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Ultrasonic Technology to Keep Fouling in CHEK

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Abstract

This paper describes our planned contributions to the EU project CHEK and first insights from the project. The project's larger context is decarbonizing shipping through innovative technologies, where ultrasonic antifouling technology is the specific contribution of HASYTEC to increase energy efficiency in operation and bring down the Carbon Intensity Indicator (CII). The application cases in CHEK are a cruise vessel and a bulk carrier.

1. Introduction

IMO, www.imo.org, has the ambition to halve GHG emissions by 2050 and to completely decarbonize shipping "as soon as possible" within this century. The initial IMO Greenhouse Gas strategy will be revised in 2023, including these goals. IMO is following a two-tier approach to implement decarbonization measures, focusing first on a set of short-term energy efficiency improving measures, before embarking on more comprehensive medium-term and long-term measures that will include alternative low-carbon/no-carbon fuels, *Bertram (2021)*.

Current measures addressing GHG emissions include three mandatory requirements:

- The Energy Efficiency Design Index (EEDI) for newbuildings mandating successive improvement in design performance of 30% compared to the average of ships built 1999-2009.
- The Ship Energy Efficiency Management Plan (SEEMP) for all ships above 400 GT in operation, making a continuous energy efficiency improvement management plan mandatory, although not stating explicit requirements to content, scope and implementation.
- The Fuel Oil Consumption Data Collection System (DCS) mandating annual reporting of CO_2 emissions for all ships above 5000 GT.

At MEPC 76, in 2021, three additional measures were adopted, affecting all existing cargo and cruise ships after 2023:

- The Energy Efficiency Design Index for Existing Ships (EEXI), essentially making requirement equivalent to EEDI Phase 2 or 3 mandatory to all existing ships.
- A mandatory Carbon Intensity Indicator (CII) and rating scheme for all cargo and cruise ships above 5000 GT. Poor CII ratings will lead to mandatory requirements for corrective action plans to improve the CII. The criteria for CII ratings will get progressively stricter by 1% per year for 2020-2022, followed by 2% per year for 2023-2026.
- SEEMP requirements were made stricter (Enhanced SEEMP) to include mandatory content, such as an implementation plan on how to achieve the CII targets.

These new requirements for existing ships will increase the focus on energy efficiency measures both in design/retrofit and operation. For the operational measures, improved hull management is widely seen as one of the most important measures, with potential gains in the order of magnitude of 10%.

2. Project CHEK

2.1. Overview

The R&D project CHEK (deCarbonising sHipping by Enabling Key technology symbiosis on real vessel concept designs) has as a goal to reduce CO_2 emissions in global shipping. The focus is on the combined application of advanced key technologies in shipbuilding. The CHEK project is supported by the European Union with a total of 10 million Euro from the Horizon 2020 funding program, https://ec.europa.eu/programmes/horizon2020/en/home. The Horizon 2020 program is the biggest EU research & innovation program ever, with nearly € 80 billion of funding over 7 years. Its aim is combining European research and innovation to achieve excellent science, industrial leadership and tackling societal challenges.

2.2. Project goals

The CHEK project proposes to reach zero-emission shipping by disrupting the way ships are designed and operated today. The project will develop and demonstrate two bespoke vessel designs – a wind energy optimised Kamsarmax bulk carrier and a hydrogen powered cruise ship, Fig.1 – equipped with an interdisciplinary combination of innovative technologies working in symbiosis to reduce greenhouse gas emissions by 99%, achieve at least 50% energy savings and reduce black carbon emissions by over 95%. The innovative energy-saving technologies include the use of wind energy, batteries, heat recovery, hydrogen as a fuel, air lubrication and ultrasound anti-fouling.

Rather than "stacking" novel technologies onto existing vessel designs, the consortium is proposing to develop a unique Future-Proof Vessel (FPV) Design Platform to ensure maximised symbiosis between the novel technologies proposed and taking into consideration the vessels' real operational profiles (rather than just sea-trial performance). The FPV Platform will also serve as a basis for replicating the CHEK approach towards other vessel types such as tankers, container ships, general cargo ships and ferries. These jointly cover over 93% of the global shipping tonnage and are responsible for 85% of global GHG emissions from shipping.

Fig.1: Application cases: Bulk carrier and cruise ship, source: Wärtsilä

In order to achieve real-world impact and the decarbonisation of the global shipping fleet, the consortium will undertake an analysis of framework conditions influencing long-distance shipping today (including infrastructure availability) and propose solutions to ensure the proposed vessel designs can and will be deployed in reality. A Foresight Exercise will simulate the deployment of the CHEK innovations on the global shipping fleet with the aim of reaching the IMO's goal of halving shipping emissions by 2050 and contributing to turning Europe into the first carbon-neutral continent by 2050 (as stipulated by the European Green Deal).

2.3. Project consortium

The CHEK project partners are:

- University of Vaasa (UV), http://www.uwasa.fi/, is a business-oriented, multidisciplinary and international university.
- Wärtsilä, www.wartsila.com, is a provider of ship machinery, propulsion and manoeuvring solutions, supplying engines and generating sets, reduction gears, propulsion equipment, control systems, and sealing solutions for all types of vessels and offshore applications.
- Cargill Ocean Transportation, https://www.cargill.com/transportation/cargill-ocean-transportation, is a freight-trading business that provides bulk shipping services to customers across the globe.
- MSC Cruises, www.msccruises.com, is a global cruise line, which is part of the Cruises Division of MSC Group, the privately held Swiss-based shipping and logistics conglomerate.
- Lloyd's Register EMEA (LR), www.lr.org, is part of the Lloyd’s Register Group, a global independent risk management and safety assurance organisation that works to enhance safety and improve the performance of assets and systems at sea, on land and in the air.
- World Maritime University (WMU), www.wmu.se, was established in 1983 by the International Maritime Organization (IMO).
- Silverstream Technologies, https://www.silverstream-tech.com/, was established in 2010 and the company specialises in Air Lubrication Technology, *Silberschmidt et al. (2016)*, which is designed to reduce the frictional impact between the flat bottom of the ship hull and water.
- HASYTEC Electronics GmbH, https://www.hasytec.de/, is market leader in ultrasound based antifouling technology, *Kelling (2017,2020)*.
- Deltamarin, https://deltamarin.com/, is a ship engineering and design company.
- Climeon AB, https://climeon.com/, has well proven technology to convert waste heat to clean power.
- BAR Technologies, https://www.bartechnologies.uk/, have used their in-house tool Ship-SEAT to design and optimise their own patented and trademarked wind propulsion system called WindWings, https://www.bartechnologies.uk/project/windwings/.

2.4. Application cases and applied technology

The project aims to combine a variety of innovative technologies to achieve its goals, Fig.2:

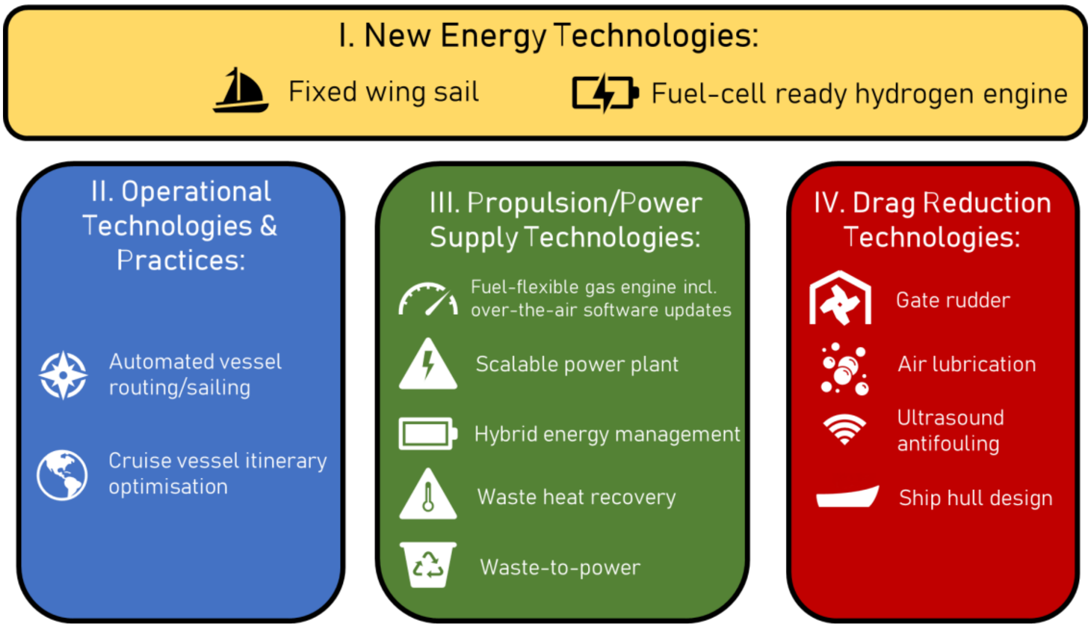


Fig.2: Technological synergy for emission savings

- New energy technologies
  - Fixed wing sails
  - Fuel-cell ready hydrogen engine
- Operational technologies and practices
  - Automated vessel routing/sailing
  - Cruise vessel itinerary optimisation
- Propulsion/Power supply technologies
  - Fuel-flexible gas engine incl. over-the-air software updates
  - Scalable power plant
  - Hybrid energy management
  - Waste heat recovery
  - Waste-to-power
- Drag reduction technologies
  - Gate rudder
  - Air lubrication
  - Ultrasound antifouling
  - Ship hull optimization

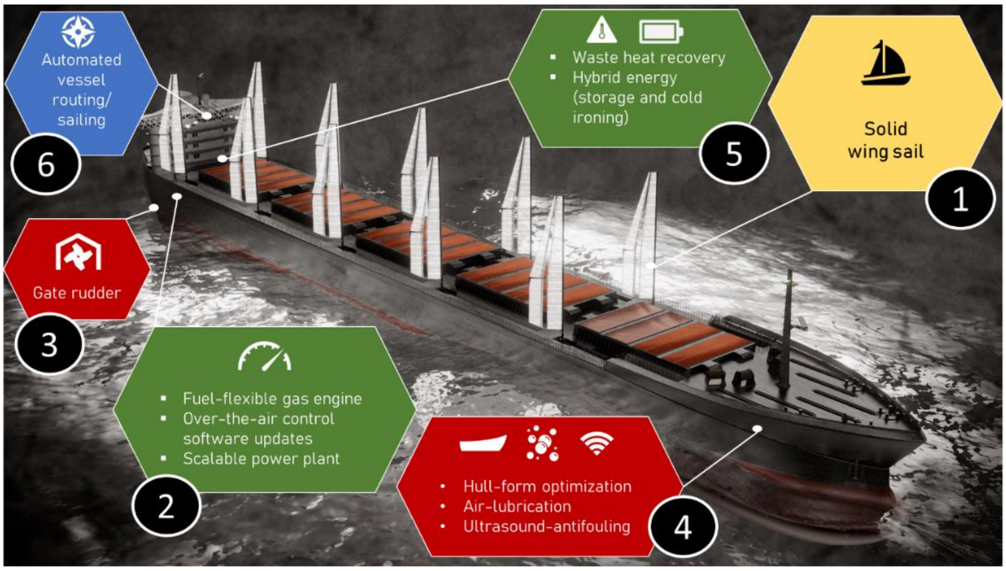


Fig.3: Emission saving technologies envisioned for bulk carrier

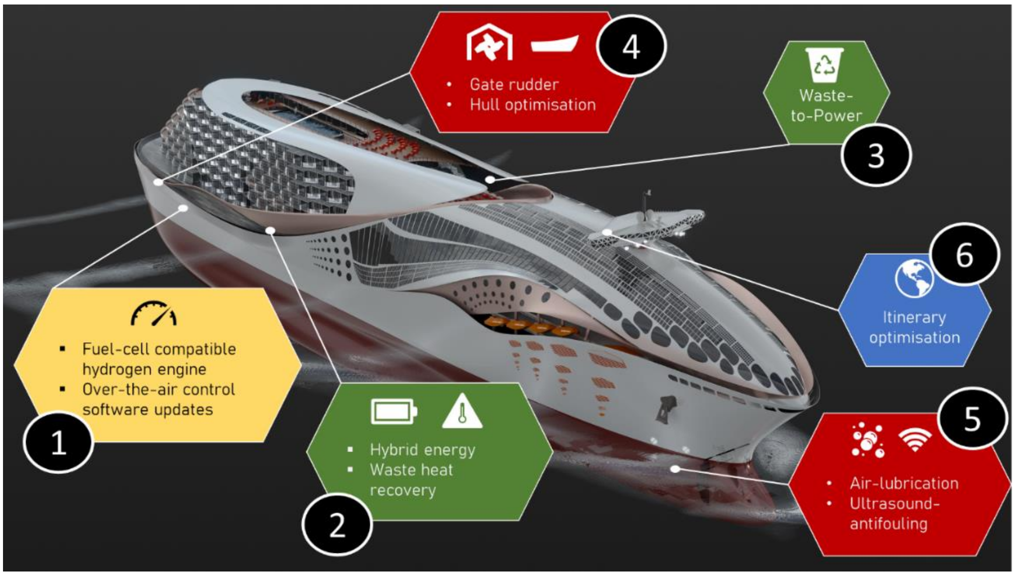


Fig.4: Emission saving technologies envisioned for cruise vessel

The effectiveness and saving potential of the various options depend on various factors, including ship types and associated typical operational patterns. Within CHEK, two very different ship types are considered, namely a bulk carrier and a cruise vessel.

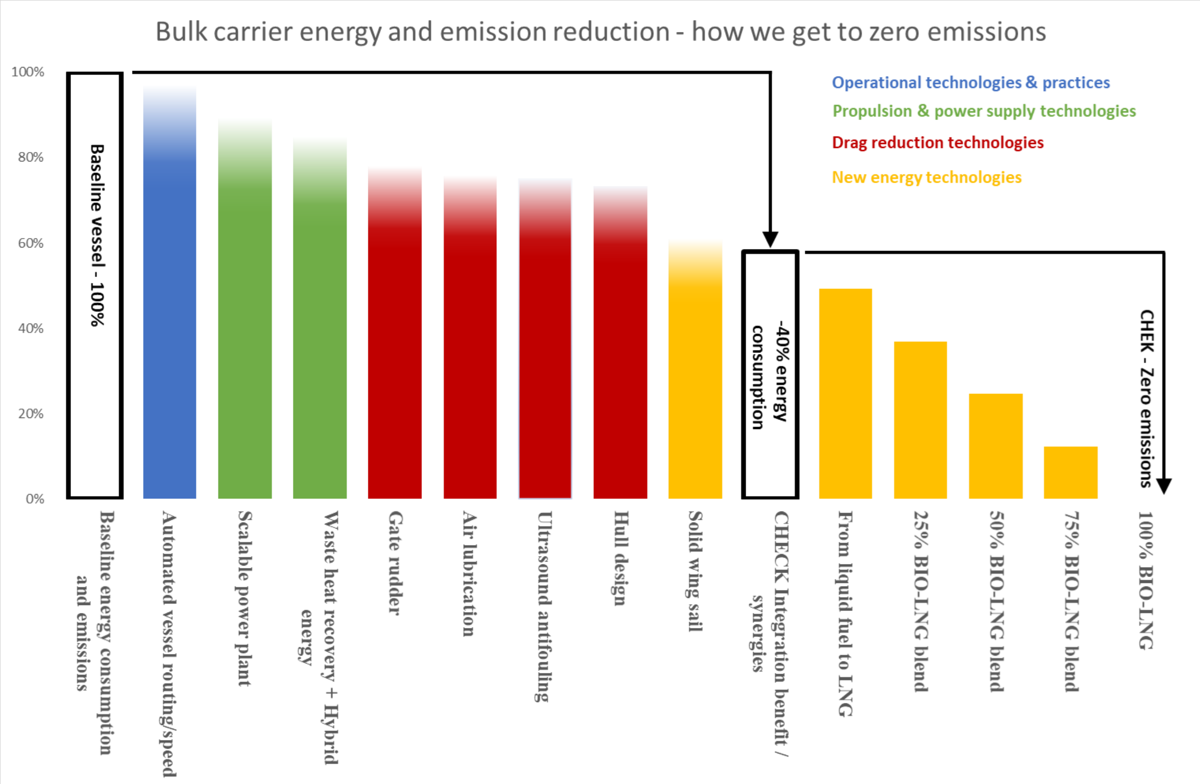


Fig.5: Expected emissions compared to baseline design for bulk carrier

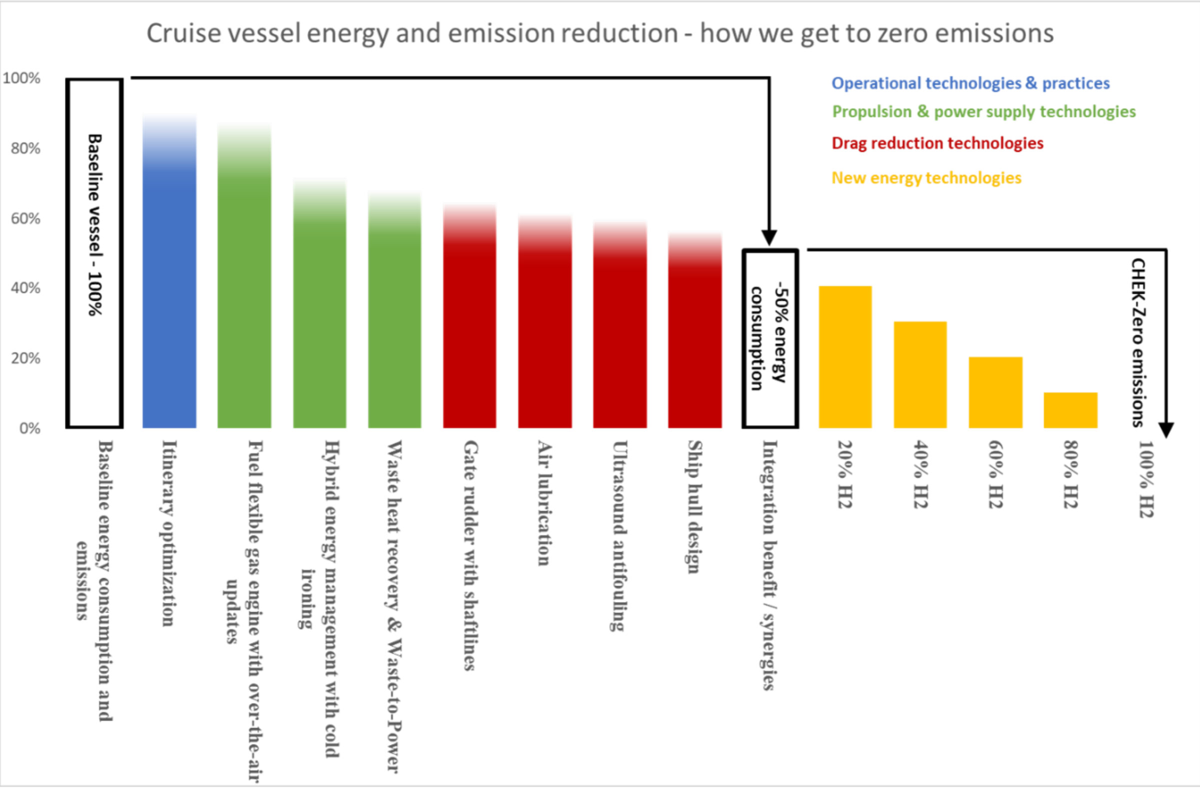


Fig.6: Expected emissions compared to baseline design for cruise vessel

Fig.3 gives the selected measures for the bulk carrier, and Fig.4 for the cruise vessel. Figs.5 and 6 compares the expected CO_2 emissions to a baseline design, where the bars are normalized to 100% for the baseline design, for bulk carrier and cruise vessel, respectively. The selected measures lead to an expected decrease in CO2 emissions of 40% for the bulk carrier and 50% for the cruise vessel.

