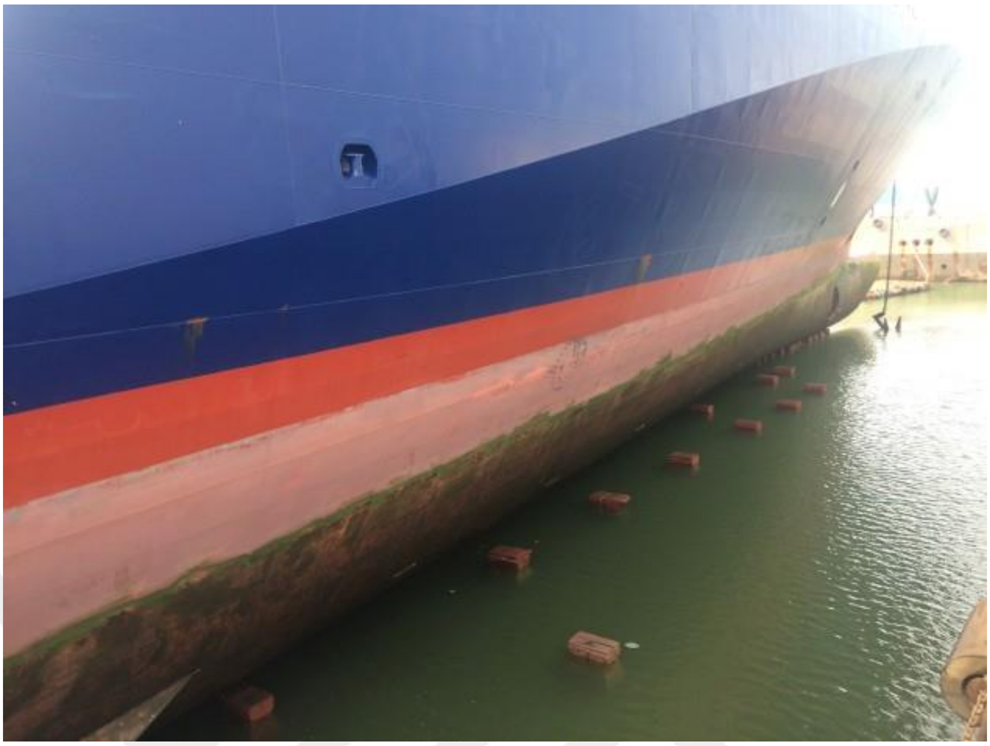

**Figure 4.60.** VESSEL 7, 2016 Dry-dock, photo of hull condition, just after entering the dry-dock

**Figure 4.61.** VESSEL 7, 2016 Dry-dock, photo of hull condition, during high pressure wash


**Figure 4.62.** VESSEL 7, 2016 Dry-dock, photo of hull condition, after 4th type self-polishing coating application


**Figure 4.63.** VESSEL 7, 2016 Dry-dock, photo of hull condition, after 4th type self-polishing coating application

**Table 4.46.** Comparison of last year before and first year after the dry-dock in 2013

| | Unit | Last year before dry-dock | First year after dry-dock | Speed Corrected data of first year after dry-dock |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 89 | 59 | 59 |
| Total Displacement | tons | 1.578.499 | 1.019.295 | 1.019.295 |
| Average Displacement | tons | 17.736 | 17.276 | 17.276 |
| Total Fuel Oil Consumption | tons | 13.495 | 8.482 | 8.638 |
| Average Fuel Oil Consumption | tons | 152 | 144 | 146 |
| Total Sailed Distance | miles | 115.652 | 74.440 | 74.440 |
| Total Sailed Hours | hrs | 5.975 | 3.872 | 3.843 |
| Average Speed | knots | 19,37 | 19,25 | 19,37 |
| Average Fuel Oil Consumption Per Hour | tons | 2,26 | 2,19 | 2,25 |
| Average Speed Loss | % | -6,96 | -6,84 | |
| Speed loss changes between last year before and first year after the dry-docking | % | | 0,12% | |
| Reduction of Fuel Oil Consumption | % | | -0,54% | |

In-Service performance after Dry-dock in 2013

**Table 4.47.** In service performance of Vessel 7

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 59 | 145 | 145 |
| Total Displacement | tons | 1.019.295 | 2.578.645 | 2.578.645 |
| Average Displacement | tons | 17.276 | 17.784 | 17.784 |
| Total Fuel Oil Consumption | tons | 8.482 | 22.618 | 23.730 |
| Average Fuel Oil Consumption | tons | 144 | 156 | 164 |
| Total Sailed Distance | miles | 74.440 | 181.121 | 181.121 |
| Total Sailed Hours | hrs | 3.872 | 9.570 | 9.408 |
| Average Speed | knots | 19,25 | 18,95 | 19,25 |
| Average Fuel Oil Consumption Per Hour | tons | 2,19 | 2,37 | 2,52 |
| Average Speed Loss | % | -6,84 | -9,94 | |
| In-service Performance according to Decrease of Speed Loss | % | | -3,10% | |
| Reduction of Fuel Oil Consumption | % | | 15,13% | |

Dry-docking Performance of Dry-docking in 2016

**Table 4.48.** Dry-docking performance of Vessel 7

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 59 | 51 | 51 |
| Total Displacement | tons | 1.019.295 | 901.360 | 901.360 |
| Average Displacement | tons | 17.276 | 17.674 | 17.674 |
| Total Fuel Oil Consumption | tons | 8.482 | 7.594 | 7.809 |
| Average Fuel Oil Consumption | tons | 144 | 149 | 153 |
| Total Sailed Distance | miles | 74.440 | 61.321 | 61.321 |
| Total Sailed Hours | hrs | 3.872 | 3.220 | 3.185 |
| Average Speed | knots | 19,25 | 19,07 | 19,25 |
| Average Fuel Oil Consumption Per Hour | tons | 2,19 | 2,36 | 2,45 |
| Average Speed Loss | % | -6,83 | -9,35 | |
| Dry-docking Performance according to Decrease of Speed Loss | % | 2,52% | | |
| Reduction of Fuel Oil Consumption | % | 11,90% | | |

Vessel 7, Paired samples statistics for fuel oil consumption and speed changes between last year before and first year after the dry-dock in 2013

**Table 4.49.** Statistical Results of Vessel 7, Fuel Consumption Changes, 2013

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 2,2590 | 59 | 0,13218 | 0,01721 |
| First year after dry-dock | 2,1909 | 59 | 0,09879 | 0,01286 |

| | N | Correlation | Sig. |
|---|---|---|---|
| last year & first year | 59 | -0,222 | 0,091 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| last year & first year | 0,06817 | 0,18175 | 0,02366 | 0,02081 | 0,11554 | 2,881 | 58 | 0,006 |

**Table 4.50.** Statistical Results of Vessel 7, Speed Changes, 2013

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 19,3805 | 59 | 0,41169 | 0,05360 |
| First year after dry-dock | 19,2517 | 59 | 0,73556 | 0,09576 |

| | N | Correlation | Sig. |
|---|---|---|---|
| last year & first year | 59 | -0,267 | 0,041 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| last year & first year | 0,12879 | 0,93379 | 0,12157 | -0,11456 | 0,37213 | 1,059 | 58 | 0,294 |

Vessel 7, Paired samples statistics for fuel oil consumption and speed changes for the dry-docking performance 2016

**Table 4.51.** Statistical Results of Vessel 7, Fuel Consumption, 2016

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 2,1900 | 51 | 0,10475 | 0,01467 |
| evaluation | 2,3624 | 51 | 0,13893 | 0,01945 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 51 | 0,036 | 0,802 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | -0,17235 | 0,17096 | 0,02394 | -0,22044 | -0,12427 | -7,200 | 50 | 0,000 |

**Table 4.52.** Statistical Results of Vessel 7, Speed Changes, 2016

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 19,2718 | 51 | 0,76293 | 0,10683 |
| evaluation | 19,0739 | 51 | 0,80152 | 0,11224 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 51 | 0,291 | 0,038 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | 0,19784 | 0,93190 | 0,13049 | -0,06426 | 0,45995 | 1,516 | 50 | 0,136 |

## 4.8. Results of Vessel 8

VESSEL 8 coated with 5th self-polishing coating technology in 2013, then she completed her docking cycle and dry-docked again in 2016 and 1st type foul release coating technology applied with full blasting. Also, propeller modification had been carried out with CLT (Contracted and Loaded Tip Propeller) blades during the same dry-docking. Result of 1st type foul release coating technology and new propellers evaluated together and compared to other sister vessels which are coated with foul release coating only in order to identify effect of propeller modification. Table 4.54 presents dry-docking history of Vessel 1.