3. Ultrasonic technology contribution within CHEK

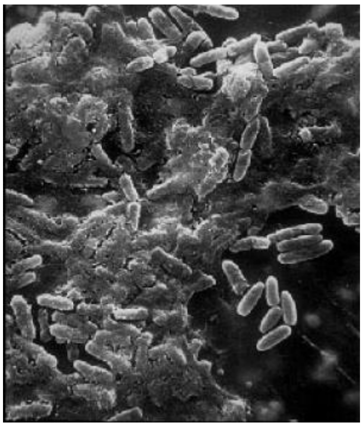
In relation to the AFS convention, *IMO (2001)*, the EU Regulation No. 528/2012 details restrictions on the marketing and use of biocide containing products. As an example, almost no copper-based active substances will get permission to be used in the future. This leaves essentially two options:

- taking the risk of using less effective antifouling systems which leads to higher costs for maintenance and repair as well as to higher fuel expenses
- looking for alternatives to replace the traditionally used antifouling systems

Ultrasonic systems are such an alternative and are increasingly adopted by various segments of shipping. Ideally, such ultrasonic systems inhibit the chain of fouling development at the beginning, namely the biofilm.

3.1. Biofilm

Biofilms are formed when bacteria adhere to a solid surface, Fig.7, and enclose themselves in a sticky polysaccharide. Once this polysaccharide is formed, the bacteria can no longer leave the surface, and when new bacteria are produced, they stay within the polysaccharide layer. This layer (the "biofilm") is highly protective for the organisms within it. In fact, many bacteria may not survive in the environment outside of biofilms. Biofilms are ubiquitous in the environment. They form on our teeth, inside our bodies, in our streams and oceans, on natural surfaces continually wetted by dripping water. They also are formed on ship hulls and inside piping in ships.



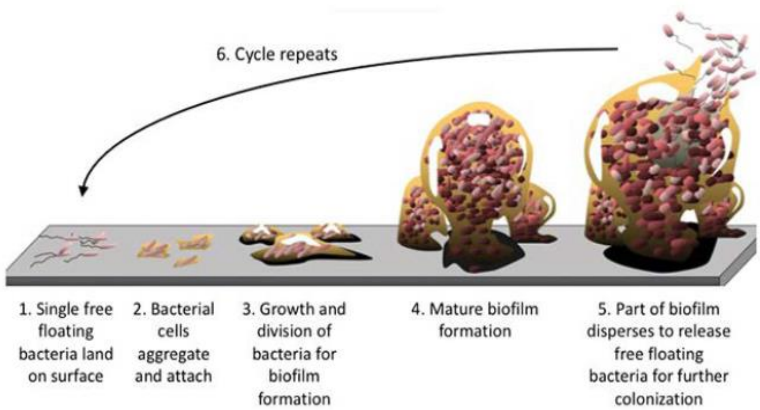


Fig.7: Biofilm under microscope (left) and biofilm growth cycle (right)

In general, while a few fungi can form their own biofilms and a few inhabit bacterial biofilms, the so-called "moulds" generally do not grow in or even on the surface of biofilms. This is because there is generally too much water. Most fungi will not grow under water, and biofilms are almost always under water. Biofilms will not go away on their own, and considerable effort is required to eliminate them.

Biofilms can be scrubbed away or disrupted, e.g. by very hot water, steam, or concentrated oxidizing agents. However, they will return quickly unless the water source is removed. Hence, there are always biofilms present where water is always present.

3.2. Ultrasonic antifouling technology

Older ultrasound methods followed the idea of getting rid of hard growth which had already attached. Using hard cavitation, this might work in certain situations but may also damage the vessel's steel or coating itself. Consequently, this approach was not accepted by the market.

Low-powered ultrasound (avoiding cavitation) destroys the cell structures in biofilm, thus the prerequisite for higher stages of fouling, such as barnacles, shells, and algae. Unlike some coating solutions, ultrasonic antifouling solution are also 100% effective at zero speed, e.g. in longer stays in port or at mooring. Ultrasonic antifouling solutions have enjoyed exponentially growing market acceptance in shipping over the last 5 years. For details, see e.g. *Kelling (2017), Kelling and Mayorga (2020).*

Fig.8. shows the effectiveness for a smaller workboat, *Kelling (2017)*. Within the CHEK project, the effectiveness of large-scale installations for hull and internal equipment of large commercial ships shall be demonstrated.

Fig.8: Tugboat without (top) and with (bottom) ultrasonic antifouling protection

4. Outlook

The CHEK project started in June 2021 and has a planned duration of 36 months. During this time, concept designs will be developed, and performance monitoring will validate expected energy savings of installed devices. Project progress and insight gained, with particular focus on the ultrasonic antifouling technology, will be disseminated in suitable conferences like this one.

Acknowledgements

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Hull Reports at Scale - Notilo Cloud AI Platform

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Abstract

With new regulations to improve ship efficiency and reduce species invasion, the number of underwater hull inspections is expected to increase greatly. But how can we scale them effectively, from in-water inspection to report generation? Notilo Plus has designed a suite of technologies that will enable fast and replicable inspections as well as automatic, consistent report generation. Using AI algorithms for image recognition, it classifies hull images according to their degree of fouling, coating conditions, and generates insights that are compliant with the best standards of the industry. Firstly, designed for the Seasam ROV with localization capability of every image on the General Arrangement plan of the hull, it is now available for all service providers, regardless of their inspection method. Any underwater, diving or ROV video can now be turned into actionable recommendations on Notilo Cloud platform. It opens the door for better hull management, optimized cleaning patterns and predictive models for shipowners and ship managers at a fleet scale, thus facilitating compliance with the strictest regulations. Seasam and Notilo Cloud are now used by shipowners and service providers around the globe, and are selected by DNV on Veracity platform.

1. Introduction

For a ship, hull fouling is responsible of a significatively increased fuel consumption, *Hakim et al. (2017),* and therefore, unnecessary GreenHouse Gases (GHG) emissions. Furthermore, globalization requires transcontinental transportation. Therefore, ships are passing by very different ecosystems, which develops on their hulls an unnatural fouling mixing up living species from incompatible environments. This last phenomenon jeopardizes wildlife in the areas around the cargo ports. Biofouling is therefore a main issue to tackle to reach sustainable maritime transportation, *Davidson et al. (2016)*. In the context of globalization where maritime transportation represents almost 3% of GreenHouse Gases emissions, *IMO (2021)*, in addition of a increasing awareness of ecosystem endangerment, many initiatives have been deployed to tackle these issues and tends toward Green shipping.

2. New standards and regulations

2.1. BIMCO and local regulations

The launching of the new Baltic and International Maritime Council (BIMCO) standards, coming into effect by 2023, intends to make biofouling detection and cleaning mandatory. This knowledge is already required for some countries (especially in Oceania) such as New Zealand whose Ministry of Primary Industries has edited "Guidelines For Diving Service Providers". These guidelines share the same purpose as BIMCO standards, and consequently, we will focus on these standards on the following as they are intended to become the global norm.

BIMCO is the largest international shipping association representing shipowners and is accredited as a Non-Governmental Organisation by the United Nations. To promote greener standards across the shipping industry, and limit the potential damage of hull-related invasive species, the council has created an in-water cleaning industry standard documentation, *BIMCO (2021)*.

This documentation states the need to perform regular inspections of the hulls, also considering aggravating factors which require an increase in inspections frequency (temperature, salinity, distance from the shore, depth, …). In addition, even if the purpose is before everything the cleaning, inspections will always be required. Indeed, despite a cleaning is already scheduled, the documentation indicates that a pre-cleaning inspection is always mandatory in order to identify the areas of the hull where the effort needs to be concentrated.

This report also requires that "during the inspection of the underwater area (hull and niche areas) of the ship, the following shall be ascertained:

- Types of biofoulings.
- Percentage of biofouling coverage for each type.
- Height of biofouling for hard calcareous types.
- Condition of the AntiFouling Systems (AFS) on the hull and reference areas."

These key pieces of information are at the center of latest Notilo Plus developments for our Shipping solution as we will explain it in the following.

2.2. EEXI/CII

The International Maritime Organization (IMO) of the United Nations adopted amendments on MARPOL on June 2021 in order to enforce by 2023 a new regulation centered around two calculations for each ship: Efficiency EXisting ship Index (EEXI) and Carbon Intensity Indicator (CII) in order to cut off GHG shipping emissions.

The EEXI indicator is based on ships specifications, and is estimated from the documentation emitted by the ship manufacturer.

The CII perfectly completes the EEXI as it is an operational carbon emissions indicator. This one will consist of a mark from A to E, with a legal target on the A to C range. It will be based on real emissions measured during the operations performed by the ship. Conforming to the regulation will consequently require an accurate, regular and efficient maintenance of the hull. At the scale of a fleet, it will be a real challenge to rise up for ship owners, and turn-key quick and efficient ship inspections solutions represent a significant asset to prepare for this new regulation, and go beyond the future standards thanks to good practices made easy to implement.

3. Notilo Plus Solution, combining reliable hardware with powerful software

3.1. State of the art

Nowadays, all these inspections are performed by diving teams or Remotely Operated Vehicles. In the first case, it requires a specific organization because of regulatory requirements to ensure a safe diving team in any port. As a consequence, the inspections take more time and human resources, for a result which is not optimized as it consists of generally poor-quality photographs and videos of the hull that are used to interpret a general status. This solution is rather expensive, sometimes complicated to schedule, and requires a long time before the report is ready because all the data collected needs to be processed by experts, but image localization is complicated to pinpoint in post-processing.

The other option, the inspection by a ROV, is quite easier on the supply part (if we consider an easy-to-pilot mini ROV) but faces the same issues on the time it takes to perform the inspection and then to edit the report. Times of 3 h of preparation, 6 h of inspection, and 10 h of post-processing have been reported in personal communication with industry players. In addition, not all the ROVs have a good stabilization system as well as a high definition to ensure enough image quality and hull visibility, so the possibility of post-processing and accurate guidelines is not necessarily satisfying.

Thus, the state-of-the-art is not satisfying at all to answer the growing needs by the main actors of Shipping. The process is tedious, unoptimized and gives poor information about the hull which will hardly encourage the inspections that are perceived today as a painful obligation. Reports are, in the best case, impossible to merge together to extract useful information such as monitoring of change over time, crossing data with other sources, etc. In the worst case, the reports can be inaccurate and partial due to inadequate survey or difficult post-processing.

With the current context in shipping and the pressure to shift towards Green Shipping for the main actors of the sector, inspections will need to scale. The industry could use a more extensive, more reliable and more informative solution.

3.2. Seasam solution: A hardware suite

Notilo Plus was historically specialized in drone conception with first automation features with an autonomous diver tracking system. Building on our ability to develop autonomous inspections scenarios, we started with developing a hardware solution to perform hull inspections easily.

The aim was to provide them with an easy-to-use solution, bringing to the surface reliable and high-quality data: localized images, steady frames, consistent distance to the hull.

To do so, our Seasam solution, Fig.1, is composed of a Seasam drone, a Seasam Navigator, a ground station, a WiFi reel and a touchscreen tablet with our application - Seasam control. It can be used as a Remotely Operated Vehicle after a very short training as the remote control makes it intuitive to pilot. Equipped with a high-definition camera and possibly with powerful lights and extra-sensors (such as acoustic camera), it is the perfect tool to perform inspections on the hull with higher quality data than a diving team, without the danger and for a lower cost . (Pay-as-you-inspect plans are available from 1000€/inspection.)

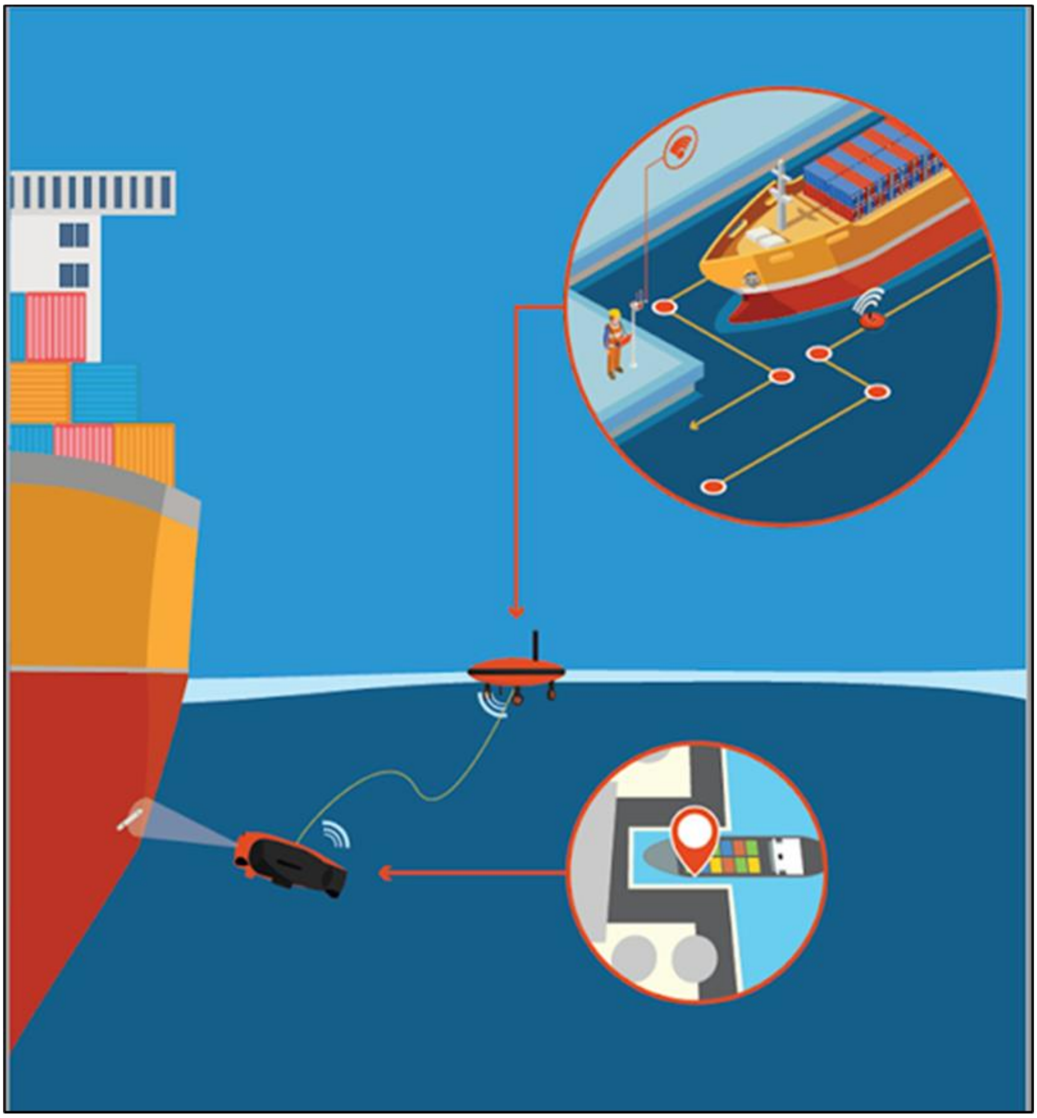

Fig.1: Seasam solution

In addition, using the ground station and Seasam Navigator —equipped with a GPS – allows live autonomous location of the Seasam drone in relation to the hull thanks to an acoustic system. It means that during the inspection, the precise location (accuracy: few meters) of the Seasam drone is recorded and linked to the data acquired on the hull, Fig.2. The correlation of these pieces of data enables a full exploitation that will be described later. Further developments allow us to propose a fully autonomous inspection, based on live location and hull-servoing to ensure the inspection is always optimized.

Fig.2: A suite of hardware, from mini-ROV with localization declaration to autonomous inspection

Fig.3: Inspection with localized images placed on the general arrangement plan of a vessel

With these several options, Seasam is a suite of Hardware that can adapt to the level of simplicity necessary during the inspection, and to the level of precision that is required for the reports.

3.3. Notilo Cloud: The platform to exploit the whole extent of the collected data

Notilo Cloud is the perfect prolongation of the Seasam suite. Designed to valorise the data collected, the videos recorded with the position are easily uploaded to the platform in order to be analysed. Indeed, we built four classifiers trained with a 25000 images dataset enabling us to determine a fouling score for each image, to evaluate the status of the coating, to identify the niche areas and to categorize the images according to their visibility.

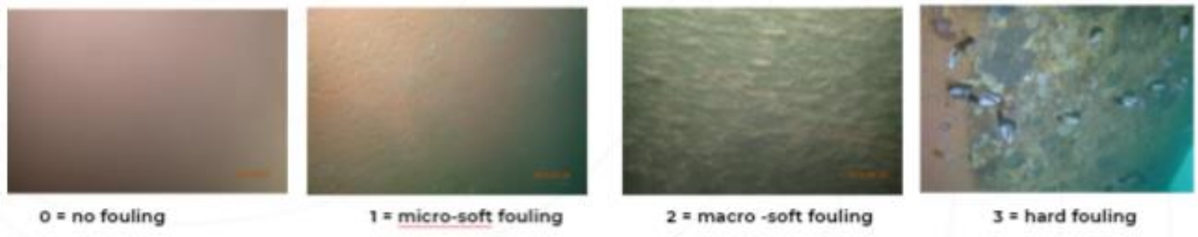

Fig.4: Example of classification for the fouling algorithm

These classifiers are Convolutional Neural Networks for which we used transfer learning: it means that they are pre-trained for classification tasks, and we added a few layers called the "Head" at the exit to adapt it to our specific problems. The whole network has then been trained again with our datasets in order to adjust the weights and to gain in accuracy. This design allows an accuracy of 90% for coating status, Fig.5 (left), 90% for visibility evaluation, Fig.5 (right) and 97% for niche areas identification, Fig.6.

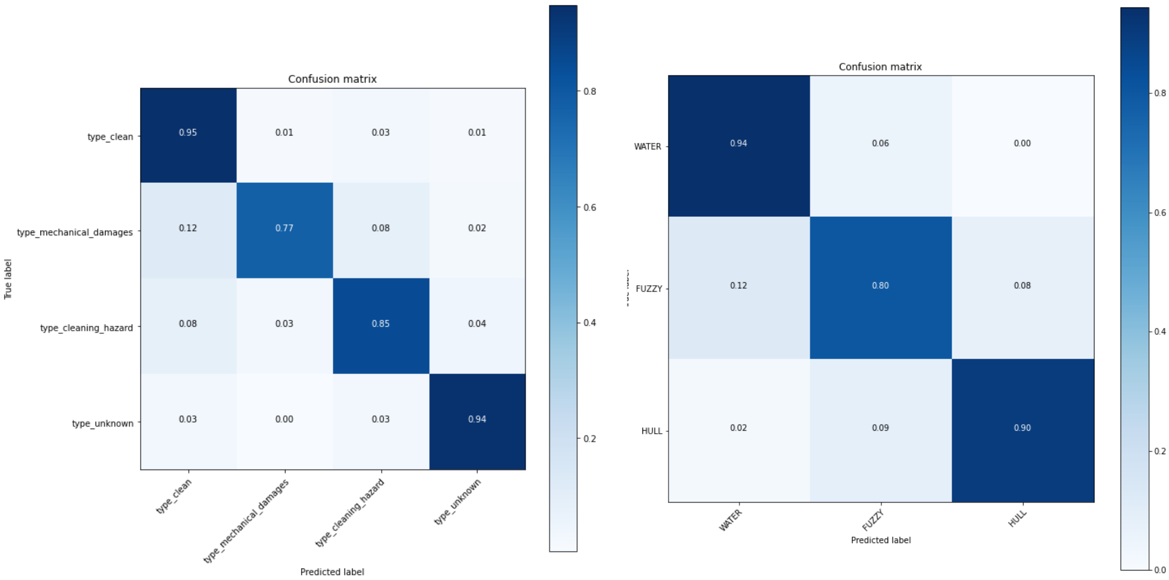

Fig.5: Neural net accuracy for coating status (left) and visibility evaluation (right)

Fig.6: Neural net accuracy for niche area identification

Concerning fouling, the accuracy is limited to 83% but the mistakes are concentrated on neighbouring scores, Fig.7. After further review, we detected that 56% of these mistakes were due to human scoring in the first place as the experts we integrated in our initial qualification process showed a lack of consensus on the concerned frames.

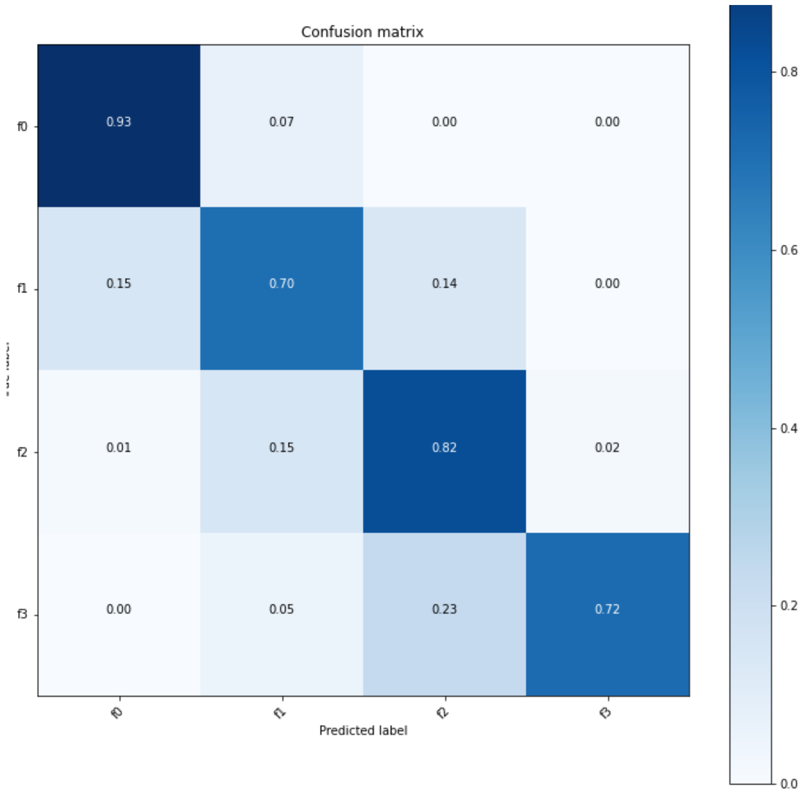

Fig.7: Mistakes concentrate on neighbouring scores

At the end of inspections, the users upload their videos on Notilo Cloud. In the software are several actions available:

- store all previous dives
- create a report
- share with relevant partners or customers.

The report generation consists in itself in several tasks and <u>four different algorithms</u>:

- Extract relevant frames from all inspection videos, with a visibility algorithm. Only images actually showing the hull will be selected. After the frame extraction, a preprocessing algo-rithm adapts the format of the data to make it compatible with the other classifiers.
- Render more precisely if the frame consists in a niche area, and in that case, which niche area
- Evaluate for each frame the level of fouling from 0 to 3
- Determine if any coating defect is present: painting defect or mechanical damage
- Link each frame to the corresponding location on the hull out of the raw dive data

All these actions lead to the creation of a report, with 30 hull sections that have color and information on the status of each area, Fig.8.

This automatic evaluation enables us to better understand the status of the hull after inspection, to identify the areas to prioritize during the next cleaning operation and to save much time because there is no requirement for an expert analysis of the video as the results of our algorithms have already been validated by experts. This first step permits the automatic edition of an inspection report in less than

30 minutes - compared to 10 hours for traditional reports - which is far quicker, more cost-effective, and more efficient than traditional inspection.

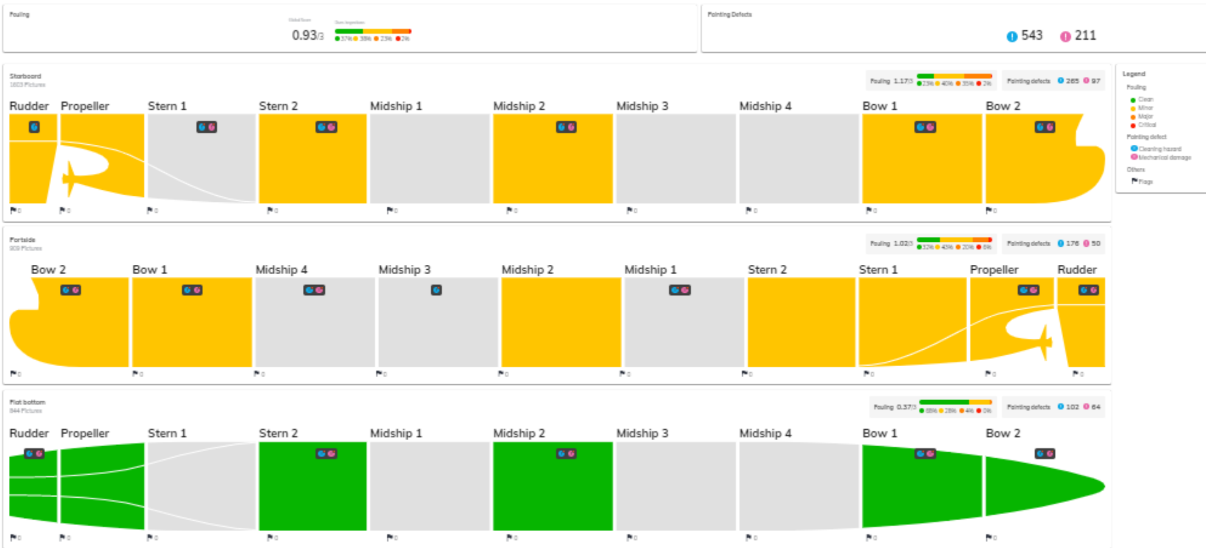

Fig.8: Example of report with various hull section inspected and degree of fouling/ number of coating defects

3.4. Notilo Cloud for any ROV source: opening data for all

Furthermore, in order to democratize the predictive maintenance of hulls and the understanding of underwater assets, Notilo Plus has opened a stand-alone version of Notilo Cloud for any ROV, Fig.9. It opens the use of our algorithms and autonomous report tool to anyone who performs underwater inspections with any underwater camera (GoPro, ROV, …). The main difference resides in the need to declare directly on the platform the location of the different images. Classification and filtering of all images is possible to have a closer look to all relevant frames of the video.

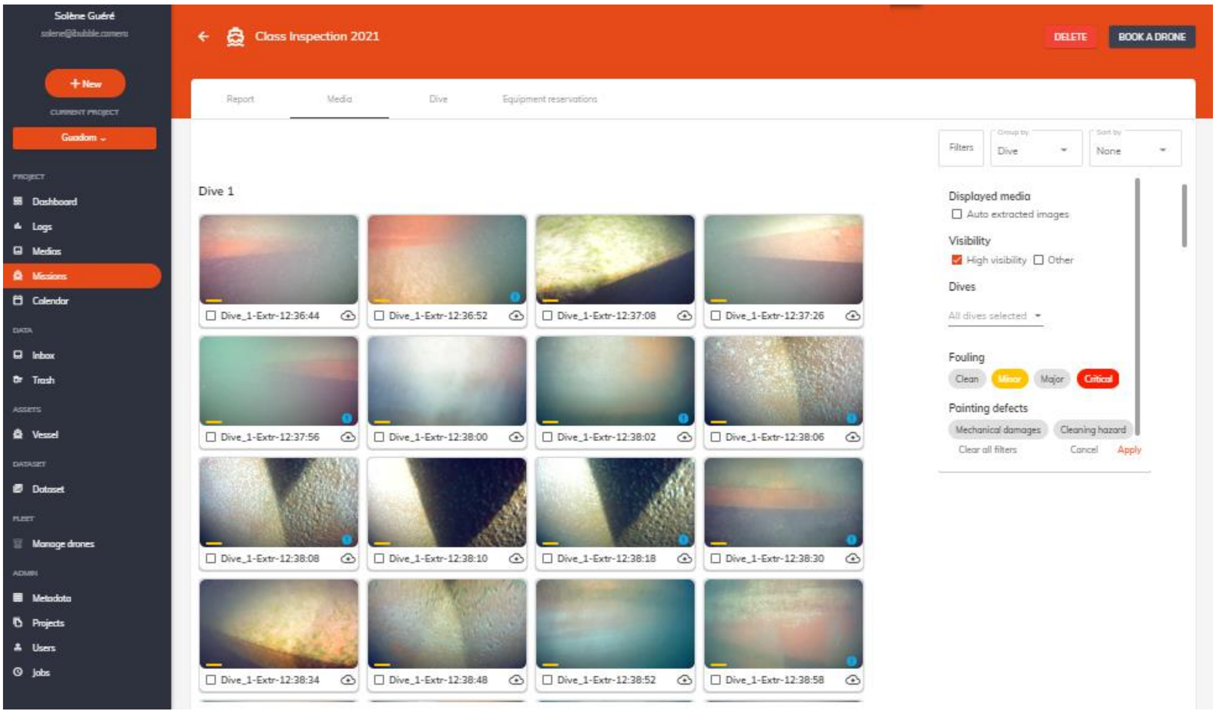

Fig.9: Notilo Cloud

4. Discussion

Currently, our solution appears as a great help for CII as it helps to understand the origin of any problem on the actual carbon consumption of the ships. Indeed, by indicating an overall fouling status of the hull to the Ship Owners, Notilo Cloud helps them to optimize their cleaning operations in order to keep the carbon (and GHG in general) emissions of their ships under control.

Our fouling algorithm is not yet fully compliant with BIMCO standards or other regulations for invasive species control. BIMCO standards differentiate many types of fouling and various types of coverage, Table I.

Table I: Fouling types according to BIMCO

Soft biofouling		**Hard calcareous biofouling**
Micro	**Macro**	**Macro**
Slime	Soft corals	Barnacles
	Sponges	Mussels
	Hydroids	Tube wroms
	Anemones	Bryozoa
	Algae	Oysters
	Tunicates	

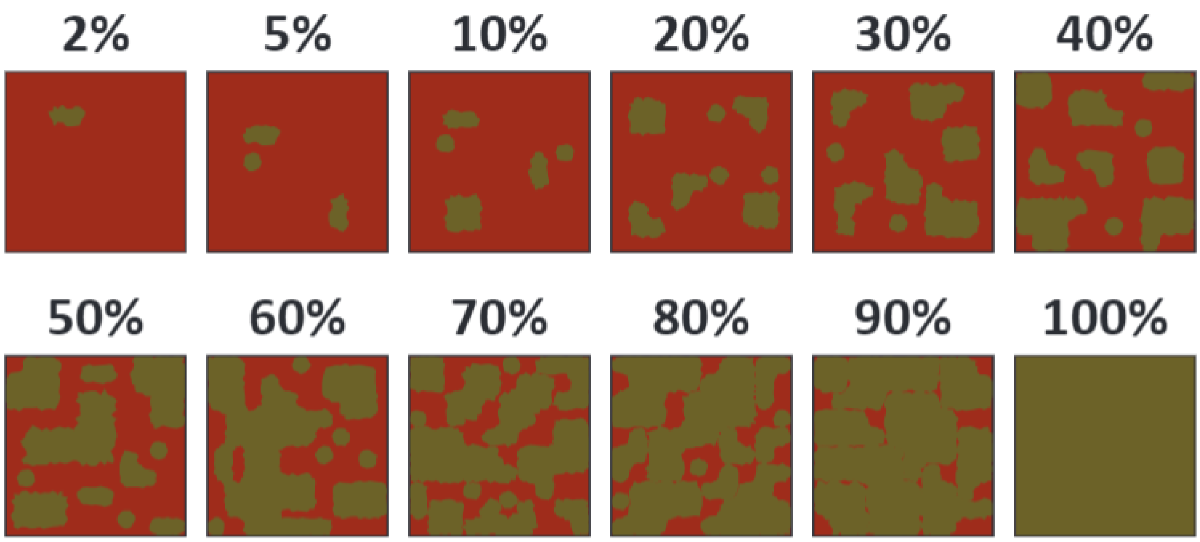

Fig.10: Coverage

We have found it difficult to find experts able to converge in their classification of images between various types of macro soft fouling and macro hard fouling. The experts had often diverging opinions on classification.

We found that, for now the type classification (hard or soft, micro or macro) was sufficient, from an operational point of view, to plan maintenance and cleaning action. We recommend that these official classifications should not be overly precise, to account for the actual capabilities of experts to differentiate between fouling types. Alternatively, a new and more complete dataset labeled by experts should allow us to tackle this challenge.

The coverage of fouling in BIMCO standards is a way of classifying images from a human eye perspective: i.e. looking at a frame, how scattered the fouling zones are, Fig.10. From an A.I. perspective, and with the possibility of extensive classification of each and every image from a video inspection, it becomes more relevant to use broader information, such as the actual severity of fouling depending on the frames.

We propose that international standards for underwater inspections use more precise, AI driven framework for underwater hull inspections.

5. Conclusion

Notilo Cloud has been designed to fit with emerging regulations. It has already been identified by many majors in the sector as a high-end tool to exploit the full extent of all the data that can be collected during inspections. Moreover, combined with the Seasam solution, it offers a turn-key solution for underwater hull inspection. Seasam solution is making possible quick, optimized, easy to set up inspections, at lower cost than traditional inspection solutions. All these features make Notilo Plus' ecosystem a key set of tools to tend toward Green Shipping through predictive maintenance. In other words, to make a step towards a sustainable activity while making savings.

As a versatile tool, that can be used anywhere in the world, from any data source, Notilo Cloud makes possible intensive hull monitoring and management, bringing together all data sources and creating predictive models for hull efficiency.

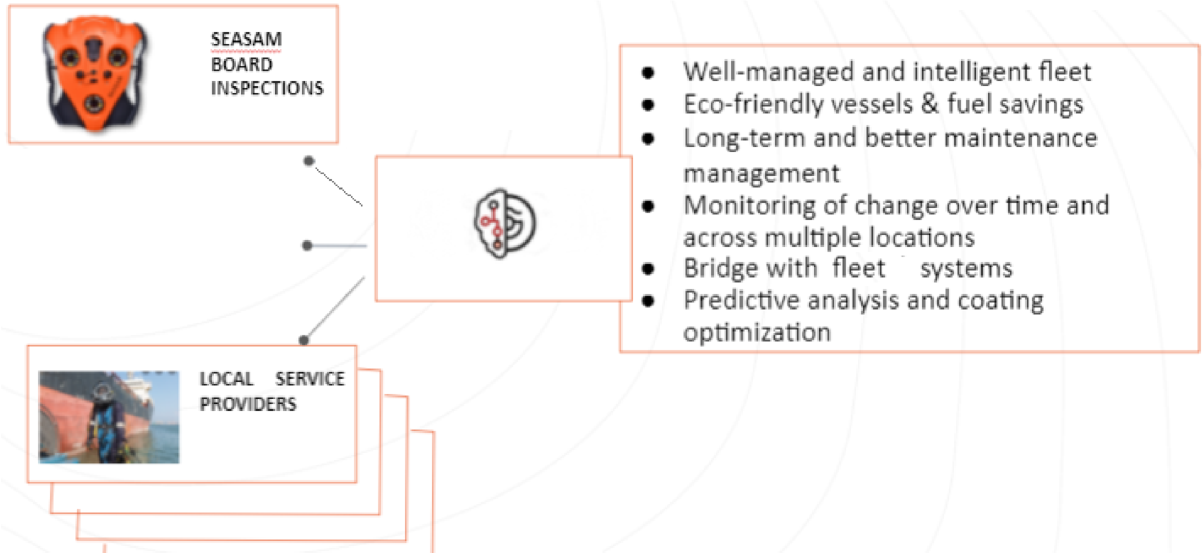

Fig.11: A vision for integrated hull management

The scoring of 83% to 97% accuracy of our algorithm will continue to improve as the number of inspections increase, and we foresee a future where inspectors will never have to spend more than 1 hour to produce a full hull inspection report, with a greater accuracy than any previous method. This opens the door to efficiently scaling hull inspections, and better protecting our planet and our oceans.

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End-to-End Biofouling Management

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Abstract

Managing biofouling on ships used to be about outrunning your enemy, then it was about fuel efficiency and now we also are interested in caring for the ecological health of our oceans, wanting to limit the spread of invasive marine species. To achieve this, we have developed an ever-increasing selection of tools, systems, regulations, and procedures. Administering and managing all the relationships needed to clean a vessel hull has become challenging. It is complicated. There are lots of moving parts. This paper describes how using block chain technology can help administer management of biofouling on underwater assets more efficiently. And, eventually, will result in automating the entire process.

1. Context

Across the world we are working to reduce the environmental impact of invasive marine species. Governments are creating legislation and regulations designed to protect their ecological and commercial assets. This has resulted in varied regulations across the globe, increasing the difficulty for compliance within the global shipping industry.

The industry is coming under increasing pressure to evidence continual improvement with respect to biosecurity efforts. Achieving a high standard of compliance is a challenge, largely inflated by the complex administrative efforts required to coordinate technology and personnel with regulatory requirements within a commercially constrained window of time. It is almost impossible to optimize all these moving parts without help.

2. The Challenge – Stakeholder complexity and lacking alignment

People have different approaches to meeting the challenges we face. We are innovators, inventors and businesspeople. The diversity of solutions tabled here at this conference, and more broadly, represents an increasingly resilient industry. Working together across this landscape of diversity presents a significant challenge.

As highlighted by *Jones (2020)*: "While making the technologies work together is a challenge, the bigger challenge is getting the various actors in the biofouling arena to work together."

One of the first steps in working together is to understand what other people want to achieve:

Regulators:	how can we reduce our risk assessment efforts, whilst increasing the trust we can put in the compliance evidence we receive?
Vessel operators:	how can we best organize end-to-end biofouling management across the full life cycle of our vessel, mitigating our risk of port access denial, and optimization our operational performance?
Service providers:	how can we grow our business by increasing the quality of our outputs, improve our delivery productivity, and provide new services to customers?
Everyone:	how can we reduce the inefficiencies at the interfaces between organizations, and get more value from information we create?

3. What is a blockchain application?

Blockchain is most often associated with crypto currency, however, given its security and transparency when it comes storing data, blockchain has many other applications.

In simpler terms, blockchain is a collection of information that is stored electronically on computers. Blockchain collects information and piles it together in groups also known as blocks. These blocks all hold a set amount of information and are limited in the amount of data they can hold. When a block reaches its maximum capacity, a new block is formed and attached to the previous one, creating a chain.

The structural gathering of data in blocks is irreversible and is given a timestamp when it is added to the chain. This technology can support complex administrative interactions in a transparent and verifiable manner. A smart contract.

4. Enabling technologies

There are many examples of enabling technology in today's world. The internet gave rise to email which allowed for a massive productivity increase. Likewise, blockchain technology is giving rise to smart contracts, forever changing the way we trade value and store information between individuals and collectives.

Blockchain enabled software, paired with machine learning algorithms can allow for gradual automation of complex commercial arrangements.

Underwater asset management, inclusive of biosecurity, within the shipping industry is about minimizing lost time which is critical to maintaining profit margins. Given the complexity of contracting, reviewing, reporting and administrating a hull cleaning operation, it is difficult to optimize this process to minimize lost time.

By utilizing an administration system founded in blockchain technology, patterns of interaction between companies and individuals can become automated over time. This allows machine learning algorithms to preemptively suggest the most time efficient course of action to take to enable hull cleaning and thereby provide smooth entry into ports around the world, by providing evidence to demonstrate compliance with local biosecurity regulations.

Today, most technology trends are pointing towards a distributed future and multi-party systems. Tech Vision 2021, *Accenture (2021)*, highlighted a key trend to shift "From Me to We. Multiparty Systems share data between individuals and organizations in a way that drives efficiency and builds new business and revenue models. They include blockchain, distributed ledger, distributed database, tokenization and a variety of other technologies and capabilities."

Can blockchain technology enable a decentralized administrative model for the effective and efficient implementation of IMO Biofouling Guidelines globally?

We have developed software a Rise-X to do just this.

5. Rise-X – Where are we now

We have developed a proof-of-concept underwater asset management software platform that allows for multiparty, real time interaction. We have begun testing with early adopters, including Australian ports and commercial ships.

Every step in the process of cleaning hulls for biosecurity (tendering, contracting, inspection work, cleaning, calibration of tools, re inspection and reporting) is captured and timestamped in a blockchain system. This gives transparency of where the process is at, who completed the previous action and who is responsible for the next action.

Using the working environment that BioPass offers, we have connected to a Deep Trekker ROV and can provide secure, real time streaming of video anywhere in the world, enabling multiparty collaboration on a job. Invasive marine species inspectors no longer need to be on the vessel or quay side.

Once inspection is completed the software can automatically generate reports and invite interested parties (regulators, clients, asset owners) to the platform as required. Evidence that supports the summary report is available for review, ensuring a tamper proof system. This removes much of the administrative burden associated with hull cleans and subsequent inspection work.

As the system collects user data, patterns of behavior begin to emerge. This allows machine learning algorithms to begin to anticipate user needs and automate contracting, engagement, reporting and administration process, allowing smooth transit from port to port.

Pairing this system with automated hull cleaning robots will provide the foundation for fully autonomous hull maintenance and reporting. Minimizing lost time and removing time spent in administration.