**Table 4.53.** Dry-docking History of Vessel 8

| | | DDn-1 | DDn | DDn+1 |
|---|---|---|---|---|
| VESSEL 8 | Date of Drydock | 17.08.2011 | 28.08.2013 | 31.03.2016 |
| | Shipyard | GEMAK | BESIKTAS | BESIKTAS |
| | Blasting | SPOT | SPOT | FULL |
| | Hull Coating | Self Polishing Coating 1 | Self Polishing Coating 5 | Foul Release Coating 1 |
| | Engine Overhaul | NO | NO | Both Engine 45.000 hours overhaul completed. |
| | Other | | | CLT PROPELLER MODIFICATION |

Vessel 8 was built in 2008 like vessel 7. She was previously dry-docked in 2011, 1st type self-polishing coating technology applied after a spot blasting like other sister vessels. Then she dry-docked again in 2013, different type of 5th type self-polishing coating technology applied after a spot blasting.

Dry-docking performance indicator of 2013 dry-docking could not be calculated due to there weren’t available data for the first year after 2011 dry-docking. But her average fuel oil consumption was increased up to 2,35 ton/hour for the last year before entering the dry-dock in 2013 and it reduced to 2,19 ton/hour during the first year after the dry-dock. Vessel’s fuel consumption seems reduced 6,80 % however vessel’s speed decreased to 18,80 knots from 19,42 knots. If vessel would have kept her speed as 19,42 knots, her consumption was going to remain same as 2,50 ton/hour which means 6,38 % increase of fuel consumption. According model test results of vessel, her speed loss was calculated as -7,38 % for the last year before dry-dock and it increased to -8,81 % with the application of same coating which represents 1,42 % decrease of ship's speed. Difference between vessel's speed (19,42 knots and 18,80 knots) found statistically significant in the 95% confidence level. Even vessel's fuel consumption seems reduced, after applying speed correction, it is found that fuel consumption increased.

According to results of in-service performance indicator calculations, vessel's speed reduced to 18,66 knots from 18,80 knots, and fuel consumption increased to 2,41 ton/hour. If the vessel kept her speed as 18,80 knots also in evaluation period, her fuel consumption would be 2,48 ton/hour which means 13,13 % increase of fuel consumption. According model test results of vessel, her speed loss was calculated as -8,81 % for the reference period and it increased to -11,46 % during the evaluation period which means vessel's speed reduced 2,65 %. This results shows that, vessel‘s hull performance reduced dramatically and vessel tried to keep her speed in same level to catch the schedule and increased engine load which resulted higher fuel consumption. Due to condition of vessel hull performance was reduced unexpectedly, diver check carried out to understand reason of reduction. Figures 4.66 and 4.67 shows heavily fouled hull which causes dramatic speed loss.

Vessel 8 dry-docked again in 2016, her hull was completely covered with heavy fouling as shown in figures 4.68, 4.69 and 4.70. Her hull fully blasted, then 1$^{st}$ type foul release coating technology applied. Also, propeller blades changed with CLT blades to improve efficiency of propellers. According to dry-docking performance, vessel's average fuel oil consumption was 2,19 ton/hour for the reference period and 2,21 ton/hour for the evaluation period. Vessel's speed increased to 19,14 knots from 18,80 knots. If vessel would have kept her speed as 18,80 knots which was the average speed of reference period, her consumption was going to reduce to 2,06 ton/hour which means 5,97 % fuel consumption reduction. According model test results of vessel, her speed loss was calculated as -8,81 % for the reference period and it improved to -7,39 % with the application of new coating which represents 1,42 % improvement on ship's speed. Results were similar with the vessel 6 which was also coated with 1$^{st}$ type foul release coating technology and propeller blades changed with Kappel propeller blades. Even there is improvement on ship's speed and fuel consumption, it was not as good as other vessels which were only full blasted and foul release coatings applied. So results of vessel 8 indicates that new propeller blades did not worked as expected and most probably had negative effect on hull performance. Only one point to note, CLT blades seems better than Kappel blades due to results were better than Kappel blades applied vessel even both of them had negative effect on hull performance.


**Figure 4.64.** VESSEL 8, 2013 Dry-dock, photo of hull condition, after high pressure wash

**Figure 4.65.** VESSEL 8, 2013 Dry-dock, photo of hull condition, after high pressure wash

**Figure 4.66.** VESSEL 8, 2013 Dry-dock, photo of hull condition, after 5th type self-polishing coating technology application

**Figure 4.67.** VESSEL 8, 2013 Dry-dock, photo of hull condition, after 5th type self-polishing coating technology application