Today is the first of many steps that will lead our industry towards autonomously executed best practice.

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RAGS - Robotic Applications for Grooming and (In-Water) Survey

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Abstract

This paper describes the purpose behind the development of a robotic hull grooming and under water inspection, energy saving device, providing proactive cleaning at the micro fouling stages and continuous monitoring of the biosecurity status and structural condition of the asset.

1. Introduction

As we envision emission credit system(s) materialising, in shipping – further enforcing the implementation of the new greenhouse gas (GHG) regulations from the International Maritime Organization (IMO), from 2023; we anticipate that the Carbon Intensity Index (CII) of an asset, shall be heavily scrutinized - through the industry's financial and commercial channels and a culture shift, now long due, is gaining momentum, embracing the entire value chain of sea transport, towards optimised and environmentally incentivised 'carbon performance' oriented - ship management.

From the dawn of the industrial revolution, we have been polluting the atmosphere, however it took the world until 1983 to agree and ratify, a regulatory framework (MARPOL) to address maritime pollution and it was not until 2013 - that the importance of ship specific performance, was placed on the table under a microscope and its management made mandatory.

Now forty (40) years since MARPOL was ratified, a wave of industry initiatives has come to support a cleaner world of shipping, with the dawn and implementation of the:

- IMO GHG regulations;
- Fuel Oil Data Collection System (DCS) for international shipping, requiring ships of 5,000 gross tonnage or above to start collecting and reporting data to an IMO database from 2019;
- EU Monitoring Reporting and Verification (MRV), as a first step towards cutting greenhouse gas emissions from maritime transport, the EU requires operators of ships exceeding 5,000 GT to monitor and report their carbon emissions and transport work on all voyages to, from and between EU ports;
- UK Monitoring Reporting and Verification (MRV), since Brexit - UK secretary of state, came up with its own MRV system which amends the legislation relating to monitoring and reporting of carbon dioxide emissions from maritime transport, with the first monitoring period starting on 1st January 2021.
- Poseidon Principles, a framework for Banks/Financial institutions to use their influence as a major capital provider to the shipping industry in order to support the objective of IMO GHG reduction;
- Sea Cargo Charter, a framework for Charterers to use their influence as cargo providers in the shipping industry to support the objective of IMO GHG reduction;
- and the long-awaited advances in Bio Security regulation, in the dawn of the international BioPass[port] concept, spined off IMO's GloFouling initiative.

Contrary to the Energy Efficiency Existing Ship Index (EEXI) indicator, which does not include any aspect of operational emission reductions, Owners and/or Charterers will be required to refere to their emissions - to demonstrate continuous improvement in operational emission reductions, with respect to the asset's Carbon Intensity Index (CII) performance level.

As the Propulsion Power Increase (PPI) on account of biofouling development, deteriorates the asset's CII with every passing month and contributes to additional fuel and excessive emissions levels - to maintain the vessel's commercial speed – it is apparent that operating at PPI levels of ~20% ie. at the heavy slime layer, as per IMO's MEPC 60/4/21 - is evidence of environmentally 'criminal' ship management - on account of the carbon cost(s) associated with (a) reaching such levels and goodness forbid (b) to continue to operate the asset at this carbon intensity.

We believe that traditional Ship Energy Efficiency Management Plan (SEEMP) 'thresholds' – which previously defined the manager's culture of cost analyzing the vessel's performance, effectively by 'waiting' for the "break even" between - the monetary savings received by an hull maintenance, at defined level(s) of PPI and the associated fuel cost of poor performance, typically in the range of ~15% of PPI is an operational measure of the past, primitive at its best and this traditional process of 'waiting for the break-even', shall be disrupted. By documenting the operational CII, the industry shall shift, towards adopting continuous 'grooming' as the most attractive operational measure – a measure that shall ultimately be provided on time, as a Port service to the asset.

We envision the operational measure of grooming will be embraced by the industry, through ship and shore collectively and eventually, be widely provided as a port service and as an integrated ship system. Robotic grooming applications offering superior hull performance, shall be the new norm. A norm that will change how the industry builds, plans, operates, and manages vessels in every segment and commercial orientation, that will drive 'new commercial' arrangements between all stakeholders that will bridge the relationship and responsibility, between the port facilities and the commercial & technical managers, of the physical asset.

The principles built around these 'new commercial' relationships, will be driven by the desire of all stakeholders to elevate their environmental and social governance, in the ship-cargo transport value chain and will involve the port, owner and charterer responsibility to optimise the carbon intensity of their operations.

2. Hull-grooming as an answer

The benefits of hull grooming are significant, from both an environmental and financial perspective and have long been documented and most importantly, the technology level has now matured, to provide the solution. A twofold solution in the form of an Energy Saving Device (ESD) (i) maintaining the asset's CII and of course (ii) provide superior commercial competitiveness – one that is able to 'Attract the Charter' – a significant advantage, where the true return on investment (ROI) in such technology can be appreciated, by the interested parties.

2.1. The Advantage of hull grooming over cleaning

'Actual AF Coating performance' for the benefit of analysis, is related to the performance of a coating system, with respect to the actual operating profile and applied biofouling pressure the system was subjected to, for the duration of the drydock cycle – managed by a common SEEMP. The reality of the commercial implications and technical challenges in the compliance to a SEEMP application, are therefore benchmarked and may equally be analysed per AF system type.

'Actual AF coating + cleaning' Vs 'Actual AF coating + grooming' performance analysis was completed, for two Capesize vessel type. The assumptions taken to allow the study have been weighted in accordance with the technical and operational specification(s) in Table I and their actual PPI profiles – as those have developed, on account of each operating profile.

The weighted propulsion power increase(s) through time for an actual dry dock cycle, are demonstrated below in Fig.1.

Table I: Indicative Operating Profiles (top) and FOC (bottom) of two Capesize

Ship :	A	B	Average
Ballast	19%	30%	24%
Laden	46%	40%	43%

Ship :	A	B	Average	
Ballast DFOC, mt :	37.9	37.8	37.9	*@13.0kts, 4BF*
Laden* DFOC, mt :	46.0	41.3	43.7	*@12.5kts, 4BF*
Forecasted WA PPI :	8.5%	9.5%	9.0%	
Paint Maker:	Same			
AF System :	Biocidal (Conventional SPC)	Biocidal (Conventional SPC)		
AF Grade :	Medium	Basic		
Type :	Capesize	Capesize		
DWT :	180.184	179.599		
Delivery :	2006	2009		
Yard :	IMABARI	DMHI		

*Laden: *[A] Design Condition (Tm = 18.2 m), Displ. Vol= 197.171 m3*

[B] Design Condition (Tm = 16.5 m) Displ. Vol= 179.685 m3

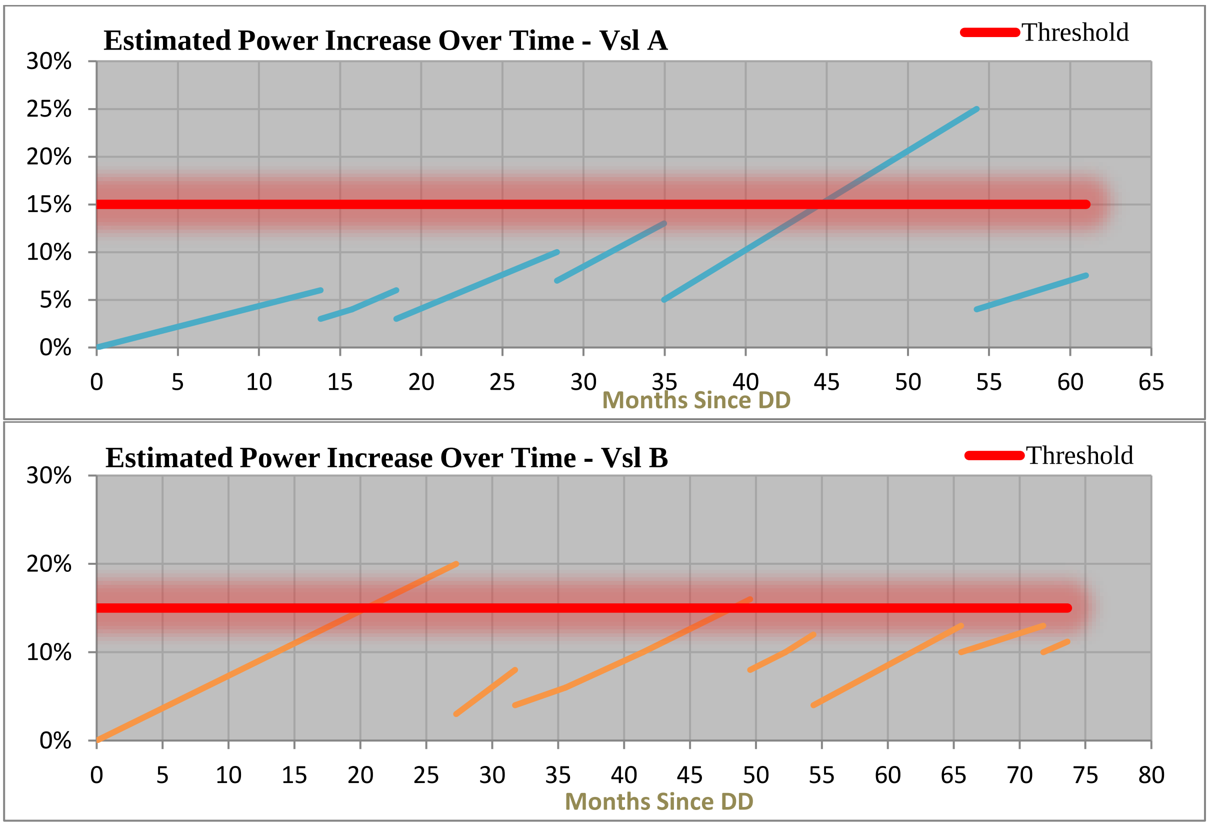

Fig.1: Developed Propulsion Power Increase through time, for two Capsize

The Weighted Propulsion Power Increase (WPPI) for the actual 'averaged' AF coating system's performance, has been derived at 8.5% for vessel A and 9.5% for vessel B ie. both scored equivalent to basic coating systems. These results average 9.0% and this average WPPI value has been used to identify the benefit, of continuous grooming, with the ESD; while a database of existing fleet of vessel's has been similarly analysed to consolidate the WPPI per Actual AF coating system performance(s).

Table II: Consolidated Actual AF coating system performance and Averaged DFOC used for analysis

WPPI **ESD**:		3.3%		
WPPI State of the Art:		6.4%		
WPPI **High**:		7.3%		
WPPI **Medium**:		8.1%		
WPPI Basic:		8.7%	9.0%	Averaged*
Fuel Price, U$:		300		
DD Cycle, yrs:		5.0		
	Speed (knots)	DFOC (MT)	Activity	
Ballast	13.0	37.9	24%	
Laden	12.5	43.7	43%	
		Total	**68%**	

AF System Type	Averaged*	**ESD**	Units
Add. Fuel Cost	1,369.0	496.4	K U$
AF System Cost	105.8	73.4	K U$
UW Cost	68.0	14.0	K U$
Excess CO_2 Emissions	14,212.4	5,153.8	MT of CO_2
Grand Total	**1,542.9**	**583.8**	K U$
Savings, U$	*Baseline*	**959.1**	K U$
Savings, CO_2	*Baseline*	**9,058.6**	MT of CO_2
OPEX	**24.0**	**8.5**	K U$/month

Thus, an excess of $870.000 and more than 9.000 MT of CO_2 can be saved in fuel cost and emissions, respectively in the Dry Dock Cycle - with the installation of the continuous grooming ESD, against actual Averaged AF Coating system and more than a 60% reduction in the OPEX can be realised.

2.2. Attracting the Charter

In a nutshell, with the installation of such an ESD the typical management of the Charter Party (C/P) warranty speed and respective Fuel Oil Consumption (FOC) table is disrupted. The device's deliverables, provide for a competitive advantage to the interested parties - on the offered C/P FOC warranties, as these can be improved/reduced by an average of ~5% - significantly contributing to the Chartering department's attractiveness, in the offered asset's market, by integrating grooming ESDs - demonstrating their Environmental Social Governance (ESG) and effectively preparing their fleet - to navigate the uncertainties approaching their bow.

As attractive asset Speed Consumption Tables are critical in the negotiation(s) leading to a Charter fix, the technical management is expected to ensure their prevailing Ship Energy Efficiency Management Plan (SEEMP), shall maintain the asset's performance within the defined Daily Fuel Oil Consumption (DFOC) rates, throughout the duration of the C/P contract to safeguard against any speed performance Claims. The commercial teams, on the other hand, need to have the most competitive DFOC tables, to differentiate the asset and attract the C/P.

The ship manager's job is difficult in this respect. Primarily because of how C/P Speed Consumption Tables are being compromised by significant biofouling pressure levels above those anticipated and the commercial and regulatory restrictions, preventing scheduled hull maintenance during the C/P – while typical C/P Clauses still do not provide nor afford adequate support to the managers or more importantly address the importance of collectively sharing the responsibility, between interested parties, to maintain the asset's warranted energy efficiency, throughout the C/P.

Until such Clauses are introduced in the C/P, that shall provide a shift in the paradigm - which shall align with the EU ETS recent concept, with respect to: a "'company' means the shipowner or any other organisation or person such as the manager or the bareboat charterer [.. and we add "and time charterer], which has assumed the responsibility for the operation of the ship from the shipowner and has agreed to take over all the duties and responsibilities imposed" by the prevailing environmental regulations; the shipowner is still very much, left alone to address the root cause of rising carbon intensity index levels of the asset, during the C/P.

It is our position, that each party involved in the asset's utilisation, must come forward and play their part, to support the actions necessary to maintain the asset's carbon footprint, at the design level, to the extent possible.

Until then, as in the design stages of Ship building - where warranted speed vs power is ultimately required to be demonstrated through speed trials, after applying the 'sea margin' on the trial results; the technical management typically and quite similarly, provides his own 'safety margin' between the clean hull baseline performance level(s) and the weighted performance of the asset, anticipated during the CP - to ensure their SEEMP shall maintain the vessel's warranted performance.

This 'safety margin' is the heart of the matter, where 'attracting the charter' is played out and the introduction of robotic grooming technology shall support and reward the innovator, disrupting the norm – drastically reducing the boundaries of the 'safety margins' on the C/P warranted DFOC tables, so as to offer the most competitive Speed Consumption(s) per asset for charter.

Utilising telemetry data one may evaluate and present the calculated Laden DFOC tables per weather state for a clean–hull condition | Safety Margin = 0, as per Fig.2, straight after dry dock.

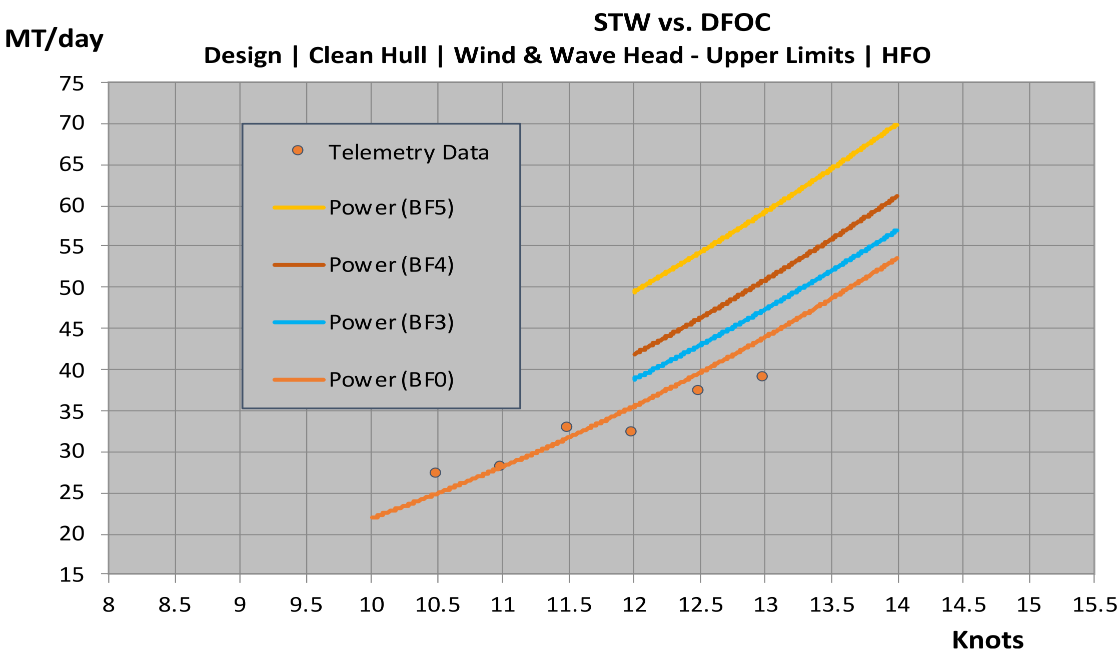

Fig.2: DFOC Table per sea state; as derived from telemetry data, for an asset straight out of dry dock

From the eyes of the shipowner, a ‘prudent’ C/P warranted performance, should provide for the anticipated deterioration of the hull’s performance and respective Propulsion Power Increase (PPI), on account of the biofouling pressure her actual operating profile shall create and associated AF system’s degradation, during service.

Considering a traditional SEEMP approach, a reactive hull scrub action would be triggered on about the ~15% PPI threshold. In this respect, a typical ‘safety margin’ in the weighted magnitude of ~7% PPI, would be required to ensure continuous performance with in the warranted DFOC tables - allowing preventive hull maintenance action(s) to be performed in a timely manner, for the duration of the C/P, to maintain the warranted performance.

This traditional approach generates DFOC table(s) for each weather state, as derived from telemetry or manual - trial data, from a freshly launched hull. A typical CP warranted performance DFOC has been overlaid, to illustrate the industry norm, which sets the CP boundaries along the particular Power (C/P) curve, for a BF4 sea state plus ‘safety margin’ - as illustrated through Fig.3.

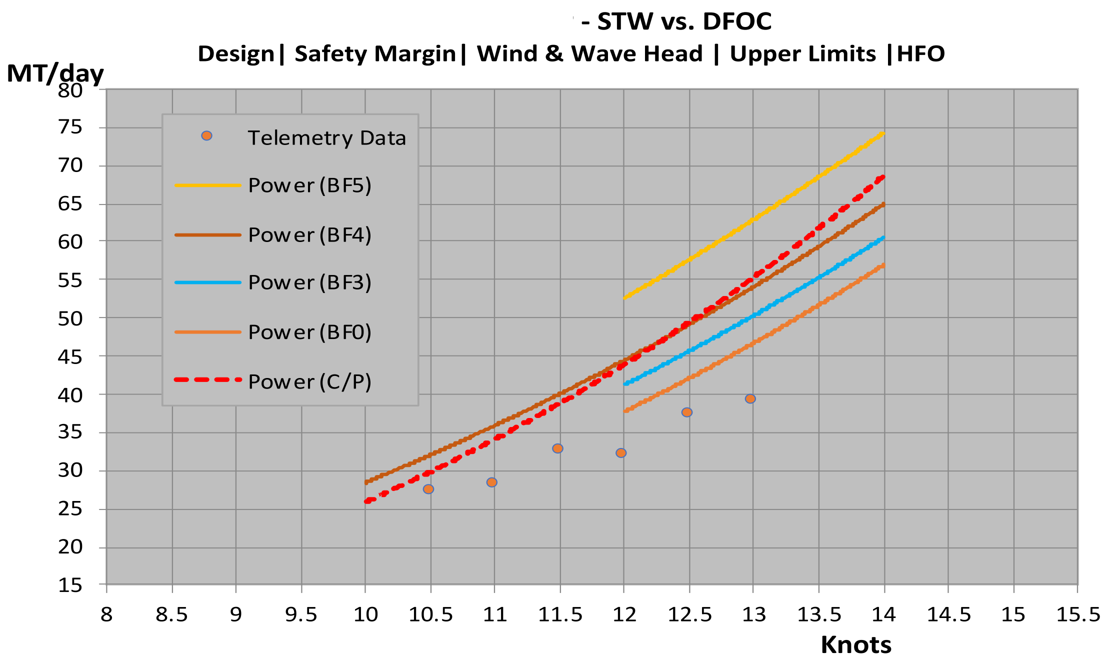

Fig.3: Graphical representation of the application of the ‘safety margin’ on the C/P DFOC table

The following results have been derived, illustrating the respective C/P DFOC table(s) that may be offered for charter, for the following cases: (a) without the employment of the ESD – utilising the ‘safety margin’ approach and (b) with the ESD installed.