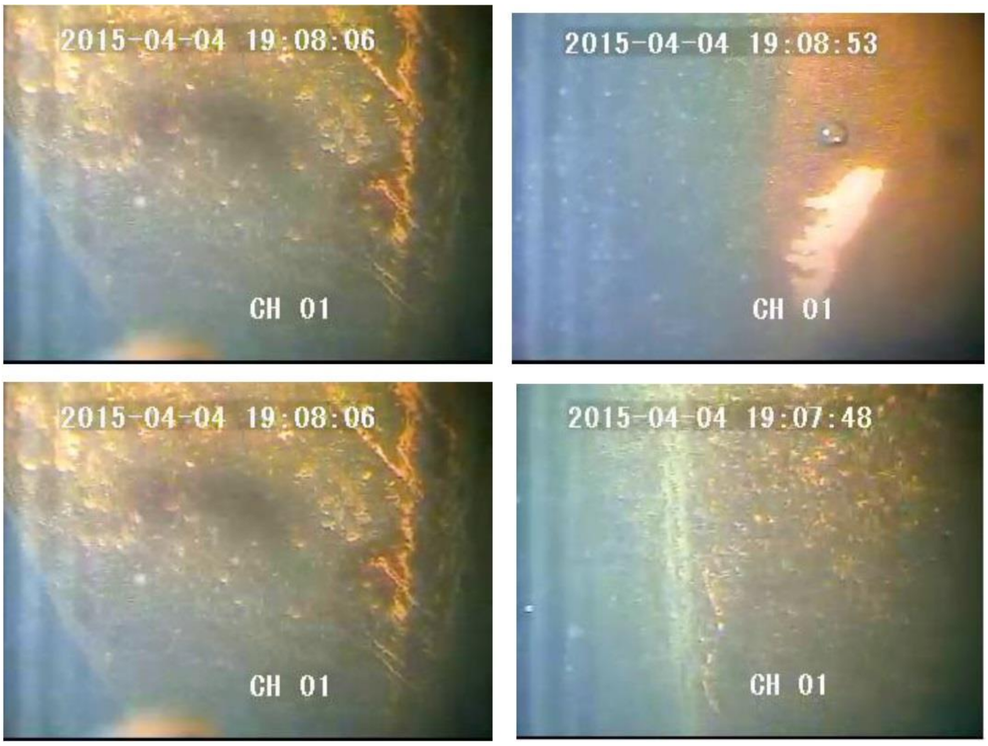


**Figure 4.68.** VESSEL 8, 2015 Diver check, photo of hull condition

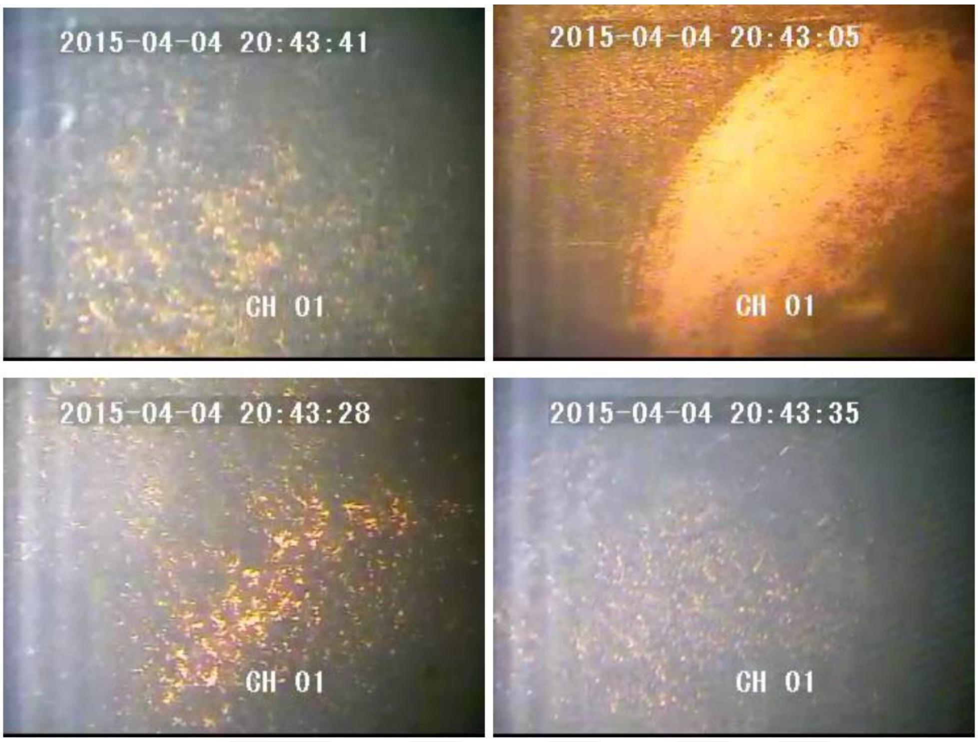


**Figure 4.69.** VESSEL 8, 2015 Diver check, photo of hull condition

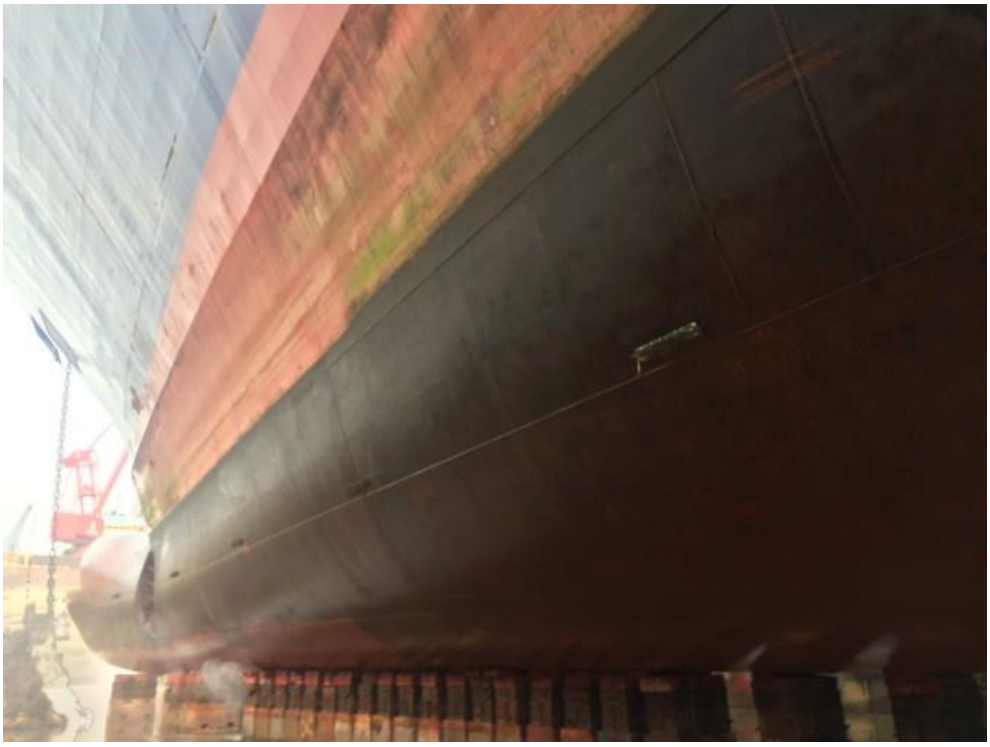

**Figure 4.70.** VESSEL 8, 2016 Dry-dock, photo of hull condition, just after entering the dry-dock

**Figure 4.71.** VESSEL 8, 2016 Dry-dock, photo of hull condition, just after entering the dry-dock

**Figure 4.72.** VESSEL 8, 2016 Dry-dock, photo of hull condition, just after entering the dry-dock

**Figure 4.73.** VESSEL 8, 2016 Dry-dock, photo of hull condition, full blasting + after 1st type foul release coating application

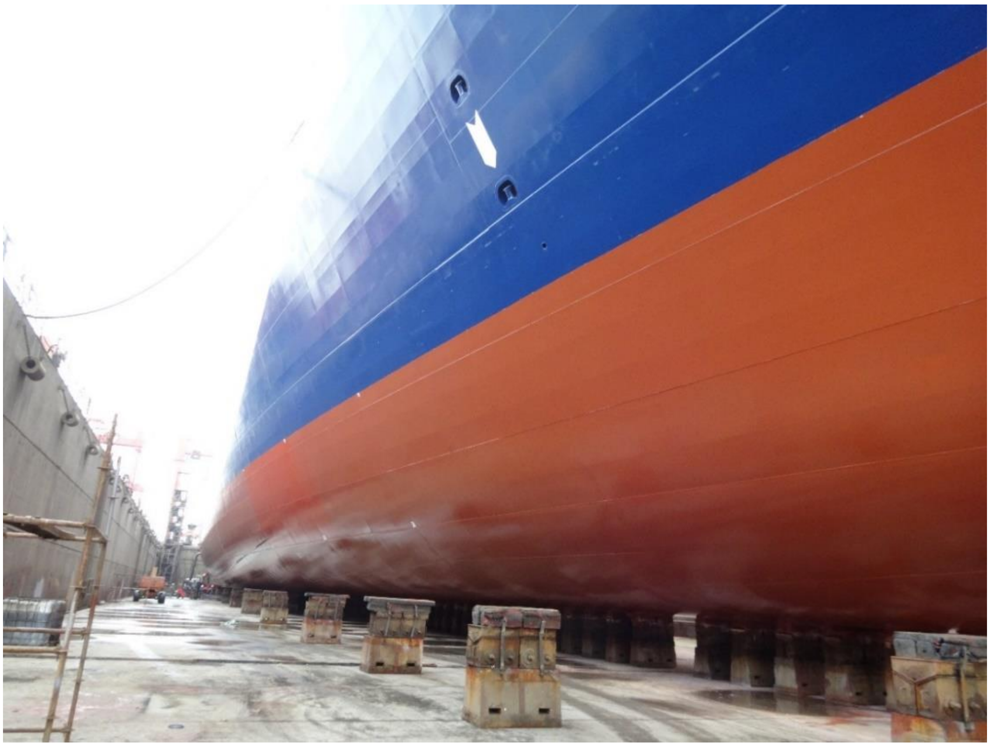

**Figure 4.74.** VESSEL 8, 2016 Dry-dock, photo of hull condition, full blasting + after 1st type foul release coating application

**Table 4.54.** Comparison of last year before and first year after the dry-dock in 2013

| | Unit | Last year before dry-dock | First year after dry-dock | Speed Corrected data of first year after dry-dock |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 34 | 47 | 47 |
| Total Displacement | tons | 604.924 | 849.794 | 849.794 |
| Average Displacement | tons | 17.792 | 18.081 | 18.081 |
| Total Fuel Oil Consumption | tons | 5.523 | 6.862 | 7.563 |
| Average Fuel Oil Consumption | tons | 162 | 146 | 161 |
| Total Sailed Distance | miles | 45.674 | 58.807 | 58.807 |
| Total Sailed Hours | hrs | 2.354 | 3.131 | 3.029 |
| Average Speed | knots | 19,42 | 18,80 | 19,42 |
| Average Fuel Oil Consumption Per Hour | tons | 2,35 | 2,19 | 2,50 |
| Average Speed Loss | % | -7,39 | -8,81 | |
| Speed loss changes between last year before and first year after the dry-docking | % | -1,43% | | |
| Reduction of Fuel Oil Consumption | % | 6,38% | | |

In-Service performance after Dry-dock in 2013

**Table 4.55.** In service performance of Vessel 8

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 47 | 62 | 62 |
| Total Displacement | tons | 849.794 | 1.120.597 | 1.120.597 |
| Average Displacement | tons | 18.081 | 18.074 | 18.074 |
| Total Fuel Oil Consumption | tons | 6.862 | 9.705 | 9.922 |
| Average Fuel Oil Consumption | tons | 146 | 157 | 160 |
| Total Sailed Distance | miles | 58.807 | 75.243 | 75.243 |
| Total Sailed Hours | hrs | 3.131 | 4.034 | 4.003 |
| Average Speed | knots | 18,80 | 18,66 | 18,80 |
| Average Fuel Oil Consumption Per Hour | tons | 2,19 | 2,41 | 2,48 |
| Average Speed Loss | % | -8,81 | -11,47 | |
| In-service Performance according to Decrease of Speed Loss | % | -2,65% | | |
| Reduction of Fuel Oil Consumption | % | 13,13% | | |