Table III: Indicative competitive gain with the employment of the ESD in ‘Attracting the Charter’

STW	C/P DFOC with Safety Margin	C/P DFOC with **ESD** installed	Δ%
10	25.7	26.7	-4%
11	34.2	33.8	1%
12	44.9	41.8	7%
12.5	49.2	46.3	6%
13	54.6	50.9	7%

With the installation of the ESD the typical management of the C/P warranty speed and consumption table(s) is disrupted. The device’s deliverables, provide for a superior competitive advantage to the offered C/P warranties, that can be improved/reduced by an average of ~5%, significantly contributing to the Chartering department's attractiveness in the offered asset's market.

3. Hull Grooming In-Port

The current industry 'practice' for hull maintenance is daunted, primarily by the far lagging - long overdue and deeply fragmented - yet escalating bio security issues associated with biofouling management, health and safety associated with the manual labor and beyond these – a 'practice' that ultimately requires the alignment of the asset's commercial window, local regulatory permission and service availability - to allow the asset to be taken out of service for an ROV and/or manual labor, to address cleaning.

But wishing on a star, to align the commercial and geo-regulatory requirements to successfully complete a scrub, is a traditional energy management system far outdated, to address CII. To reach the typical SEEMP threshold level for cleaning, is to blatantly pollute the environment, beyond the asset's EEXI. Operating beyond the EEXI may currently not be treated, as criminal – however – considering that the most appropriate and immediate operational measure that shall allow vessels, to continuously operate within their design carbon intensity is continuous grooming, at the micro fouling stages; it does seem criminal, that the Port(s) are not required to provide such a grooming service, as a mandatory port service – a service required to have been completed - for the commercial permit to sail the port, to be issued.

BIMCO's concentrated effort to standardize capture as a means to address hull performance, is wrong – for capture, only addresses an acceptable operation, for a niche area of the industry; that of managing Layups being brought into service. BIMCO's efforts focusing on standardizing capture systems, threatens to normalize our industry, against the required path - allowing responsible parties to stretch the envelope of SEEMP's acceptable PPI, blatantly, currently legally – catering for an industry to consider that it is acceptable, to continue to operate their asset beyond the design Carbon Intensity.

It is without a shadow of a doubt that Vessels during service should be groomed, period and it is the ports they visit - that should assist the industry and be required to provide the service, period. Only layups, are to be allowed to be scrubbed, by capture – period, period.

As such, the Geopolitical Bio Regulatory framework has to shift. The Port/Terminal must become an active member and accept its responsibility to support the industry's effort to maintain the maritime CII at the asset design level.

Within our venture, we aim to educate our domestic Port authorities, by providing the means for grooming as a Port service. But the path is not laid with roses and though the maritime industry is not renowned for its swift embrace of innovation; we seek to educate the shipowner first and provide our grooming Energy Saving Device as an integral part of the ship, to permit her compliment to carry out autonomous grooming at sea - until the shore and port facilities have picked up their socks and undertaken their responsibility to support the industry and cater for these needs, across the market and for all whom visit, the sea and shore facilities, within their jurisdiction.

We embrace the Global Industry Alliance (GIA) for Marine Biosafety, established by the IMO and its GloFouling Partnerships Project as an alliance of leaders from the private sector representing maritime industries, who work together to support improved biofouling management and marine biosafety initiatives and have commissioned a report, to identify existing and impending biofouling regulations and standards.

The aim of the report is to provide higher clarity to the industry, with a view to facilitate compliance and identify regulatory barriers that hamper adoption of new practices and/or technologies related to biofouling prevention and management three different surveys targeted at different sectors, namely: (a) Shipowner/operator survey, (b) Ports, shipyards and (c) governments and In-water cleaning providers.

Concurrently with these efforts, which we believe shall assist to align the currently fragmented legislative landscape of biofouling management, once the results shall be publicly available end of 2021, we have initiated a Technical Report through AMPP, SC19 | TR21517 - Grooming and Remote Inspection of Ship Hull Surfaces, where we have received their approval to reside on the development of a technical report specifically targeted to the maritime industry, related to the use of drones and robotics inspection with the objective to utilize proactive grooming and remote inspection capabilities, to maintain the vessel's carbon intensity and extend the dry dock interval.

The project has gained significant attention from the maritime industry's shareholders and participation consists of ROV manufactures, Underwater Service providers, Paint Maker's, Ship Owners, Classification Society and Academia aiming to consolidate the technology readiness level and harmonize the deliverables currently available to the industry, to better align the technical specification and regulatory compliance requirements, of such energy saving devices.

4. Energy Saving Device as an integral part of the ship

As a start-up, we envision that there shall be a significant delay in the readiness level of the "Port Grooming Service" our environmental consciousness cannot bear and are extending our development of the grooming robot, as an integral part of the ship, for the immediate future.

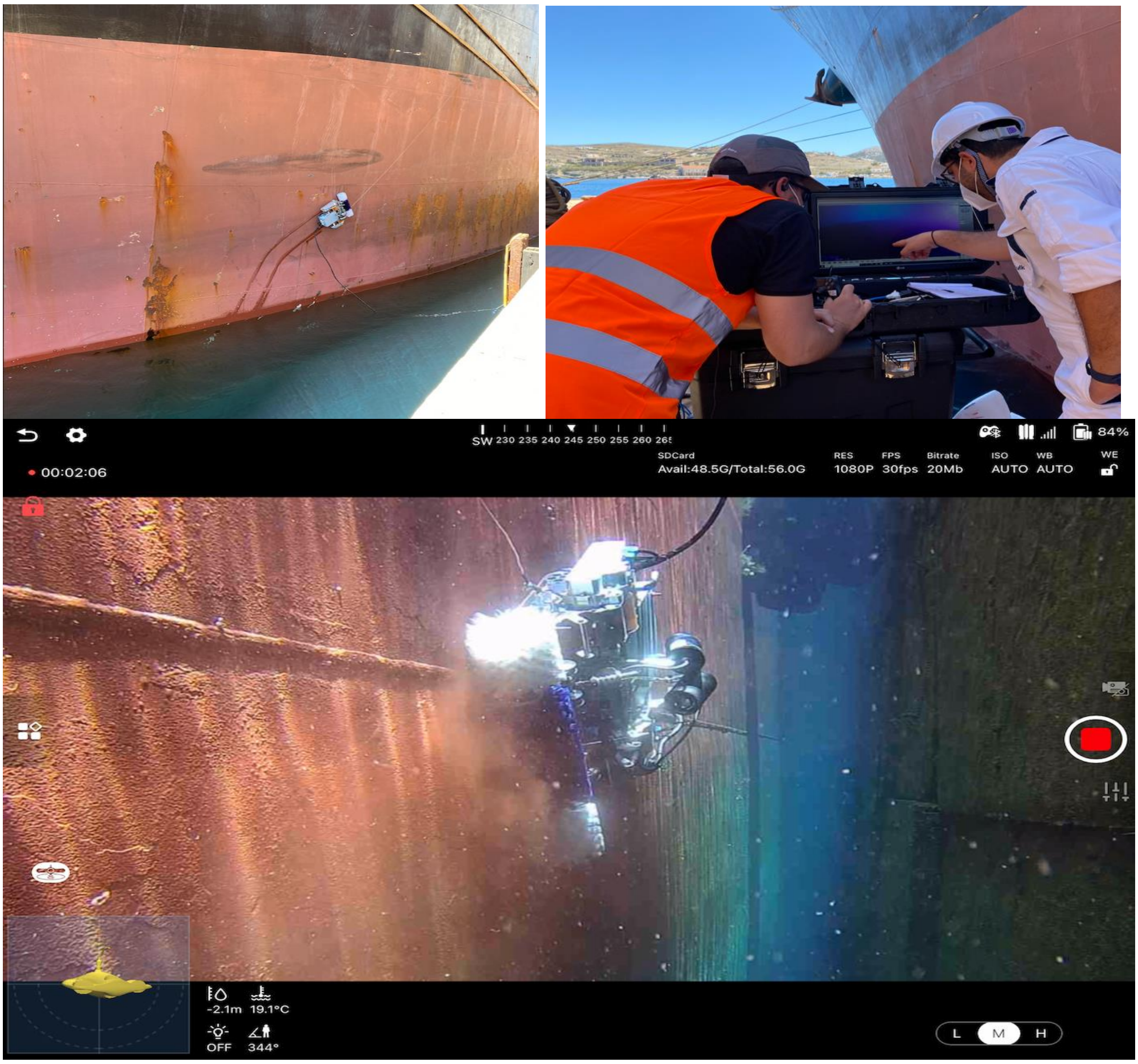

Fig.4: Demo to Ship and Port Authorities of the Grooming concept

Working alongside with DNV on the ESD robotic application's Type Approval, allows for the utilisation of the device to cater and encompass In Water Survey Class notation requirements and advance the principles of determining the type of biofouling on a vessel by inspection, by remotely/ autonomously operated cameras. Documentation of each inspection, provides (i) data entry in the asset's Biofouling Record Book, and/or (ii) a copy of a report of the inspection, as adequate evidence of the type of biofouling on a vessel for submitting permit requests for grooming operation, upon arrival.

In this regard, we are piloting our biofouling reporting structure from the ESD to be compliant with BioPass solution and allow for harmonising the asset's biofouling management with the anticipated industry norm.

In collaboration with renowned innovative Ship Owners and the backing of the Hellenic Shortsea Shipowners Association (HSSA), we are performing a series of in-port grooming missions on their assets, to demonstrate the "port service" to the Authorities and develop and mature the integral ship design, for the market.

By presenting the benefit of 'grooming as the answer' against the traditional 'scrub mentality' i.e. contrary to addressing underwater hull maintenance with a 'too fouled to operate' approach; we have been able to educate the market on the readiness level of the technology and carry out in situ demonstrations of the process.

We rely heavily on the existing guidelines on "Biofouling on Vessels Arriving to New Zealand" - CRMS-BIOFOUL, the MPI Technical Paper on "Technical Guidance on Biofouling Management for Vessels Arriving to New Zealand" and Australian Government's Dept of Agriculture and Environment's "Anti-Fouling and In-Water Cleaning Guidelines" - to demonstrate the recognised means applied, to address biosecurity issues in the industry and ultimately refer to the "Procedures for evaluating in-water systems to remove or treat vessel biofouling" of MPI Technical Paper No: 2015/39; in order to quantify the acceptable fouling rate of the candidate vessels for grooming.

Fig.5: Indicative of the Heavy Slime condition, typical in the current traditional 'scrub mentality' - addressing underwater hull maintenance, with a 'too fouled to operate' approach.

As indicated by MPI, “Microfouling, regardless of origin, may be removed or treated without the need for full containment of biofouling waste, provided the cleaning method is consistent with the antifouling coating system manufacturer’s recommendations. Where microfouling is removed using a gentle, non-abrasive cleaning technique, the chemical contamination risk is likely to be minimised to an acceptable level.”

Currently we note a significant gap in the micro fouling legislative framework in our domestic market, making the establishment of ‘grooming’ permits a difficult task to achieve and rely on the end user’s consent and support, to address the local Authorities. Currently, our biofouling pre-inspection report provided, together with the Owner’s request for the service; is proving to suffice to receive ‘grooming permits’, ad hoc.

With the support of HSSA we anticipate reaching a mature level of understanding, from the local port authorities and hope to be able to advance the green concept, in a very short time and play our part to support vessel’s from operating outside their design carbon intensity and underwater images such as these, to become a thing of the past – exactly where they belong.

5. Conclusions

Hull grooming and in-water Survey by robotic devices, will play an instrumental role towards shipping decarbonisation over the next decade.

The potential impact of robotic devices, in the grooming and inspection is threefold. On the financial side we have immense savings generated for the ship manager, as a result of reduced fuel consumption and diver & coating maintenance fees. On the environmental side we save tones of GHG emissions, which may be traded for emission credit(s), so one can only imagine the additional savings for the ship owner and most importantly – reach significant reduction of GHG emissions, contributing to saving a good part of the 400K lives per year accounted to poor air quality due to shipping operations, according to the European Federation of Transport and Environment.

As we envision emission credit system(s) materialising and the actual Carbon Intensity Index (CII) of an asset, to be heavily scrutinized - through the industry’s financial and commercial channels; we consider our ship’s integrated robotic application to hull performance, the new norm. A new norm, that shall significantly differentiate the innovative, early adopters – who shall capitalise on decarbonising investments; demonstrating their Environmental Social Governance, by effectively preparing their fleet - to navigate the uncertainties approaching their bow.

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Better Safe Than Sorry

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Abstract

The underwater maintenance industry is dominated by small sized (1-49 employees) diving companies. Although commercial diving is a high-risk profession, the introduction of ROV's as alternative technology improving health and safety conditions for the workers has not resulted yet in a global increase in health and safety of the underwater maintenance industry. This paper presents factors in the supply chain influencing the health and safety standards of workers in the underwater maintenance industry. Some suggestions for different stakeholders in the supply chain are given which can be implemented to increase the health and safety standards in this industry.

1. Introduction

The underwater maintenance industry for commercial shipping is dominated by diving companies performing underwater maintenance work. About 18 years ago the first industrial hull cleaning ROV's were introduced into the market, *Song and Cui (2020)*. These ROV's provided significant better health and safety conditions for workers performing underwater maintenance. The ROV's made it possible that risky diving operations were no longer necessary. Despite the improved health and safety conditions and available technology, the maintenance ROV's are not dominating the underwater maintenance industry nowadays. In this paper we will describe the factors influencing the health and safety conditions for workers in the underwater maintenance industry.

The maritime industry is an industry characterized by a fragmented relation between labor supply and company operation. In the last two decades, we have witnessed a major change in both the nature of labor force, its relationship with ship owners and the way in which work in the industry is organized. The large majority of the more than 1 million seafarers working on merchant ships worldwide now comes from a small number of developing countries such as the Philippines, India, Ukraine, and China. They are recruited by crewing agencies on a short-term contract working on ships managed by ship management companies. Compared to land-based standards, their working conditions are extreme, involving long working days, shift work and intensive work patterns as well as serious physical hazards. Another trend is the intensification of the work onboard by operating ships with a smaller crew. The consequences of these changes are seen in the fact that occupational mortality and morbidity rates for seafaring remain among the highest of all occupations, *Walters and James (2009).*

It is well known that commercial diving is a high-risk profession. Only a few studies have been conducted about the risks in this sector. In the United States, the OSHA (Occupational Safety & Health Administration) conducted such a study during 1989-1997 on an estimated population of 3.000 commercial divers. They concluded that the annual fatality rate was about 181 per 100.000, which was at that time about 40 times higher than in any other sector. In the UK the fatality rate ranges from 20 to 40 per 100.000. In France the rate was estimated to be 112 per 100.000 and in Belgium 233 per 100.000 divers. The number of divers working in the commercial diving sector in France and Belgium are relatively small which may lead to a relatively high fatality rate. Similar to seafarers, the mortality rate of commercial divers is very high, *Hermans (2016)*.

These risks are well-known by the shipping industry, which contracts the commercial diving companies to perform underwater maintenance work. In the 2020 annual report of Maersk the health and safety of contractors is mentioned in their risk analysis, with potential high impact on business disruption and reputational damage, *Maersk (2021)*. Throughout the supply chain there is an interest to improve the health and safety conditions in the underwater maintenance industry.

2. Influencing factors

Several factors may have an influence on the health and safety conditions of workers in the underwater maintenance industry. In this section we will describe five important factors for the underwater maintenance industry.

2.1. Company size of underwater maintenance contractors

The underwater maintenance industry is characterized by relatively small sized contractors, geographically located around ports or cleaning hubs. There are many small companies because the barriers of entry in the underwater maintenance market are relatively low:

- On many locations no specific permits are required to perform maintenance work.
- Technology is widely available and final quality of the work is often hard to measure, so distinguishing between contractors is complicated.
- There is no first mover advantage since it is not a winner takes all market.
- Brand loyalty of clients is relatively low because it is a cost-driven market.

There is evidence that health and safety conditions are related to company size. Eurostat data for 1999 showed, for 15 countries that were then member of the European Union, that the average fatal injury rates per 100.000 worker for micro (1-9 employees) and small (10-49 employees) companies was around double that of medium and large (50+) size companies. The majority of underwater service companies are micro or small sized (1-49 employees), with higher probability of a poorer health and safety performance. Besides that, many underwater contractors hire self-employed workers to make sure they have a flexible labor force, further increasing health and safety risk due to possible lack of training and experience in safe working procedures with the contractor's team and equipment, *Walters and James (2009)*.

2.2. Certification of suppliers

Certifications could help the principal of underwater maintenance work, like the ship management companies or ship operators, to choose qualified and competent contractors able to undertake the work safely and without risk to health, working according to a certified safety management system, *Walters and James (2009)*.

Besides local certifications for contractors, there are also third-party certification systems for health and safety conditions. Many shipping companies are certified according to the OHSAS 18001 certificate which will be replaced by ISO 45001. The ISO 45001 standard states, "The organization shall establish and maintain processes to ensure that the requirements of the organization's OH&S management system are met by contractors and their workers" and "the organization shall establish controls to ensure that the procurement of goods and services conform to its OH&S management system requirements". So, the health and safety of contractors is to be treated the same as that of the internal organization, and it is essential that the health and safety management of its subcontractors is checked. Clients which are ISO 45001 certified have the responsibility to make sure that subcontractors comply with their OH&S management system, *Hartly (2018).*

2.3. Associations

Another factor that may influencing the health and safety conditions within the underwater maintenance industry are suppliers' associations. Underwater service companies or workers may join an association to make sure that their interest is represented by the association, to have more bargaining power within the industry to other stakeholders, *Walters and James (2009)*. As the separate contractors are large in number and small in size, the bargaining power of a single contractor towards clients is very small. In addition, knowledge and standards are developed by the associations which is beneficiary for the entire industry. For underwater diving companies there are several national and international associations such as the Association of Diving Contractors International (ADCI) and the International Marine Contractors associations (IMCA). These associations are working on topics such as safety, training, education, and qualifications. For underwater robotic service providers there is no dedicated association that cultivates and promotes robotic maintenance and establish safety standards.

The buyers also have associations which represent the joint interests of their group, such as the International Association for Dry Cargo Ship Owners (INTERCARGO), the International Association of Independent Tanker Owners INTERTANKO) and the Baltic and International Marine Council (BIMCO), creating for instance standardized documents and contracts, and recently creating a standard for underwater cleaning. Since there is also a vast number of other shipping companies, the bargaining power of a single buyer towards the collected group of subcontractors is limited, but associations can use their collective power to influence the health and safety standards of the underwater maintenance contractors.

2.4. Regulatory framework

The underwater maintenance industry is a global market with companies working under varying local legislation, regulations, and standards. There are no global laws prescribing certain health and safety standards for underwater maintenance contractors, resulting in different legal standards for each port. In some jurisdictions the law requires that companies need to use contractors that comply with occupational safety and health laws. Companies may be held liable for breaching the law by their contractors. A regulatory framework is only effective when it is implemented together with inspections and enforcement of the regulations by the authorities.

2.5. Procurement conditions and power

Researchers on supply chain relations point to the opportunities that procurement gives clients to influence improvement in health and safety conditions from their suppliers. If the purchaser has a lot of purchasing power, it is a potentially powerful lever for improving health and safety conditions of the workers employed by suppliers. For the underwater maintenance industry, the biggest purchasers still have a relatively small market share in the sector. As example, Maersk Line holds approximately a 17% market share in the container sector. The container sector has a market share of approximately 14% based on dead-weight tonnage, *UNCTAD (2017)*. So, Maersk Line's total market share is roughly 2% if all the underwater maintenance is purchased for both the owned and chartered vessels by Maersk Line. As a consequence, the purchasing power of the biggest shipping companies in world is relatively small and it is difficult for one company to push local contractors to improve their health and safety standards.

3. Recommendations

In this paper we described five factors influencing the health and safety conditions for workers in the underwater maintenance industry. These factors are used for the following recommendations for three important stakeholders in the industry.