Dry-docking Performance of Dry-dock in 2016

**Table 4.56.** Dry-docking performance of Vessel 8

| | Unit | Reference Period | Evaluation Period | Speed Corrected Evaluation Period |
|---|---|---|---|---|
| Sample Size ( Voyage Quantity) | pcs | 47 | 36 | 36 |
| Total Displacement | tons | 849.794 | 649.823 | 649.823 |
| Average Displacement | tons | 18.081 | 18.051 | 18.051 |
| Total Fuel Oil Consumption | tons | 6.862 | 5.014 | 4.752 |
| Average Fuel Oil Consumption | tons | 146 | 139 | 132 |
| Total Sailed Distance | miles | 58.807 | 43.355 | 43.355 |
| Total Sailed Hours | hrs | 3.131 | 2.267 | 2.307 |
| Average Speed | knots | 18,80 | 19,14 | 18,80 |
| Average Fuel Oil Consumption Per Hour | tons | 2,19 | 2,21 | 2,06 |
| Average Speed Loss | % | -8,81 | -7,29 | |
| Dry-docking Performance according to Decrease of Speed Loss | % | | 1,42% | |
| Reduction of Fuel Oil Consumption | % | | 5,97% | |

Vessel 8, Paired samples statistics for fuel oil consumption and speed changes between last year before and first year after the dry-dock in 2013

**Table 4.57.** Statistical Results of Vessel 8, Fuel Consumption Changes, 2013

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 2,3472 | 34 | 0,09835 | 0,01687 |
| First year after dry-dock | 2,1635 | 34 | 0,08410 | 0,01442 |

| | N | Correlation | Sig. |
|---|---|---|---|
| last year & first year | 34 | 0,134 | 0,449 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| last year & first year | 0,18364 | 0,12052 | 0,02067 | 0,14159 | 0,22570 | 8,885 | 33 | 0,000 |

**Table 4.58.** Statistical Results of Vessel 8, Speed Changes, 2013

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Last year before dry-dock | 19,4160 | 34 | 0,56418 | 0,09676 |
| First year after dry-dock | 18,8330 | 34 | 0,42244 | 0,07245 |

| | N | Correlation | Sig. |
|---|---|---|---|
| last year & first year | 34 | 0,152 | 0,389 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| last year & first year | 0,58298 | 0,65123 | 0,11168 | 0,35576 | 0,81021 | 5,220 | 33 | 0,000 |

Vessel 8, Paired samples statistics for fuel oil consumption and speed changes for the dry-docking performance 2016

**Table 4.59.** Statistical Results of Vessel 8, Fuel Consumption, 2016

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 2,1658 | 36 | 0,08395 | 0,01399 |
| evaluation | 2,2125 | 36 | 0,09921 | 0,01653 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 36 | -0,085 | 0,623 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | ###### | 0,13529 | 0,02255 | -0,09244 | -0,00089 | -2,070 | 35 | 0,046 |

**Table 4.60.** Statistical Results of Vessel 8, Speed Changes, 2016

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| reference | 18,7981 | 36 | 0,43557 | 0,07260 |
| evaluation | 19,1364 | 36 | 0,56721 | 0,09453 |

| | N | Correlation | Sig. |
|---|---|---|---|
| reference & evaluation | 36 | 0,058 | 0,736 |

| | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| reference - evaluation | -0,33833 | 0,69477 | 0,11580 | -0,57341 | -0,10326 | -2,922 | 35 | 0,006 |

# 5. CONCLUSION

Actual field data of Ro-Ro fleet used in this study where all vessels were sisters and built in same shipyard in Germany with same technical properties. Changes of ship's speeds evaluated according to new international standard ISO 19030 methodology together with the fuel consumption changes comparisons. Data of reference periods and evaluation periods described in ISO 19030 compared to measure and evaluate hull performance. In order to proof results statistically, paired samples t-test was used for fuel consumption and speed parameters. Two different technology of foul release coatings and five different technology of self-polishing coatings tested.

First type of foul release coating technology initially tested on Vessel 1's fully blasted hull. She sailed approximately 3 years with this coating and dry-docked again in 2016. Her hull condition was clean and coating condition was very good. Only few slimes observed on vertical side with a 0,5-meter width on the loaded draft area where is open to sunshine. Flat bottom was completely clean and no slime were observed. Visual checks confirmed that new coating performed well against fouling. According to comparison of last year before dry-dock and first year after dry-dock, her average fuel oil consumption reduced to 2,20 ton/hour from 2,32 ton/hour and her speed increased to 19,71 knots from 19,38 knots. After the speed correction to fuel consumption, results confirmed 11,27 % fuel consumption reduction. Regarding speed changes, fully blasted and 1$^{st}$ type foul release coating applied hull increased ship's speed 2,67 %. According to in-service performance, her speed reduced 1,77 % while her fuel consumption remained same as 2,21 ton/hour until the dry-dock in 2016. If the vessel would have kept her speed as 19,71 knots during 2$^{nd}$ and 3$^{rd}$ years after the dry-dock, her fuel consumption would be 2,39 ton/hour which means 8,06 % increase of fuel consumption. It was used to dry-dock the vessel every 2,5 years. With the performance of advanced hydrogel silicone technology, company decided to dry-dock the vessel every 5 years.

Vessel 2 was also tested with first type of foul release coating technology together with full blasting. She sailed approximately 3 years with this coating and dry-docked again in 2017.  Her hull condition was clean and coating condition was very good. Only few slimes observed on vertical side with a 0,5-meter width on the loaded draft area where is open to sunshine. Flat bottom was completely clean and no slime were observed. Visual checks confirmed that new coating performed well against fouling. According to comparison of last year before dry-dock and first year after dry-dock, vessel's average fuel oil consumption reduced to 2,11 ton/hour from 2,27 ton/hour and her speed increased to 19,49 knots from 18,88 knots. After the speed correction to fuel consumption, results confirmed 18,14 % fuel consumption reduction. Regarding speed changes, fully blasted and first type of foul release coating technology applied hull increased ship's speed 4,48 %. According to in-service performance, her speed reduced 0,83 % while her fuel consumption remained same as 2,12 ton/hour until the dry-dock in 2017. If the vessel would have kept her speed as 19,49 knots during 2$^{nd}$ and 3$^{rd}$ years after the dry-dock, her fuel consumption would be 2,19 ton/hour which means 3,6 % increase of fuel consumption. It was used to dry-dock the vessel every 2,5 years. With the performance of 1$^{st}$ type foul release coating technology, company decided to dry-dock the vessel every 5 years.

Vessel 3 kept as a control sample during 2013 dry-docking and did not tested with any new technology coating. Her hull spot blasted and coated with same self-polishing coating technology (1$^{st}$ type). Then she sailed more than 2 years until March 2015. According to comparison of last year before dry-dock and first year after dry-dock, vessel's average fuel oil consumption reduced to 2,33 ton/hour from 2,44 ton/hour while also her speed reduced to 18,91 knots from 19,29 knots. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,53 ton/hour if she also sailed with 19,29 knots after the dry-dock. It means 3,57 % increase of fuel consumption just in the 1$^{st}$ year after the dry-dock. According to in-service performance, her speed reduced to 18,19 knots which means 2,87 % speed loss while her fuel consumption reduced to 2,27 ton/hour from 2,33 ton/hour. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,65 ton/hour if she also sailed with 18,91 knots after 1$^{st}$ year to next dry-dock which means 13,80 % increase of fuel consumption. Vessel 3 had been dry-docked every 2,5 years and her hull was not fully blasted at any dry-docking sequence since she built in 2005. Results of vessel 3 confirmed that if hull not fully blasted and coated with same self-polishing technology as previous, hull performance goes worst, ship's speed reduces and fuel consumption increases dramatically.

Vessel 3 dry-docked again in 2015, hull and coating condition was very poor as shown in findings chapter which explains dramatic speed loss and fuel consumption increase presented above. Then her hull fully blasted and 2$^{nd}$ type of foul release coating technology applied. According to dry-docking performance, fuel consumption was 2,33 ton/hour at reference period and reduced to 2,30 ton/hour during evaluation period. Vessel's speed increased to 19,48 knots from 18,91 knots. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,04 ton/hour if she also sailed with 18,91 knots after the dry-dock. It means 12,41 % reduction of fuel consumption just in the 1st year after the dry-dock. According to in-service performance, her speed again increased to 19,66 knots from 19,48 knots and her fuel consumption increased to 2,36 ton/hour from 2,30 ton/hour. If the vessel would have kept her speed as 19,48 knots also after the first year to next dry-dock, her fuel consumption would be 2,27 ton/hour which means 1,26 % decrease of fuel consumption. Results of 2$^{nd}$ type of foul release coating confirmed significant fuel saving. It is required to check her hull condition when she enters dry-dock again in 2018 in order to understand how this technology mitigated against fouling.