- Purchaser of underwater services

  In the underwater maintenance industry, the purchaser of underwater services can be the ship owner, ship management company, ship operator, coating manufacturer or agent. If the purchaser of the underwater services wants to have more certainty about the health and safety conditions for workers, it is wise to choose one of the largest service providers available because larger companies are more likely to have better working conditions for their workers and to work according to a safety management system. The second way to increase the conditions is to require the service provider to be certified with the relevant health and safety certifications such as ISO 45001. When selecting a contractor, performing controls regarding the health and safety systems in place at that contractor is also recommended, to check if these are compliant with the client's own health and safety standards

Another recommendation is to discuss and share knowledge about the health and safety aspects of underwater maintenance workers in associations such as BIMCO, INTERCARGO and INTERTANKO. If more ship owners and operators work together and combine their purchasing power over the fragmented underwater maintenance contractors, these service providers will be collectively required to improve the health and safety conditions because more clients force them to.

- Regulatory authorities

Authorities can improve the health and safety conditions by making regulations. Maybe even more important is to have sufficient workplace inspections and law enforcements to make sure service providers comply with regulations. Secondly, it is wise to make the purchaser liable for the health and safety conditions of her own workers but also for the workers employed by contractors. In this way, the purchaser has more incentive to make sure that there is a safe workplace to perform the underwater maintenance work.

- Underwater service providers

The service providers could certify their organization and equipment to constantly improve the health and safety conditions of their employees. Third-party certification such as ISO 45001 can be implemented.

Underwater service providers should form a dedicated association to share knowledge about health and safety, educate and to lobby for the combined interest of its members. Such associations can use their bargaining power to increase health and safety standards in this cost-driven market. Reputable service providers have a combined interest to improve the health and safety conditions of the underwater maintenance industry.

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Integrating Cleaning of Hull and Niche Areas – Is There a Commercial Niche without Regulation?

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1. Introduction

The case of invasive aquatic species (IAS) is in many respects a classic case of the 'tragedy of the commons' occurring when historically unrestricted and free access to graze livestock on the commons led to over-exploitation of the pasture and resulting in collapse of the shared resource. In modern cost-benefit terms the true cost of unsustainable usage was not internalised and hence the users did not factor in the consequence of the loss of the resource. The usage of shared environmental resources for disposal of waste is reducing but still widespread. In the maritime transport sector SOx and NOx were recently regulated and a target has been set by IMO to dramatically reduce emissions of carbon and other greenhouse gases. Even the discharge of IAS has received its own attention and ballast water is now regulated globally. However, with respect to one issue we are still exploiting the commons and that is the IAS transmitted through biofouling of ships and other floating constructions.

Biofouling is responsible for 50-60% of the IAS reported, i.e. at least a proportion similar to that of ballast water, and particularly the niche areas of a vessel are the source of IAS. The average niche areas account only for 10% of the Wetted Surface Area (global fleet data 1999-2013) ranging from 7-8% in the bulker/tanker segment up to 27% in passenger vessels, *Moser et al. (2017)*. Globally, mandatory biofouling management for hull and niche areas is only required in New Zealand and in Western Australia with some lesser requirements instigated in certain US states and in Australia.

Recent estimates of the costs of impacts of IAS put the accumulated costs at US$345 billion and at least US$23 billion from shipping IAS in 2020, *Cuthbeth et al. (2021)*. According to Cuthbeth costs of IAS are likely considerably underrepresented compared to terrestrial IAS; only 5% of reported costs were from aquatic species, despite 26% of known invaders being aquatic. Additionally, only 1% of aquatic invasion costs were from marine species. Costs of aquatic IAS are thus substantial, but likely underreported, and still enough for a place in the GDP Top 100. Nevertheless, the cost of the impacts of IAS from biofouling are not internalized in shipping and vessels are not in any practicable sense held liable for the damage cause (although it may legally be so).

When biofouling obviously parallels the ballast water vector, why are the IMO member states then only planning a review of the 2011 Biofouling Guidelines rather than a binding convention to deal with the issue? Well, it is not possible to see a proposal on IAS in biofouling from recent history on ballast water and the many other issues in shipping, *Roura-Pascal et al. (2021)*:

> 'When it comes to an analysis of IAS and how to manage the issue it is an important part of the scene that while shipping and biofouling is a direct carrier of IAS it is not isolated mechanisms. There are strong underlying driving forces for the continuous occurrence and impact of IAS such as 'global trade, land use change/development and climate change, as well as drivers associated with societal variables: international politics, governance and legislation; lifestyle and social norms; and technological development and innovations'.

Shipping's growth over the next decades could yield a 3- to 20-fold increase in global invasion risk, *Sardain et al. (2019)*, and few in the maritime sector express serious doubt that biofouling IAS will evade regulation. However, having experienced the laborious implementation of the BWMC, many stakeholders are experiencing a strong sense of fatigue regarding the matter. In addition, the technological development regarding biofouling management has for the most part been slow and not taken place to reduce the IAS part of the problem. So, despite the policy fatigue, is there room for shipping to inject innovation in the field of in-water cleaning (IWC) to steer clear of a future technology gap?

2. Biofouling management of hull

Few countries and states have a regulation mandating the management of biofouling on ships, and here as in the rest of the world, the 2011 IMO "Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species" is the foundation of biofouling management. However, on the global scene it is not invasive species that are prompting good hull management and cleaning, but the ambition to reduce the fuel penalty arising from the drag entailed by fouling of the hull. Today, many vessels run a performance software monitoring the fuel consumption and these often also provide a prediction of fouling levels and will alert the operator to have biofouling removed once above a criteria level.

The technological landscape of IWC of hulls has been mapped repeatedly over the last decade and the table show a summary of our current database. If compared to the technologies available in 1990's very little has changed, and the majority are mature technologies.

Table I: Main hull cleaning technologies

Technology	No of systems
Brush based	21
Rotary brush/ contactless	3
High water pressure jets	7
Cavitational jet	5
Other (ultrasound, heat)	3

It is clear that a new technological platform is not available and that an operational paradigm shift, e.g. to proactive cleaning, has not occurred. It is still the case that brush-based methods and hydro-jets with or without cavitation are the mainstream choices. Several methods based on ROV rather than diver operation have emerged, and the use of magnetic wheels for traction and use of collection systems for residuals have infused the IWC sector.

3. Biofouling management in niche areas

Main reactive technologies in the niche area comprise smaller and hand-held diver operated versions of the tools used for cleaning hull surfaces. Proactive management may include higher quality coatings, MGPS, and more recently the full-scale application of permanently installed ultrasound devices is an addition to the market's offering.

Hull cleaning is performed because the powerful driver of fuel cost is internalized in shipping. There is no immediate benefit from cleaning the niche areas except avoiding non-compliance in the few jurisdictions where mandatory cleaning is required. The general impression of the development of reactive niche area cleaning is that innovation and technology development is more or less absent since very little reward is dangled in front of entrepreneurs.

A niche area cleaning, at least when calling ports that are not in the above-mentioned locations, may be triggered by a loss of cooling water capacity or simply that the sea chest grating is "overgrown". But the conditions to be re-established include some related to fuel consumption issues (propeller etc.) and some related to flow (sea chest etc), see Table II. Removal of biofouling to lessen the potential for IAS is not on the top of a shipowner's mind.

Table II: Niche areas drivers for cleaning.

Driver for cleaning	Niche area(s) in ships	Niche area(s) in offshore energy installations
Fuel consumption	Propeller, bilge keel, thrusters/tunnels	Submerged turbine blades
Flow conditions	Sea chest, internal piping, stabilisors, rudder, gratings, box cooler	Seawater piping and cooling water systems, exposed structures
Coating condition	Dry dock support strips	Corrosion concerns
IAS considerations	None, unless by regulation then all, and add anchor chain well to other niche areas	None, unless by regulation typically when changing location

4. The innovation and technology maturation

It appears that the only recent innovations that resembles new paradigms are the concept of proactive cleaning, i.e. frequent cleaning to keep fouling at the level of slime and soft fouling (grooming) and the development of prototypes of onboard technologies to be permanently installed on the individual ships. But the innovation has not included e.g.

- Fundamentally new materials or equipment (coating or brush)
- New business models of cleaning technology and surface coating
- Autonomous IWC crawlers

Table III: Modernization of the IWC over the last decade

Parameter	Hull cleaning	Cleaning niche areas
Efficiency	Increasing	No significant change
Digitization	Included in fuel performance software and stand-alone	Vessel specific software (for IAS risk)
Monitoring of IWC work	Sensors and continuous visual images	Before and after images
Automation	Remote operation, no autonomous	Very little
Environmental	Waste recovery	Few with waste recovery

5. The room for coupling hull IWC and niche area IWC

The software systems available for predicting the biofouling mediated fuel penalty or at least monitoring key parameters allowing for the planning of a hull or propeller IWC are already on the market for some time and major shipowners and first movers are subscribers. The systems allow the operator to be alerted that the fuel penalty is above a criteria value and that they should initiate a remediation, e.g. IWC. During the last few years, software employing algorithms that predict the risk of biofouling invasive species have also emerged following a similar development regarding ballast water mediated invasive species. The pre-arrival tools are used by Port State Control to identify "high-risk" vessels and some tools include self-assessment user interfaces for the ship's operator. To our knowledge no shipowner employs the ballast water risk assessment tools when trading outside of locations where such tools are mandated. One may reasonably guess that shipowners do not wish to potentially incriminate themselves when vessels undertake voyages that would be classified as "high-risk" by such an algorithm.

6. Are there any free money (from hull and propeller cleanings)?

Now this is indeed a theoretical exercise since in the mind of the shipowner the answer is a firm and convincing "No". Nevertheless, we have tried to estimate the cost profile for different IWC strategies at different fuel prices.

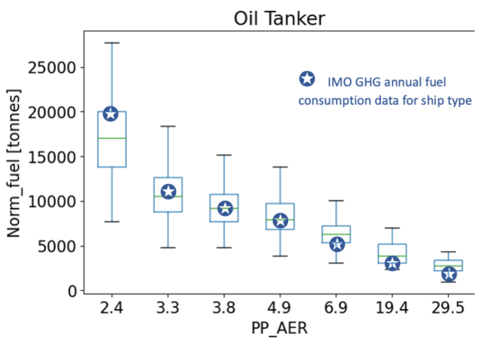


Fig.1: Annual fuel consumption for oil tankers based on EU MRV

Table IV: Assumptions for IWC strategies

Assumptions on cost estimates			
No. IWC/yr	1 (Hard)	2,4 (Medium)	40 (Proactive)
Fuel penalty	15%	10%	5%
Fouling costs (USD)	12000	8000	4000
Fuel costs (USD)	350 (2020)	550 (2021)	1250 (2030?)

On an anonymized and collated level the fuel consumption data is available through the IMO GHG Studies. We have used the GloMEEP tool, *IMO (2014)*, for the fuel consumption of the ship types analysis. We have used the EU MRV dataset (approx. 11,000 vessels in 2019), which is not anonymized and allows detailed ship type specific analyses, to identify the distribution of vessels' fuel consumption. Since the dataset only cover voyages to, from and within EU, which for most vessels do not cover the entire year's 'days at sea' we have normalized this to a fixed number (a maximum of 275 days) and converted this to an annual metric used in estimating the (fuel/emissions) performance of a vessel, the Annual Efficiency Ratio (AER) assuming that vessels exhibit similar operational performance on the voyages covered in EU MRV as they do in the rest of the world, *EC (2020)*. Fig.1 is an example of the fit between fuel consumption estimation via EU MRV and actual fuel consumption for the ship type from IMO GHG, *IMO (2021)*. Box and whisker plot shows mean, 25/75 fraction and data range after omission of outliers. The conditions of IWC strategies and fuel costs are given in Table IV.

Costs of hull cleaning were estimated based on interviews and the niche cleaning costs from time consumed and estimated for three fouling levels (a hard fouling, a medium fouling and a slime level proactive scenario). The ship types ranged from 7-10% niche areas and size classes were progressively assigned relative hull cleaning costs (only oil tankers shown).

Table V: Annual savings (mill. USD) at three fuel costs and IWC strategies

Oil tanker size	**350 USD/t**			**550 USD/t**			**1250 USD/t**		
DWT	Hard	Medium	Proactive	Hard	Medium	Proactive	Hard	Medium	Proactive
200000-+	1.0	1.3	1.3	1.7	2.2	2.8	3.8	5.0	6.3
120000-199999	0.6	0.8	0.7	1.0	1.3	1.7	2.3	3.0	3.8
80000-119999	0.5	0.6	0.6	0.8	1.0	1.3	1.7	2.3	2.9
60000-79999	0.4	0.6	0.6	0.7	0.9	1.2	1.6	2.1	2.6
20000-59999	0.3	0.4	0.4	0.5	0.7	0.9	1.2	1.6	2.0
10000-19999	0.2	0.2	0.2	0.3	0.4	0.5	0.7	0.9	1.1
5000-9999	0.1	0.1	0.1	0.2	0.3	0.3	0.4	0.6	0.7

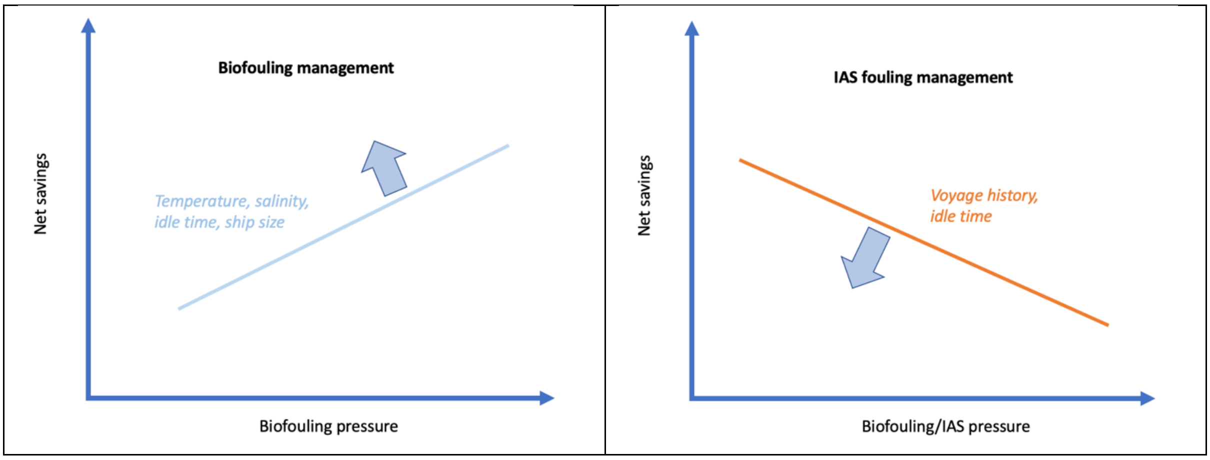
The dividend from fuel savings were estimated for three fuel pricing scenarios: During 2020/2021 the 0.5%S fuel has increased from 350 USD/metric tonnes to 550 USD/metric tonnes. With a view to the future age of decarbonization it is not unlikely that market-based measures are introduced and/or that a global levy on carbon-based fuels will be invoked to the effect of dramatically increased fuel cost. The

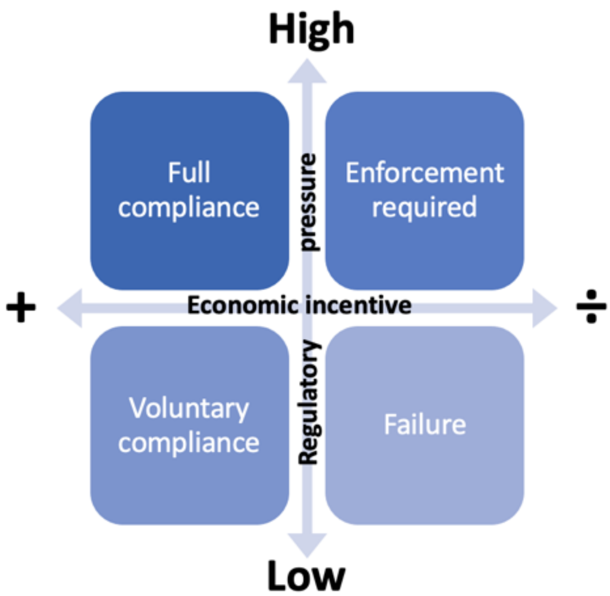
Maersk CEO called for 450 USD/tonne to a total of 900 USD/tonne at the time, while others have floated a total of 1250 USD/tonne as a target since this corresponds to what alternatives are currently estimated to cost (in comparable kW).

7. Conclusions

The incentives for addressing biofouling are present regarding the hull fouling due to the fuel penalty and most owners and operators voluntarily invest in management of this issue. With the expected development in market based measures and decarbonization policies fuel cost will increase in the coming decade(s) and the premium for proper hull management will increase.

However, the mechanisms and drivers of biofouling management for hull performance do not follow those of management for IAS. While increasing biofouling pressure will provide more net savings on the bunker bill if you act, increasing IAS pressure mainly on your niche areas will only cost you (negative net value).





Therefore, there seems to be very little incentive for the bulk of shipowners to engage in voluntary compliance for cleaning of niche areas for IAS. Although, we are providing the estimates of costs only as examples it is clear that there may be a dividend to pay for niche areas and still yield a saving for the owner without a mandatory internalization of IAS cost.

It is also clear though that few owners will be motivated and ready to divert a part of savings on fuel to this purpose if their competitors are not forced or enticed to do so.

If we are to avoid the failure category shown regarding biofouling mediated IAS we should work on increasing the economic incentive and increase the innovation to make IWC cheaper and better. If mechanisms to allow the IAS and the niche areas to be specifically targeted leading to development of new technology and new business models, a wider penetration of the shipping industry with respect to niche area cleaning may ease the regulatory pressure and avoid a technology gap.

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Responsible Bio-Fouling Management Plans

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Abstract

This paper describes the feasibility for ship owners to conduct environmentally responsible biofouling management programs, so their vessels operate with clean hulls, delivering significant commercial benefits, including reduced travel times, lower fuel consumption, reduction maintenance and importantly decreasing carbon emissions while making it easier to detect and eradicate invasive species.

1. Introduction

One of the biggest worldwide maritime industry challenges has been the need for highly environmentally protective in-water hull cleaning capabilities that provide sustainable solutions to highly regulated jurisdictions around the world and realistic solutions to those jurisdictions that are following the leads of the IMO and alike, and becoming more environmentally protective. Extensive research has shown manageable, regular, in-water hull cleaning protocols, significantly reduce fuel consumption and carbon emissions, while protecting biodiversity, in the maritime sector. This paper describes the feasibility for ship owners to conduct environmentally responsible biofouling management programs, so their vessels operate with clean hulls, delivering significant commercial benefits, including reduced travel times, lower fuel consumption, reduction maintenance and importantly decreasing carbon emissions while making it easier to detect and eradicate invasive species.

New technologies are providing solutions to an old worldwide problem: Dirty ship hulls. Envirocart, https://cleansubsea.com.au/the-envirocart/, is the first of its kind, and an example of a complete closed circuit clean, capture, containment and filtration, in water hull cleaning system. It protects our marine eco-system biodiversity, decreases GHG (greenhouse gas) emissions, and reduces vessel operating costs.

It also offers a clear fit with rising Environmental, Social and Governance (ESG) objectives:

- It proactively contributes to the global combat on climate change, offering significant reductions on GHG emissions.
- It offers real solutions for socially expected standards to protect our marine environment.
- Cleaning hulls while addressing energy efficiency and preventing the spread of aquatic invasive species makes commercial sense for the operators, creating a win-win situation.

2. The Envirocart solution

2.1. The industry problem and solution

The problem from the perspective of the industry can be described by the vicious triangle in Fig.1. Biofouling is the accumulation of marine organisms on a ship's hull. Traditionally, Anti-Fouling Coatings (AFCs) are a vessel’s primary defence against biofouling. Even a modest slime build-up on a ship’s hull increases its drag, which in turn increases fuel consumption and GHG emissions.

After two years of accumulating fouling, a 280 m container ship may burn an additional 70 t of fuel per day. For heavy fuel oil, this converts to 14000 t per year (200 days operation assumed), or 37000 t of additional CO_2 emissions per year.

On the other hand, cleaning in port to remove the fouling comes with its own issues. Aquatic Invasive Species (AIS) from the removed fouling and heavy metal contamination from the removed antifouling paint pose threats that have motivated an increasing number of ports worldwide to ban or restrict in-port cleaning. In response, shipping operators may clean illegally or use inappropriate technologies that pollute the marine environment.