Vessel 4 was best test vessel where self-polishing coating and foul release coating applied with full blasting at consecutive dry-dockings in 2013 and 2015. It was possible to separate additional effect of silicone coating on individual ship. She sailed 2 years with fully blasted and self-polishing coating applied hull, then sailed again with fully blasted and 1$^{st}$ type of foul release coating applied hull for 1,5 years. According to comparison of last year before dry-dock and first year after 2013 dry-dock, vessel's average fuel oil consumption reduced to 2,38 ton/hour from 2,48 ton/hour, her speed remained same as 19,16 knots. Fully blasted and 2$^{nd}$ type of self-polishing coated hull provided 4,16 % fuel consumption reduction. According to in-service performance, her speed reduced to 18,84 knots from 19,16 knots, also fuel consumption reduced to 2,29 ton/hour from 2,38 ton/hour. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,46 ton/hour if she also sailed with 19,16 knots after first year to next dry-dock. According to corrected fuel consumption, her consumption increased 2,98 % during in-service period.

Vessel 4 dry-docked again in 2015. Even her hull was fully blasted in 2013, her hull found completely covered with fouling. Her hull fully blasted again, then 1st type of foul release coating applied which was also applied to Vessel 1 and Vessel 2 before. According to dry-docking performance, vessel's average fuel oil consumption reduced to 2,22 ton/hour from 2,38 ton/hour while her speed increased to 19,28 knots from 19,16 knots. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,16 ton/hour if she also sailed with 19,16 knots after the dry-dock. It means 9,42 % decrease of fuel consumption just in the 1st year after the dry-dock. According to results of in-Service Performance, vessel's speed increased to 19,32 knots from 19,28 knots, while also fuel consumption increased to 2,38 ton/hour from 2,22 ton/hour. If the vessel would have kept her speed as 19,28 knots after the first year to next dry-dock, her fuel consumption would be 2,37 ton/hour which means 6,64 % increase of fuel consumption.

Result of Vessel 4 proofed efficiency of foul release silicone coatings versus self-polishing coatings. According to comparison of dry-docking performance of 2013 and 2015 dry-dockings, 9,42 % fuel consumption difference observed on corrected results.

3rd type of self-polishing coating was tested on Vessel 5 at her 2013 dry-docking. Her hull was not fully blasted, only flat bottom area fully blasted, but vertical sides spot blasted. According to comparison of last year before dry-dock and first year after dry-dock, vessel's average fuel oil consumption reduced to 2,28 ton/hour from 2,42 ton/hour however vessel's speed decreased to 19,18 knots from 19,44 knots. If vessel would have kept her speed as 19,44 knots, her consumption would increase to 2,40 ton/hour which means 0,75 % fuel consumption decrease. According to results of in-service performance, vessel's speed decreased to 18,80 knots from 19,18 knots, while fuel consumption slightly increased to 2,33 ton/hour from 2,28 ton/hour. If the vessel would have kept her speed as 19,18 knots after 1st year to next dry-dock, her fuel consumption would be 2,52 ton/hour which means 10,70 % increase of fuel consumption. Ship's hull visually checked at her next dry-dock in 2015 in order to observe how new self-polishing coating mitigated with fouling. Vertical sides where not full blasted was covered with heavy fouling as shown in findings chapter, but flat bottom area was respectively better than vertical sides, only slight slime layer observed. It is required to test this coating with a fully blasted hull in order to say certain results about if it’s good for high-speed Ro-Ro vessels or not.

2nd type of foul release coating applied to vessel 5 during 2015 dry-docking. Her hull full blasted. According to dry-docking performance, vessel’s average fuel oil consumption increased to 2,35 ton/hour from 2,28 ton/hour, but her speed also increased to 19,72 knots from 19,18 knots. After speed correction to fuel consumption, fuel consumption would be 2,10 ton/hour if she sailed with 19,18 knots also after the dry-dock which means 7,93 % fuel consumption reduction. According to results of in-service performance, vessel’s speed decreased to 19,24 knots from 19,72 knots, while fuel consumption slightly increased to 2,37 ton/hour from 2,35 ton/hour. If the vessel kept her speed as 19,72 knots also in evaluation period, her fuel consumption would be 2,62 ton/hour which means 11,73 % increase of fuel consumption. 2nd type of foul release coating performed well during the first year after the dry-dock in 2015, but vessel’s speed decreased up to 0,5 knots after first year. Results of in-service performance was not good as Vessel 3. It is required to check her hull condition with diver to understand why coating performance reduced dramatically after first year and why we couldn’t observe same successful results of Vessel 3 on this vessel.

Vessel 6 kept as a control sample during 2013 dry-docking and did not tested with any new technology coating. Her hull spot blasted and coated with same self-polishing coating. Then she sailed more than 2,5 years until October 2015. According to comparison of last year before dry-dock and first year after dry-dock, vessel’s average fuel oil consumption reduced to 2,31 ton/hour from 2,39 ton/hour while also her speed increased to 19,31 knots from 19,19 knots. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,25 ton/hour if she also sailed with 19,19 knots after the dry-dock. It means 5,82 % fuel consumption reduction. According to in-service performance, fuel consumption remained same as 2,31 ton/hour however her speed reduced to 18,53 knots from 19,31 knots. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,72 ton/hour if she also sailed with 19,31 knots after the first year to next dry-dock which means 17,88 % increase of fuel consumption. Vessel 6 had been dry-docked every 2,5 years and her hull was not fully blasted at any dry-docking sequence since she built in 2006. Results of Vessel 6 also confirmed importance of full blasting. It is observed that, if hull not fully blasted and coated with same self-polishing technology as previous, hull performance goes worst, ship's speed reduces and fuel consumption increases dramatically.

Vessel 6 dry-docked again in 2015, her hull fully blasted and 1st type of foul release coating applied. Also, propeller blades were renewed with new Kappel propellers. According to dry-docking performance, vessel's average fuel oil consumption remained same, however her speed increased to 19,46 knots from 19,31 knots. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,26 ton/hour if she also sailed with 19,31 knots after the dry-dock. It means 2,07 % fuel consumption reduction. In-service performance calculations couldn't perform due to there was not enough data after the dry-dock in 2015.

We couldn't observe significant improvement on vessel 6 which we observed on other test vessels which are coated with 1st type of foul release coating. We suppose new propeller blades did not worked as expected and most probably had negative effect on hull performance where we couldn't observe usual effect of silicone coating.

Vessel 7 was another good control sample where we tested what would be results if same self-polishing coating applied after spot blasting and different technology of self-polishing coating applied with spot blasting again. She was built in 2008 and had 2 dry-dockings until 2013 and only spot blasted at each dry-dockings. She previously dry-docked in 2012. After applying spot blasting, 1st type of self-polishing coating applied. Then dry-docked again in 2013. Hull condition checked visually, vertical sides were completely fouled and flat bottom was covered with slime even she dry-docked and coated with conventional self-polishing coating just 11 months ago. Her hull spot blasted and same self-polishing coating applied again in 2013. According to comparison of last year before dry-dock and first year after dry-dock, vessel's average fuel oil consumption reduced to 2,19 ton/hour from 2,26 ton/hour and her speed also reduced to 19,25 knots from 19,37 knots. After speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,25 ton/hour if she also sailed with 19,37 knots after the dry-dock. Result indicated that spot blasting and conventional self-polishing coating did not improve ship's speed and fuel consumption reduction even for the 1st year, just kept same condition as before the dry-dock.

According to in-service performance, fuel consumption increased to 2,37 ton/hour from 2,19 ton/hour and ship's speed reduced to 18,95 knots from 19,25 knots. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,52 ton/hour if she also sailed with 19,25 knots after the first year to next dry-dock which means 15,13 % increase of fuel consumption.

Vessel 7 dry-docked again in 2016. After spot blasting, 4th type of self-polishing coating technology applied. As this vessel was not tested with any foul release technology and not fully blasted since she delivered from shipyard, it was a good sample to evaluate what happens if self-polishing technologies applied to same vessel with only spot blasting. According to dry-docking performance, vessel's average fuel oil consumption increased to 2,36 ton/hour from 2,19 ton/hour and ship's speed reduced to 19,07 knots from 19,25 knots. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,45 ton/hour if she also sailed with 19,25 knots during evaluation period which means 11,90 % increase of fuel consumption.

Results of vessel 7 confirms that, without full blasting, hull performance goes worst every year and even new coated hulls cannot perform well due to increased frictional resistance of hull because of previous coating layers and deformation of hull surface. In-service performance calculations couldn't perform due to there was not enough data after the dry-dock in 2016.