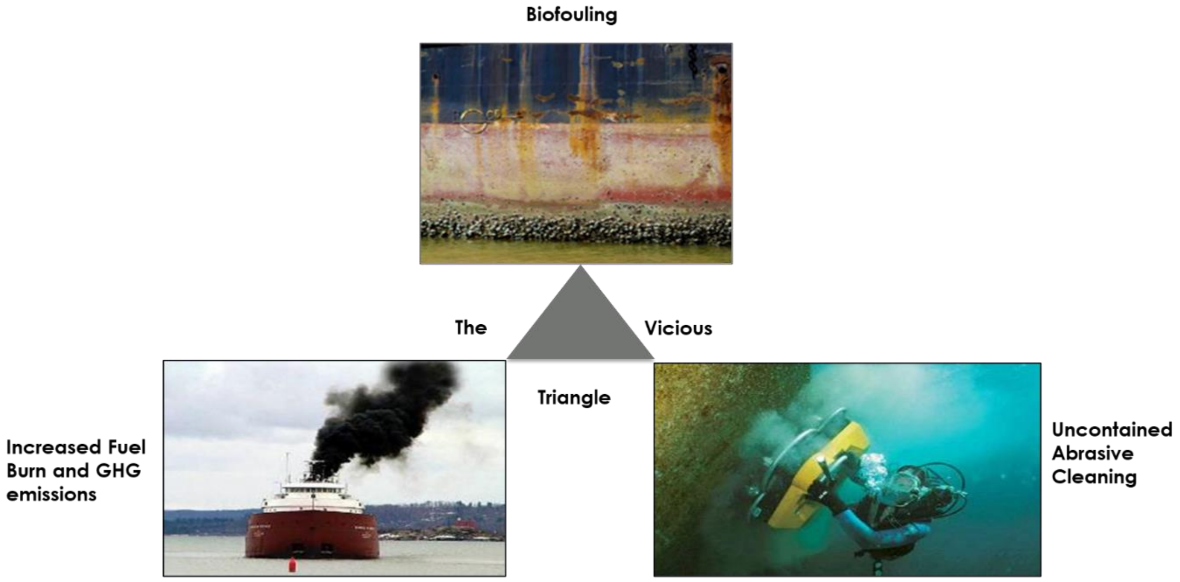

Fig.1: Vicious triangle in hull cleaning

Technology is revolutionizing in-water hull cleaning systems that completely clean, capture, contain and filters all discharge matter from a vessel's hull without damaging the antifouling paint or polluting the surrounding marine environment. The Envirocart, Fig.2, is an example of a complete capture, containment & filtration in-water hull cleaning system.

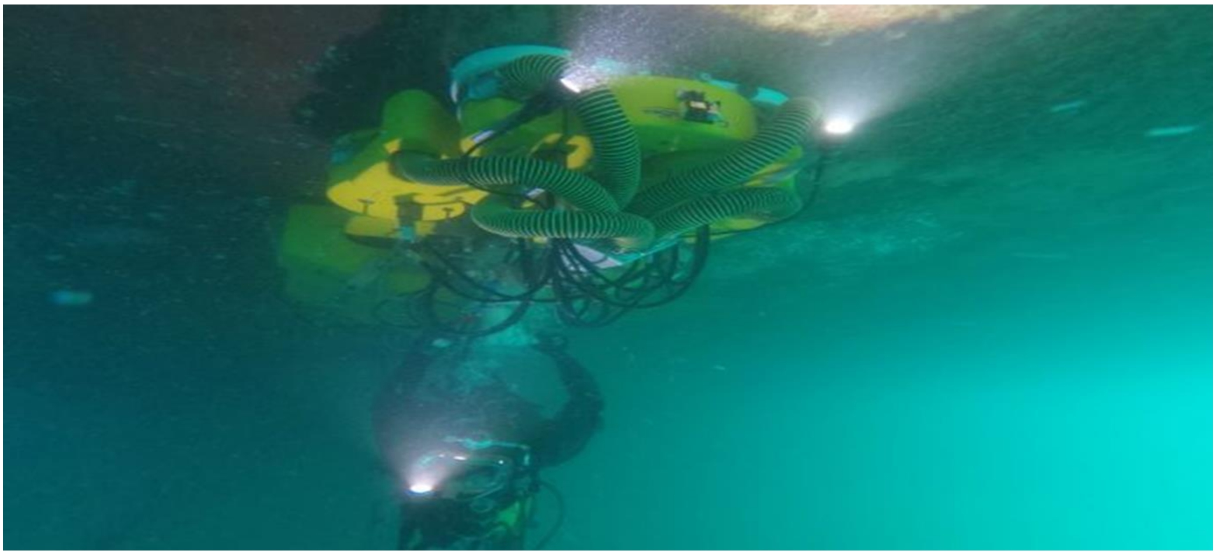
Fig.2: Envirocart

2.2. Environmental advantage

The winds are changing on the worldwide attitude towards environmental awareness and value systems. The signs for global change on environmental policies are palpable:

- Reduction of Greenhouse Gas emissions is required by global and regional policies. Carbon dioxide (CO2) is naturally present in the atmosphere. However, human activities – including the combustion of fossil fuels such as gasoline and diesel to transport people and goods have lifted it to dangerously high levels.

- The most effective way to reduce CO2 emissions is to reduce the amount of fossil fuel consumed. In shipping, this can be done quickly and easily by removing biofouling from the hull to reduce drag.
- By using certified in-water hull cleaning systems, ship operators will not only reduce fuel costs and travel time, but they will also cause less damage to the environment by reducing CO_2 emissions released into the atmosphere.
- IMO Bio-Fouling Management regulatory standards are widely viewed as imminent following the introduction of new mandatory Sulphur Emission reduction standards. The GloFouling initiative, https://www.glofouling.imo.org/, already established by the IMO is considered to be the start of that process.

2.3. Commercial advantage

Dirty hull biofouling increases fuel consumption by 10% to 40%; this means higher operating costs and more GHG emissions:

- The shipping industry worldwide burns some 325 million tons of fuel oil annually.
- Doing this generates around a 1 billion tons of GHG emissions annually.
- This equates to almost 3 times the total annual net domestic GHG emissions of the UK.
- Assuming a conservative savings benefit of 15% annually and direct GHG emissions reduction of 150 million tons.
- A reduction in fuel consumption of 48.75 million tons equals cost savings of about $26.8 billion.
- Total GHG reduction of >150 million tons annually would be roughly equivalent to 40% of the UK's entire domestic GHG emissions.

2.4. Social-economic advantage

Global awareness and social expectations for reductions in GHG emissions are putting the limelight also on the maritime sector. A recent example is the mandatory introduction and enforcement worldwide of IMO's 2020 global Sulphur caps, reducing significantly the SOx (Sulphur oxides) content in emission content levels.

There are clear signs that next in line are regulations for the enforcement of responsible biofouling management standards, both to reduce fuel consumption and to reduce spread of aquatic invasive species. The establishment of IMO's GloFouling initiative is such a sign. New standards for enforcing responsible practices in proactive jurisdictions such as Australia, New Zealand and California are another such sign. Cleaning vessels in unregulated jurisdictions will become socially unacceptable.

3. Concluding summary

Global shipping consumes ~325 million tons of fuel annually, generating roughly a billion ton of GHG emissions annually. This is equating to roughly 3x the UK's total domestic GHG emissions!

A modernised version of a simple in-water hull cleaning process which has been around for hundreds of years could enable annual GHG emissions reductions of >150 million tons (equating to ~40% of the UK's annual domestic GHG emissions) whilst simultaneously saving USD 27 billion in fuel costs for ship owners every year.

Marine environment protective technology to deliver these GHG emissions reductions and ship owner financial benefits now exists. A legislative imperative by IMO similar to ballast water management

convention related biofouling is now widely viewed as imminent as part of IMO's overall environmental strategy. Such a biofouling convention would be a game changer in this sector.
IMO has demonstrated unequivocally its commitment to environmental protection, accepting to pose an estimated USD 30 billion burden (according to OECD) on the shipping industry with the 2020 global Sulphur cap. It is time for industry to come up with technologies that can provide realistic solutions to support these initiatives with responsible biofouling management options.

Technologies are now providing environmentally protective solutions with new in-water hull cleaning closed systems that clean, capture, contain and filtrate everything that is cleaned off a vessels hull. This approach is environmentally protective while delivering realistic solutions and solves the apparent dilemma of the vicious triangle in Fig.1.

ROBUST - Integrated Coating & Cleaning Concept for Offshore Structures

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Abstract

This paper describes the first experiences of the R+D project ROBUST with newly developed, non-biocidal and robust test coatings for Offshore constructions by the partners Fraunhofer IFAM and Momentive Performance Materials GmbH under the impact of brush cleaning and high-pressure cleaning. The test panels have been immersed by the Dr. Brill + Partner (DBP) Institute for Antifouling and Biocorrosion on the North Sea Island Norderney in different ways and have been cleaned in different intervals to simulate a long service-life. Additionally, a graduated concept of brushes has been developed to find out the best way of cleaning without damaging the surface of the hard coatings with foul-release properties. Cleaning efficacy and mechanical damages have been evaluated at regular inspections.

1. Introduction

The challenge of this project is the development of an integrated concept of fouling control on offshore strucures. Offshore foundations as static buildings in the Sea suffer from high fouling pressure. Fouling growth on these constructions increases the weight and hydrodynamic resistance. This has an influence on the hydrodynamic impact and might lead to a decrease of stability.

Moreover, fouling hampers the required regular controls of welding seams e.g., on corrosion, cracks, or other damages. Divers previously must clean these areas, which is laborious and sometimes even dangerous.

One goal of this project is to design coatings, which meet two requirements: They must be resistant against mechanical impacts and should have foul-release properties to reduce the adhesion of the fouling organisms to allow a simple and quick cleaning of the surface.

Besides these features some more properties like chemical stability, abrasion resistance, hardness, color retention und kathodic delamination are important, *Momber (2011)*. The scientific and technological challenge is to create such robust coatings with non-stick properties.

Another goal of the Brill-Institute for Antifouling and Biocorrosion is the development of cleaning methods to simulate the real cleaning process at offshore constructions, which are difficult to access, under coastal conditions with easy access.

2. Coating development

In Germany, biocidal coatings are not authorized for offshore constructions by the German authority Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie (BSH)). Non-biocidal coatings are based on polymers that shall minimize the adhesion of the organisms to the coatings. The design of such coatings requires the knowledge of chemical and physical interactions between the glue of the organisms and the Foul-Release (FR) polymer coatings, *Callow and Callow (2011)*. FR coatings are not primarily aimed at preventing colonization by organisms in general, but at weakening the interfacial bond so that attached organisms are more easily removed by the hydrodynamic shear forces generated by the movement of the vessel through the water, *Kavanagh et al. (2005)*, or by gentle "grooming" devices, *Tribou and Swain (2010)*. Most of today's commercial FR coatings are based on poly(dimethylsiloxane) elastomers (PDMSe). The disadvantage of this technology is that FR coatings are most effective when used on highly active, fast-moving (>15 knots) vessels. For static structures, therefore, this technology is virtually ruled out. For these and other reasons, intensive research is being conducted into alternative FR technologies. These include the use of fluoropolymers, *Finnie and Williams (2010)*. Further research efforts are in amphiphilic or zwitterionic systems, whose heterogeneous surface, characterized by hydrophilic and hydrophobic areas, not only has FR properties, but also is a less attractive substrate for many fouling organisms (e.g., barnacles) from the beginning (e.g., projects "Foulprotect", funding code 03SX370). Furthermore, several other experimental approaches exist such as bioinspired topographies, *Ralston and Swain (2009)*, inorganic-organic nanohybrids, *Bennet et al. (2010)* as well as nanocomposites and superhydrophilic surfaces, *Beigbeder et al. (2008)*.

2.1 Momentive Performance Materials GmbH

The coating for the exposure and cleaning tests is composed by two layers, Fig.1. It is common practice to use epoxy primers as heavy corrosion protection for steel constructions. Three different commercial epoxide primer coatings have been used as a basic layer, all certified following DNV-OS-J101 (Design of offshore wind turbines), NORSOK M-501 (Surface preparation and protection), ISO 12944 (Paints and coatings - Corrosion protection of steel structures by protective coating systems) and VGB/BAW-Norm (Corrosion protection for offshore wind structures and wind farm components). The layer thickness of this primer coating was 100 µm and applied by spray-coating.

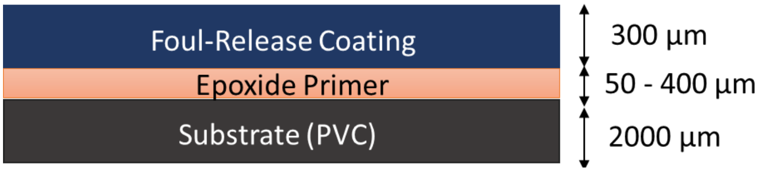

Fig.1: Layered structure of the coating approach (Momentive Performance Materials GmbH)

On top of this layer the foul-release topcoats have been applied by spiral bar coater, flood coating or spray-coating. For these topcoats, new additives with foul-release properties have been synthesized, to achieve weathering resistant cleanability.

15 new formulations of additives and coatings have been synthesized. The surface properties should be attained by hydrophilic and hydrophobic end groups in the polymers. A covalent binding of the additives to the coating matrix for long term durability has been realized by a reactive group. For a sufficient compatibility to the polymer, the hydrophobic and hydrophilic groups have been bound chemically to polymeric siloxane backbone, Fig.2. Both the reactive groups as well as the hydrophobic connecting polymers must be adjusted to UV-curing and physical drying. This guarantees the reactivity under both conditions and a resilient chemical incorporation, Figs.3 and 4.

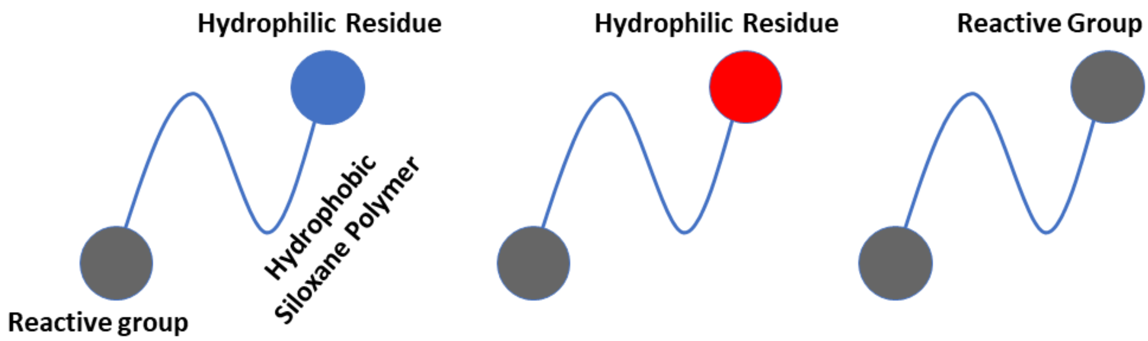

Fig.2: Scheme of the different additives

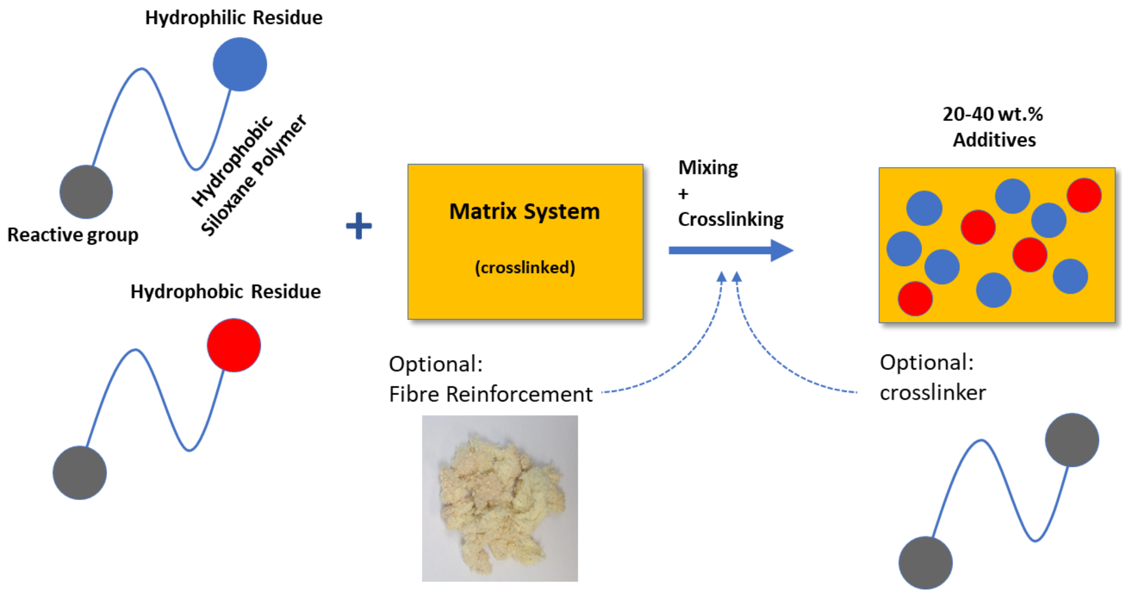

Fig.3: Scheme of physical drying

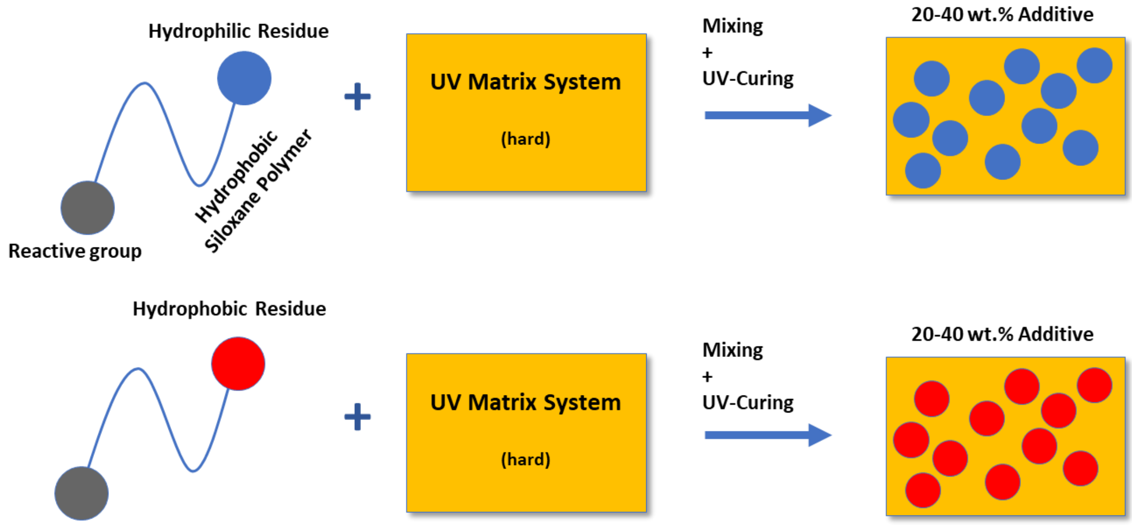

Fig 4: Scheme of UV-curing

The coatings mentioned so far are solvent-based. Solvent-based coatings emit volatile organic compounds (VOCs) during application, which are a risk for human health and meanwhile often limited by law. For this reason, additionally a water-based coating has been created and tested, Fig.5.

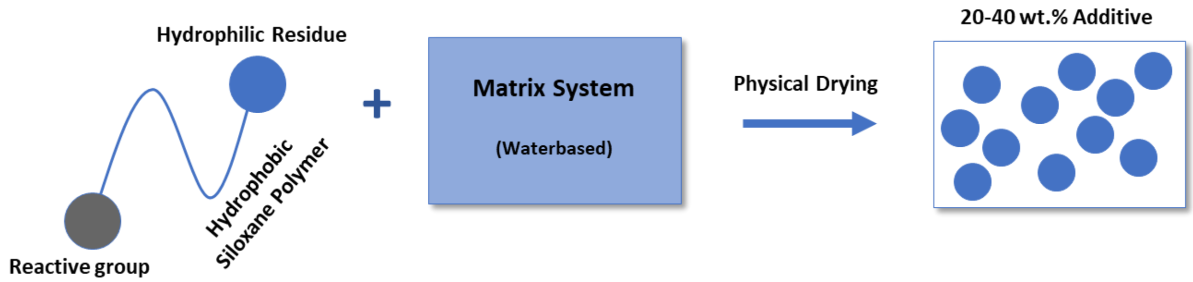

Fig.5: Scheme of physical drying of water-based coatings

In 2021, Momentive Performance Materials GmbH could select 23 formulations for simulated field tests at the Brill Institute for Antifouling and Biocorrosion on the island Norderney. One of them was a non-biocidal polyurethan acrylate coating as a positive control for foul-release effects and mechanical resistance. In lab tests all test formulations met the requirements for scratch resistance, adhesion, and some special surface properties like wettability.