Vessel 8 dry-docked in 2013 and 5th type of Self-polishing coating applied after a spot blasting. According to comparison of last year before dry-dock and first year after dry-dock, vessel's average fuel oil consumption reduced to 2,19 ton/hour from 2,35 ton/hour but her speed also dramatically reduced to 18,8 knots from 19,42 knots. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,50 ton/hour if she also sailed with 19,42 knots after the dry-dock. It means 6,38 % increase of fuel consumption just in the 1st year after the dry-dock. According to in-service performance, her speed reduced to 18,66 knots which means 2,65 % speed loss while her fuel consumption increased to 2,41 ton/hour from 2,19 ton/hour. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,48 ton/hour if she also sailed with 18,80 knots after 1st year to next dry-dock. It means 13,13 % increase of fuel consumption. This vessel's results also confirmed that without full blasting, hull performance goes worst every year and even new coated hulls cannot perform well due to increased frictional resistance of hull because of previous coating layers and deformation of hull surface.

Vessel 8 dry-docked again in 2016, her hull was completely covered with heavy fouling as shown in findings chapter. Her hull fully blasted, then 1st type of foul release coating technology applied. Also, propeller blades renewed with CLT Blades to improve propeller efficiency. According to dry-docking performance, vessel's average fuel oil consumption remained same as 2,21, but her speed increased to 19,14 knots from 18,80 knots. After the speed correction to fuel consumption, results confirmed that her fuel consumption would be 2,06 ton/hour if she also sailed with 18,80 knots after the dry-dock. It means 5,97 % fuel consumption reduction. In-service performance calculations couldn't perform due to there was not enough data after the dry-dock in 2015.

Results of vessel 8 indicates that new propeller blades did not worked as expected and most probably had negative effect on hull performance. Only one point to note, CLT blades seems better than Kappel blades due to results were better than Kappel blades applied vessel even both of them had negative effect on hull performance.

4 vessels used as a control sample to evaluate what would be result if self-polishing coatings applied to spot blasted hull. Table 5.1 presents results of these vessels together. Results indicated that, if hull spot blasted and self-polishing coating applied, hull performance goes worst after first year to next dry-dock. Fuel consumption increases dramatically and speed of vessel decreases. Therefore, full blasting is very critical for maintaining hull performance and avoiding increase of fuel consumption.

**Table 5.1.** Performance of self-polishing coated and spot blasted vessels

| SELF POLISHING COATING + SPOT BLASTING APPLIED VESSELS' PERFORMANCE | | | | |
|---|---|---|---|---|
| | Comparison of last year before and first year after dry-dock | | In-service Performance | |
| | *Speed Loss %* | *Fuel Consumption mt/hr* | *Speed Loss %* | *Fuel Consumption mt/hr* |
| ***VESSEL 3*** | -0,84% | 3,57% | -2,87% | 13,80% |
| ***VESSEL 6*** | 1,33% | -5,82% | -3,70% | 17,88% |
| ***VESSEL 7*** | 0,12% | -0,54% | -3,10% | 15,13% |
| ***VESSEL 8*** | -1,43% | 6,38% | -2,65% | 13,13% |
| ***Average*** | -0,20% | 0,90% | -3,08% | 14,99% |

Vessel 4 was a control sample to evaluate if full blasting applied to hull together with self-polishing coating application. Results indicated that, even fuel consumption reduces for the 1st year, it again increases until next dry-dock. Table 5.2 presents result of vessel 4. When we compare in service performance results of self-polished + spot blasted vessels and self-polished + full blasted vessels, full blasted vessel's hull performance was better than spot blasted vessels. There were more than 2 % speed and 11 % fuel consumption difference observed between results.

**Table 5.2.** Performance of Self polishing coated and full blasted vessel

| SELF POLISHING COATING + FULL BLASTING APPLIED VESSELS' PERFORMANCE | | | | |
|---|---|---|---|---|
| | Comparison of last year before and first year after dry-dock | | In-service Performance | |
| | *Speed Loss %* | *Fuel Consumption mt/hr* | *Speed Loss %* | *Fuel Consumption mt/hr* |
| ***VESSEL 4*** | 0,93% | -4,16% | -0,71% | 2,98% |

Vessel 7 was only the sample where we could have chance to evaluate dry-docking performance of self-polishing coatings. We compared results of first year after 2013 dry-docking and first year after 2016 dry-docking where hull was completed coated with new coating. Results indicates that hull performance is reducing on every docking cycle and approximately 12 % fuel consumption increase proofs how hull condition is deteriorated dramatically without full blasting.

**Table 5.3.** Performance of self-polishing coated and full blasted vessel

| DRY-DOCKING PERFORMANCE OF VESSEL 7 | | |
|---|---|---|
| | Dry-docking Performance | |
| | *Speed Loss %* | *Fuel Consumption mt/hr* |
| ***VESSEL 7*** | -2,52% | 11,90% |

2 different technology of foul release coatings tested on 7 vessels. Results indicated that, foul release coatings performed well. Fuel consumption of all vessels reduced 7,5 % in average regarding dry-docking performance results. Also, ships' speeds increased up to 2 %.

**Table 5.4.** Dry-docking performance of foul release coated vessels

| DRY-DOCKING PERFORMANCE OF FOUL RELEASE COATINGS | | |
|---|---|---|
| | ***Speed Loss %*** | ***Fuel Consumption mt/hr*** |
| ***VESSEL 1*** | | |
| ***VESSEL 2*** | | |
| ***VESSEL 3*** | 3,00% | -12,40% |
| ***VESSEL 4*** | 2,21% | -9,42% |
| ***VESSEL 5*** | 1,94% | -7,93% |
| ***VESSEL 6*** | 0,49% | -2,01% |
| ***VESSEL 8*** | 1,42% | -5,97% |
| ***Average*** | 1,81% | -7,55% |

When we focus on dry-docking performance of vessel 4 which was full blasted + self-polishing coated and again full blasted + foul release coating applied on next dry-dock, foul release coating provided extra 9,42 % fuel consumption reduction and 2,21 % speed increase in respect to self-polishing coating. Below figure 5.1 represent speed loss changes of vessel 4.

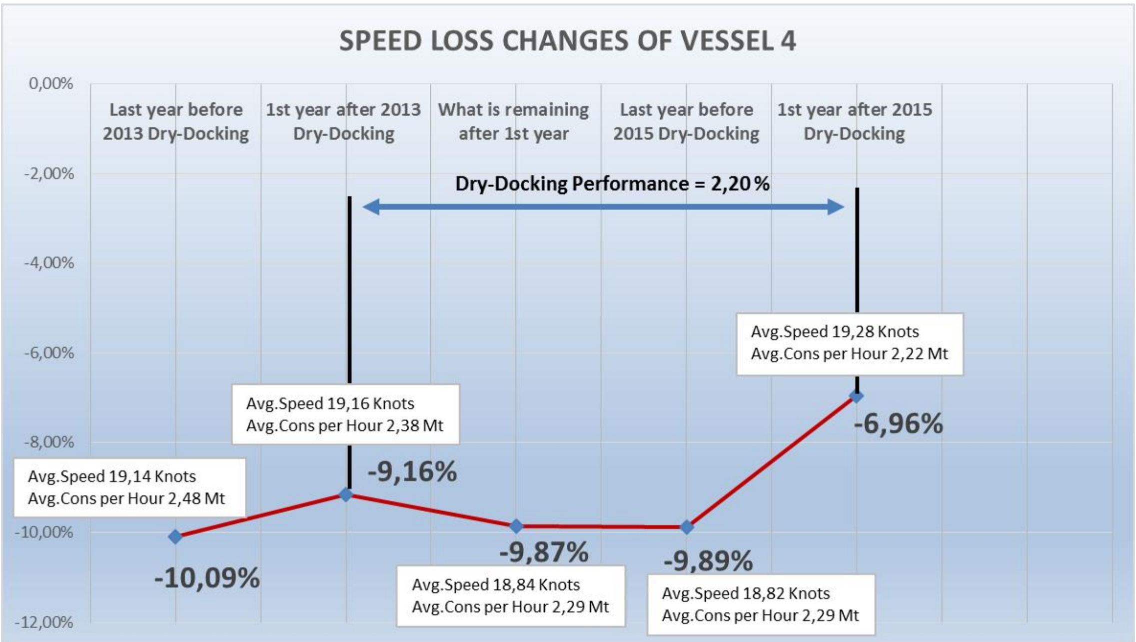


**Figure 5.1.** Speed loss changes of Vessel 4

Regarding in-service performance comparison of self-polishing and foul release coated vessels, foul release coated vessels performed better that self-polishing coated vessels in respect to speed loss and fuel consumption. Table 5.5 presents compared data of both coatings.

**Table 5.5.** In-service performance comparison of self-polishing and foul release coatings

| IN-SERVICE PERFORMANCE COMPARISONS | | | | |
|---|---|---|---|---|
| | Speed Loss % | | Fuel Consumption mt/hr | |
| | ***SELF POLISHING*** | ***FOUL RELEASE*** | ***SELF POLISHING*** | ***FOUL RELEASE*** |
| ***VESSEL 1*** | | -1,77% | | 8,06% |
| ***VESSEL 2*** | | -0,82% | | 3,60% |
| ***VESSEL 3*** | -2,87% | 0,28% | 13,80% | -1,26% |
| ***VESSEL 4*** | -0,71% | | 2,98% | |
| ***VESSEL 5*** | -2,25% | -2,55% | 10,70% | 11,73% |
| ***VESSEL 6*** | -3,70% | | 17,88% | |
| ***VESSEL 7*** | -3,10% | | 15,13% | |
| ***VESSEL 8*** | -2,65% | | 13,13% | |
| ***Average*** | -2,55% | -1,22% | 12,27% | 5,53% |

Application of foul release coatings reduced fuel consumptions of test vessels, increased speed and improved operational efficiency. Figure 5.2 demonstrates change of speed loss values of test vessels which proof improvement of hull performances with application of foul release coatings for the tested vessels.

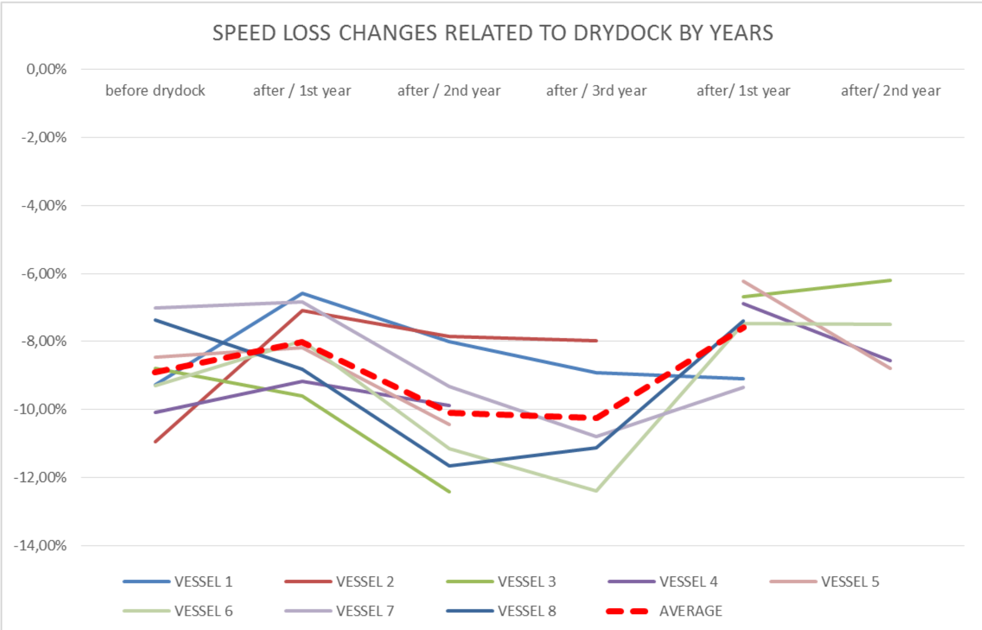


**Figure 5.2.** Speed Loss Changes of test Vessel by years after dry-dockings

This study confirmed below results:

- Foul release silicone technologies seems performing well for 2-3 years of period for high speed Ro-Ro vessels. We don't have available data to say something for longer periods.
- Only 1 vessel was full blasted and tested with self-polishing coating. It is required to evaluate results of more samples which are full blasted and self-polishing coated in order to separate effect of full blasting and coating, also for better comparison of self-polishing and foul release coatings.
- 1st type of foul release coating technology performed well on all tested vessels.
- 2nd type of foul release coating technology performed well for both test vessels during first year after dry-dock. But regarding in-service performance results, it performed well only on 1 vessel and did not on another.
- Full blasting is very critical and important for hull performance. If ship's hull only spot blasted, even if it's completely coated with any self-polishing coating, ship's hull performance reduces dramatically. Most of the ship operators do not want to carry out full blasting for economic reasons and they do only spot blasting to reduce dry-docking cost. However, this approach causes more fuel cost and reduced operational efficiency of ships.
- It is observed that self-polishing coatings perform well max 1 year for high speed Ro-Ro vessels unless it is applied together with full blasting which increases this beneficial period. And it is observed that all self-polishing coated vessels arrived to next dry-dock with a fouled hull.
- Hull performance of foul release coated vessels also reduces during in-service period but reduction seems not dramatic like self-polishing coatings.
- It is observed that; hull fouling occurs for the foul release coated vessels but it was not worst as self-polishing coated vessels. Photos taken just after entering the dry-docks confirms foul release coated vessels' hull were in good condition.

This study was about results of different hull coating technologies applied to high-speed Ro-Ro vessels under different conditions. Result of same coating technologies may differ on different ship types and under different operational conditions.

With the implementation of ISO 19030, we expect that more studies will be carried out for evaluating hull performance changes with real field data which literature needs more studies in this area. It is clear that uncertainty of real field data will be always high unless they carried out according to ISO 19030 Part 2 requirements which requires complete performance monitoring and logging system. It is the fact that most of vessels don't have performance monitoring and logging system. Therefore, this kind of studies will be helpful for ship owners, paint producers, academicians and all related parties.

It would be very useful if ISO to strengthen the standard with new methods to cover voyage base methodology for liner vessels. Part 3 requires daily collected data to analyze. However, it would be more beneficial for liner vessels to compare results of each voyage or each leg if the vessel is trading on the same line for a period which covers required analysis duration.

ISO 19030 have been recently published on 15.11.2016 and all parties offering performance monitoring systems have been started to implement their systems according to requirements of the standard.

For the future studies, it would be more beneficial to carry out analysis of sister vessels which have performance monitoring and logging systems required as ISO 19030. Uncertainty will be very low and results would be more useful for all parties cares with hull performance solutions.

# REFERENCES


Aldous, L., Smith, T., Bucknall, R., Thompson, P., (2015) Uncertainty analysis in ship performance monitoring, *Ocean Engineering*, **110,** 29 – 38.

Almeida E., Diamantino T. C., De Sousa O., (2007) Marine paints: The particular case of antifouling paints, *Progress in Organic Coatings*, **59,** 2–20.

Candries, M., Atlar, M., Anderson, C. D., (2001) Foul Release systems and drag, *Consolidation of Technical Advances in the Protective and Marine Coatings Industry; Proceedings of the PCE 2001 Conference,* 273-286.

Chambers L.D., Stokes K.R., Walsh F.C., Wood R.J.K., (2006) Modern approaches to marine antifouling coatings, *Surface & Coatings Technology*, **201**, 3642–3652.

Corbett J. J., Winebrake J. J., Green E., Corner B., (2010) Energy and GHG Emissions Savings Analysis of Fluoropolymer Foul Release Hull Coating.

Deligiannis P., (2016) Ship performance indicator, *Marine Policy*, 1-6.

Demirel Y. K., Khorasanchi M., Turan O., Incecik A., Schultz M. P., (2014) A CFD model for the frictional resistance prediction of antifouling coatings, *Ocean Engineering*, **89,** 21 – 31.

Demirel, Y. K., Khorasanchi M., Turan, O., Incecik, A., (2013) On the importance of antifouling coatings regarding ship resistance and powering, *Low Carbon Shipping Conference*, 1-13.

Demirel, Y. K., Khorasanchi M., Turan, O., Incecik, A., Schultz, M. P., (2014) A CFD model for the frictional resistance prediction of antifouling coatings, *Ocean Engineering* **89,** 21-31.

International Maritime Organization. (2013) Time for international action on $CO_2$ emissions from shipping.

International Organization for Standardization, (2016) IS0 19030 Ships and Maritime Technology – Measurement of Changes in Hull and Propeller Performance

Lejars, M., Margaillan, A., Bressy, C. (2012) Fouling Release Coatings: A Nontoxic Alternative to Biocidal Antifouling Coatings, *Chemical Reviews*, 4347-4390.

Lindholdt, A., Dam-Johansen, K., Olsen, S. M., Yebra, D. M., Kiil, S., (2015) Effects of biofouling development on drag forces of hull coatings for ocean-going ships: a review, *Journal of Coating Technology*, 415 – 444.

Meng Q., Yuquan Du, Wang Y., (2015) Shipping log data based container ship fuel efficiency modeling, *Transportation Research Part B*, 207 – 229.

Milne, A., (1990) Roughness and Drag from the Marine Paint Chemist's View-point, *Marine Roughness and Drag Workshop, London.*

Mirabedini S.M., Pazoki S., Esfandeh M., Mohseni M., Akbari Z., (2006) Comparison of drag characteristics of self-polishing co-polymers and silicone foul release coatings: A study of wettability and surface roughness, *Progress in Organic Coatings*, **57,** 421–429.

Paik, B., Kim, K. Y., Cho, S. R., Ahn, J. W., Cho, S. R., (2014) Investigation on drag performance of anti-fouling painted flat plates in a cavitation tunnel, *Ocean Engineering,* **101**, 264 – 274.

Schults, M. P., (2004) Frictional Resistance of Antifouling Coating Systems, *Journal of Fluids Engineering*, **126**, 1039 – 1047.

Schultz, M. P., (2007) Effects of coating roughness and biofouling on ship resistance and powering. *Biofouling* **23(5),** 331–341.

Søyland, S., Oftedahl, G. A., (2016) ISO 19030 – Motivation, Scope and Development, 292-297.

Swain G., Cassé F., Kavanagh C., (2007) Measuring the Performance of Today's Antifouling Coatings, *Journal of Ship Production*, 1 – 7.

Swain G., Lund G., (2016) Dry-Dock Inspection Methods for Improved Fouling Control Coating Performance, *Journal of Ship Production and Design*, **32,** 186 – 193.

Taylan, M., (2010) An overview: Effect of roughness and coatings on ship resistance, *In: Proceedings of the International Conference on Ship Drag Reduction, Istanbul, Turkey.*

Townsin R.L., Anderson C.D., (2009) Fouling control coatings using low surface energy, foul release technology, *Advances in marine antifouling coatings and Technologies*, 693 – 708.

Townsin, R. L., (2003) The Ship Hull Fouling Penalty, *Biofouling,* **19,** 9-15.

Tripathi R., (2016) Advances in Antifouling Coatings Technology, *Coatings World*, 62.

Trodden D.G., Murphy A.J., Pazouki K., Sargeant J., (2015) Fuel usage data analysis for efficient shipping operations, *Ocean Engineering,* **110,** 75 – 84.

Van Manen, J. D., Van Oossanen, P. (1988) Resistance In: Lewis, E. V. (Ed.), Principles of Naval Architecture, Second Revision, Volume II: Resistance, Propulsion and Vibration, *The Society of Naval Architects and Marine Engineers, Jersey City, NJ.*

Wigforss, J. (2012) Benchmarks and measures for better fuel efficiency, Master Thesis, 5.

Yebra, D. M., Kiil, S., Dam-Johansen, K., (2003) Antifouling technology—past, present and future steps towards efficient and environmentally friendly antifouling coatings, *Progress in Organic Coatings* **50,** 75-104.

# CURRICULUM VITAE

Name: Hasan
Surname: GÖLER
Address: Hilal Konutları B-7 Blok Daire 28 Pendik / İSTANBUL / TURKEY
Home Tel: 0216 378 90 19
Mobile: 0543 907 38 00
E-mail: cptgoler@gmail.com
Date of Birth: 20/11/1980
Civil status: Married
Military Obligation: Completed
https://tr.linkedin.com/pub/hasan-göler/45/2a6/472

## CAREER PROFILE

After completing Haydarpaşa Anatolian Technical High School, graduated from Istanbul Technical University Maritime Collage Deck Branch and completed probation on board of MV BARRIER which is owned by Kıran Shipping Company and working between South Africa and Mozambique. After receiving Ocean Going Deck Officer licence, worked as second and chief officer on board of bulk carrier vessels owned by Manta Shipping Company. Then started to work for UN RO-RO in 2002 and worked as second and chief officer until 2007. Also completed Anatolian University Management Faculty while working at UN RO-RO. After that, worked as Guarantee Department Manager Assistant at Yardımcı Shipyard until 2009. Between 2004 and 2009, took care of Mobile Ice Rink systems which was new in Turkey and received Entrepreneurship reward from Eurowards Turkey which was organised by the European Parliament. The reward was given for the interesting Entrepreneurship story of a young Entrepreneur. Built the first Mobile Ice Rink in Turkey at Kanyon Shopping Mall in 2006 and sold 2 new ice rinks to Kayseri. Featured in the news as "Investment of the year, Mobile Ice Rinks" at Economist Magazine for 3 times. Due to military obligation, I had to stop working with ice the rink business for a long time and could not return back.

After Military obligation, returned back to UN RO-RO as Chief Officer in 2009 then appointed as Purchasing Superintendent position in 2010. Also received Ocean Going Master Licence during working as Chief Officer. I have been working as Purchasing

Superintendent in a UN RO-RO and managing all purchasing activities of 12 Ro-Ro vessels since 2010. During working as Purchasing Superintendent, I attended to Purchasing Academy trainings which was organised by Koç University and CIPS-Chartered Instutue of Purchase & Supply which is located in the UK. Training was about Category management, Supplier Relationship and Performance Management, Cost and Price Analysis subjects. Also I worked for CIT- Continuous Improvement Team in UN RO-RO and my “Route Optimisation” project was well accepted and applied to our vessels which then reduced their fuel consumptions using Route Optimization. Then also had a positive effects in protecting environment due to reduced toxic gas emissions. Recently I continued Master degree program at Piri Reis University and also studying second licence program at Istanbul University which will finish in 2016. I published 2 academic papers at National Port Congress of Turkey and International Logistic Congress 2014 during my master program. I am married and have 2 beatiful sons.

**EDUCATION**

**Haydarpaşa Anatolian High School 1994 – 1998**

**İstanbul Technical University Maritime Collage Deck Branch 1998-2001**

**Anatolian University Management Faculty 2001-2005**

**İstanbul University Engineering Faculty**

Still continue…

**Piri Reis University Master Degree**

Maritime Transportation and Management Engineering

Still Continue…

**PROFESSIONAL EXPERIENCE**

**Operation Superintendent**

**U.N RO-RO Isletmeleri A.S.**

February 2017 - continue

**Purchasing Superintendent**

**U.N RO-RO Isletmeleri A.S.**

September 2010 – February 2017

**Chief Officer**

**U.N RO-RO Isletmeleri A.S.**

May 2009 – September 2010

**Guarantee Department Manager Assistant**

**Yardımcı Shipyard**

January 2007 – December 2008

**Chief Officer**

**U.N RO-RO Isletmeleri A.S.**

June 2006 – December 2006

---

**2nd Officer**

**U.N RO-RO Isletmeleri A.S.**

July 2002 – June 2006

**Chief Officer**

**Manta Shipping**

December 2001 – June 2002

**2nd Officer**

**Manta Shipping**

July 2001 – December 2001

**Deck Cadet**

**KIRAN SHIPPING**

June 2000 – June 2001

**LANGUAGE**

Advanced writing and speaking English

**REWARDS**

Eurowards Turkey Entrepreneurship Honor Reward

European Parliament – November 2006

**CERTIFICATES**

- **OCEAN GOING MASTER**
  Turkish Maritime Administration February 2011
- **SHIP SECURITY OFFICER CERTIFICATE** April 2006
- **ISO9001:2008 QUALITY, ISO14001:2004 ENVIRONMENTAL MANAGEMENT SYSTEM, OHSAS 18001:2007 OCCUPATIONAL HEALTH & SAFETY MANAGEMENT SYSTEM**
  BUREAU VERITAS June 2008
- **INTERNAL AUDITOR - OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT SYSTEM**
  **INTERNAL AUDITOR - ISO 9001:2008- ISO 14000:2004 - OHSAS 18001:2007**
  BUREAU VERITAS June 2008
- **THE TRAINING COURSE CERTIFICATE ON RESPONSE TO OIL AND OTHER HAZARDOUS SUBSTANCES POLLUTION AT SEA**
  Turkİsh Maritime Administration Lisans 2012/2010-04/16 January 2013
- **INTERNAL AUDITOR ISM-ISPS-MLC FOR SHIPPING COMPANIES**
  GERMANISCHER LLOYD August 2013
- **Supplier Relationship and Performance Management**
  Chartered Institute of Purchasing & Supply September 2014
- **Category Management and Strategic Sourcing**
  Chartered Institute of Purchasing & Supply September 2014
- **Purchase Price and Cost Analysis**
  Chartered Institute of Purchasing & Supply September 2014
- **CIPS - Purchasing Academy**
  Koç University September 2014

**PUBLISHES**

- Paper : Shore Connections Systems at Ports

Dokuz Eylül University - 1St National Port Congress of Turkey
2013

- Paper : Evaluating The Effect of Hull Coating on The Total Cost of Maritime Logistics
  12th International Logistics Congress
- Economist Magazine - Investment of the year, Mobil Ice Rinks
  2006
- Economist Magazine - Different Investment , Mobil Ice Rinks
  2006
- Economist Magazine Yearly Entrepreneurship Publish - Different Investment , Mobil Ice Rinks 2006