In addition to the analysis of the mechanical properties, other analytical methods were used to test the physicochemical properties of the paint surface as a model. For this purpose, the water contact angle of surfaces is usually analyzed. The contact angle of the physically dried coatings showed a so-called "flip-flop mechanism" when the combination of hydrophobic and hydrophilic compounds was added. The surface switches from hydrophobic to hydrophilic upon water contact. The contact angle decreases from ~ 80° to <20° within 40 s, Fig.6. This behavior was also observed after the field test with the physically dried coatings. Therefore, we assume that the flip-flop effect on the surface, which presumably triggers a fouling-release effect, does not diminish even after some weathering time, Fig.7. This flip-flop mechanism could, if the coating is not in water, protect the hydrophilic groups on the surface from UV radiation and thus provide better long-term stability of the coating, Fig.8. This effect needs to be investigated in more detail and be applied to more scratch-resistant coatings, such as UV-curable coatings.

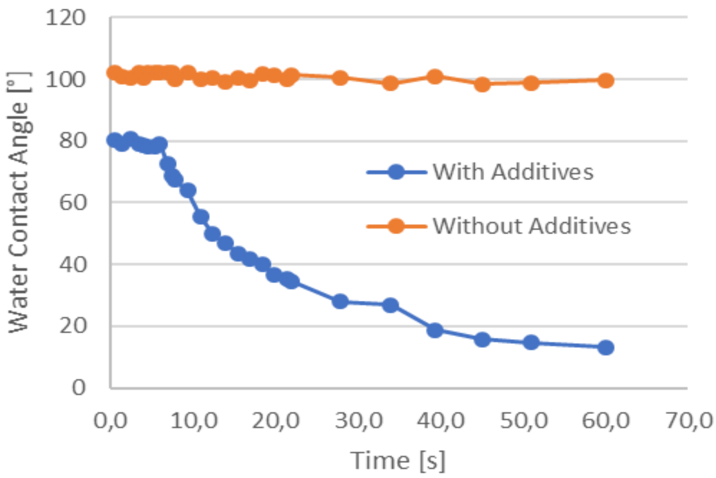

Fig.6: Time-dependent water contact angle measurement of physically drying coatings with and without additives

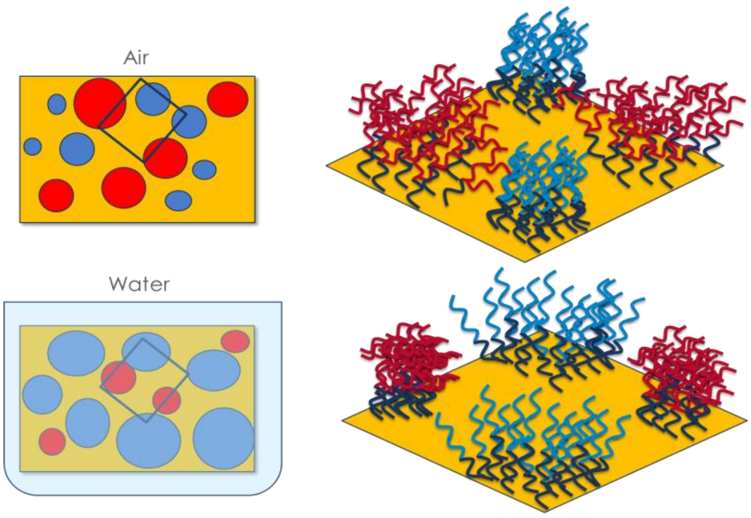

Fig.7: Flip-flop mechanism of hydrophobic and hydrophilic domains from surface-air contact (upper part) to surface-water contact (lower part)

2.2 Fraunhofer IFAM

The coating approach pursued by Fraunhofer IFAM is also based on a double layer system consisting of a commercial epoxy primer for corrosion protection and the experimental non-biocidal fouling release top-coat to be investigated in the present project. The coating formulations concept follows a stepwise approach of relatively simple basic formulations with different degrees of hardness tested in the first fouling season within the project (2020). This shall provide a principle understanding on the relationship of various surface properties and fouling control performance, Fig.8. In the second project year, the formulations of the best coating candidates were optimized with regard to mechanical stability and fouling release properties and exposed in 2021.

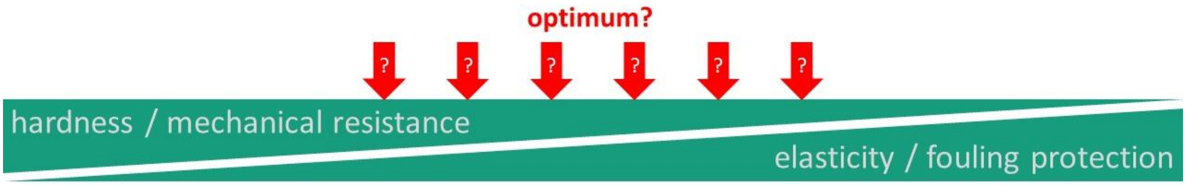

Fig.8: Schematic illustration of the considerations driving the coating development approach of Fraunhofer IFAM in finding an optimum between mechanical robustness without compromising the good fouling release performance of elastomeric materials

The formulations were based on the following materials:

- Soft to medium-hard, pure PDMS coatings
- PDMS-urethane hybrids
- PDMS-epoxy coatings

Contact angles measurements showed that the pure PDMS systems had the lowest surface free energy values, followed by the PU-PDMS coatings and the EP-PDMS samples had the highest values, Fig.9.

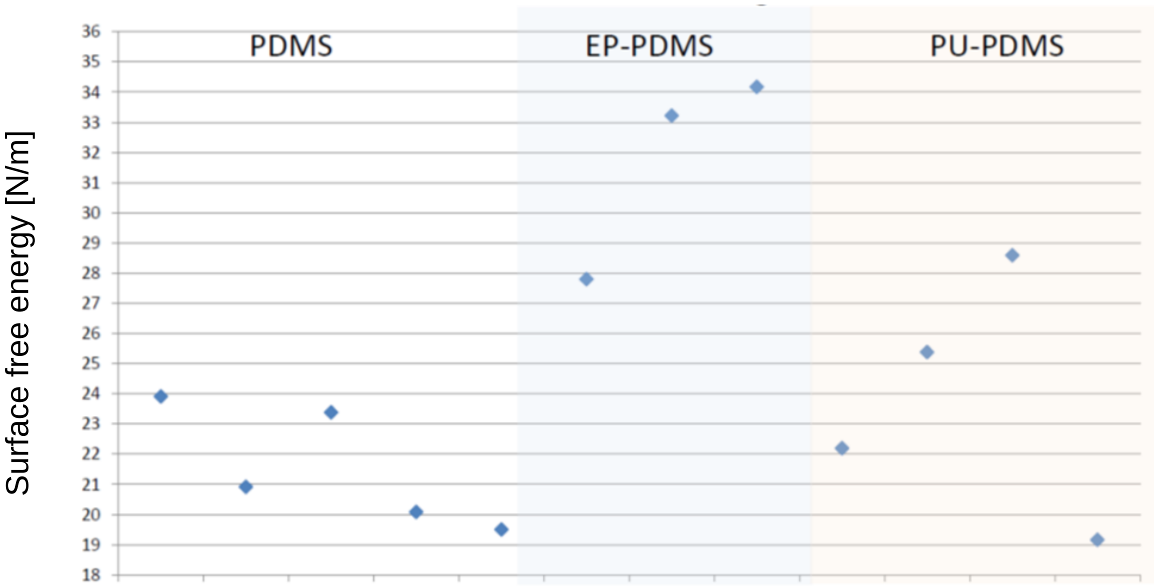

Fig.9: Surface free energy of the different samples exposed in 2020

Shore-A hardness measurements demonstrated that these coating formulations covered a broad range from the hard EP-PDMS systems to the medium hard PU-PDMS mixtures and the soft pure PDMS formulations, Fig.10.

Additionally, two further binder material categories were investigated: a silanized 2K polyurethane (unmodified and hydrophilized) and an extremely hard inorganic polymer (unmodified, mixed with PDMS, and hydrophilized).

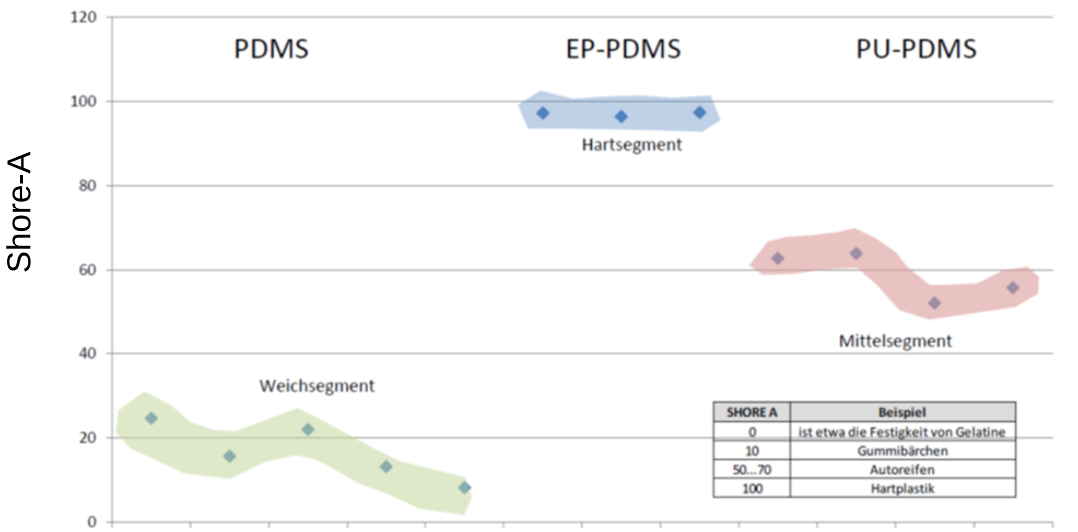

Fig.10: Shore-A hardness of the different coatings exposed in 2020

3. Simulated Field Tests

3.1 Norderney

Dr. Brill + Partner exposed the test panels at two different sites on the island Norderney (Fig.11). One test facility is located in the harbour of Norderney, the other one is at the beachside of Norderney, which is more exposed to waves and currents.

Fig.11: Exposure sites of the Institute for Antifouling and Biocorrosion at the beachside and in the harbour of the North Sea Island Norderney

In the harbour of Norderney, the test panels were immersed sublittoral at a Brill-owned swimming pontoon, Fig.12. At the Beach Station, the panels were exposed eulittoral as well as sublittoral, Fig.13. The eulittoral panels fall dry for ~90 minutes at every low tide two times a day.

Fig.12: One pontoon for static exposure of test panels in the harbour Norderney

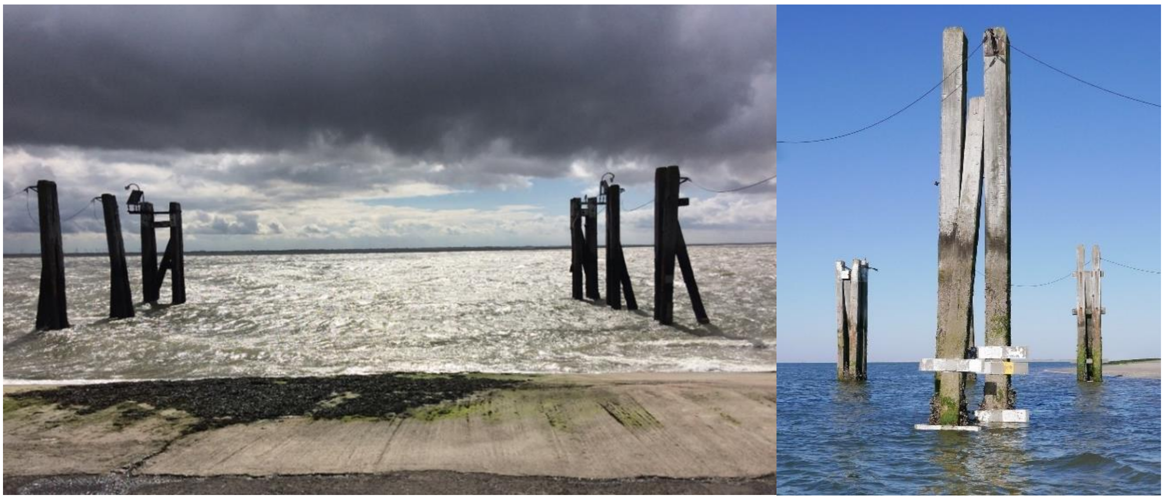

Fig.13: Dolphins for static exposure of test panels at the beachside of Norderney (left), dolphins with eulittoral und sublittoral frames, each for five test panels

3.2 Helgoland

Helgoland is a North Sea Island located about 50 km from the mainland in the German Bight. Due to its location in the open sea as well as its rocky subsoil, it is home to unique biocoenoses that differ significantly from the ecosystems of the other German coastline islands.

Fig.14: Overview of the Fraunhofer IFAM test stands on Helgoland

The biological diversity makes this location particularly attractive for the investigation of biofouling. The Fraunhofer IFAM operates three different test stands on Helgoland, Fig.14, which make use of these climatic and biological characteristics for specific material investigations:

i) a test rig at the western pier of the southern harbour for corrosion tests in splash water, intertidal and permanent immersion zones;
ii) a floating raft for static immersion testing according to ASTM D6990-20 in the southern harbour, where the test panels of the present investigation were exposed; as well as an area for atmospheric weathering in the corrosion categories C5 (according to DIN EN ISO 12944).

4. Simulated Cleaning Methods

Generally, there are three methods for cleaning of underwater constructions: Brush cleaning, high water pressure cleaning, and cleaning by cavitation, *Watermann (2019)*. In the ROBUST-project only brushes and high-pressure water jetting are used.

4.1. Graduated Brush Cleaning

The brush cleaning is conducted by three different kinds of brushes with an increasing hardness of the bristles, Fig.15. The brushes are fixed by an extension to a cordless screwdriver with defined settings. At soft coatings with high foul-release performance the cleaning process might start with a sponge or a soft white brush for 30 s. If afterwards less than 95% of the panel is free of fouling, the blue brush with medium hard bristles is used for another 30 s. If the medium brush cannot clean 95% of the panel, the red hard brush will be applied, but only at last inspection, because it has been proven to be too abrasive for the test coatings in 2020.

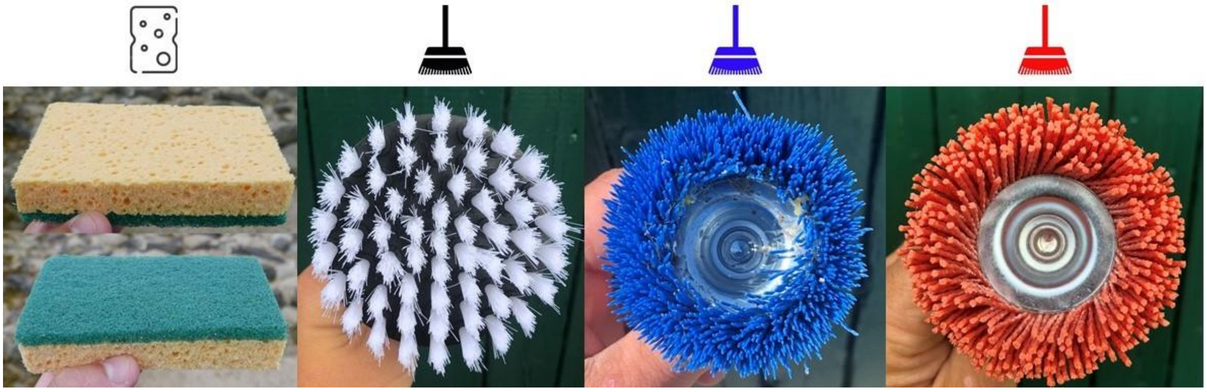

Fig.15: Sponge and Brushes and their icons with graduated hardness: Sponge softest cleaning, white soft brush, blue medium hard brush, and red hard brush

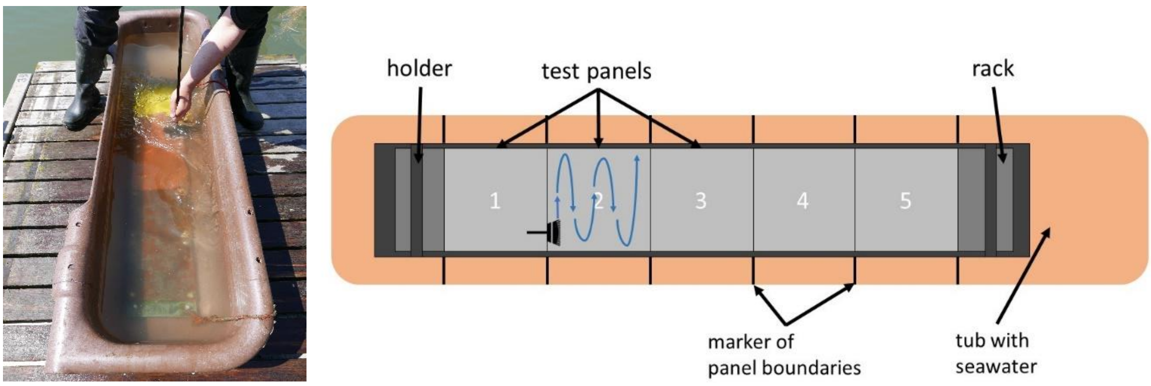

Fig.16: Left: Basin for in-water cleaning; Right: Scheme for positioning of the brushes

Test panels for cleaning are exposed on the supporting rack for five panels. The cleaning of the test panels is always conducted in a prepared basin, where the rack can be fixed easily, Fig.16 (left). The panels are always covered by sea water when they become cleaned to simulate real-life conditions. At the cleaning process the brushes are positioned always in the same scheme, Fig.16 (right).

4.2. Graduated high water pressure Cleaning

Like the brush cleaning, the graduation in high-pressure cleaning is obtained by different nozzles, which are inserted into the pistol lance of a petrol-powered high-pressure washer with defined settings, Fig.17 (top). The variable factor which determines the force of the cleaning is the angle, which the water jet forms when exiting the nozzle. The bigger the angle the less energy per cm^2 the water jet has. Used nozzles had angles from 40° (white), being the gentlest water jet, to 25° (green) through to 15° (yellow) which had the most abrasive force, Fig.17 (bottom). The red nozzle (0°) was not been used yet.

The procedure of cleaning was the same as for the brush cleaning. After 30 s of cleaning with the white nozzle and if less than 95% of the panel are free of fouling, the cleaning and evaluation is repeated with the green and afterwards with the yellow nozzle, if necessary. The setup for the high-pressure cleaning was the same as for the brush cleaning. For the cleaning itself the water jet followed the same movement pattern as the brushes, Fig.16 (right).

Fig.17: Top: Petrol-powered high-pressure washer; bottom: Nozzles and the corresponding angles of the exiting water jet

5. Test Campaigns

The groundings of offshore structures have a lifetime of 20 years or more, *Blanco (2009)*. Damages of the anticorrosive coatings can have a serious impact on the stability of the constructions. The steel constructions and specifically the welds and connecting parts must be controlled regularly every three years all over the time. The means that some parts of the constructions will be cleaned several times in the lifetime. To simulate the long-term conditions in a 3-year R+D project three different kinds of test campaigns have been initiated.

5.1. Standard testing

Standard testing gives the opportunity to investigate many test coatings. These coatings are cleaned only once at the end of the fouling season and replaced by modified systems in the next season.

5.2. Wear testing

This test variation shall simulate the total number of cleanings during the service-life. Offshore structures have to be cleaned every three years over a period of at least 20 years. This means seven cleanings or more at the end of the lifetime. In the limited project time of three years the coatings become cleaned three to four times a year to simulate this total of cleanings. It is important that new fouling has been grown before every next cleaning procedure.

5.3. Long-term testing

As three years are the average time between two cleaning procedures the fouling organisms will have grown up to larger dimensions. Coatings of this test campaign will be cleaned only once at the end of the project after three years of immersion in 2022. This test variation shall simulate the cleaning of three-year-old fouling individuals.

6. Results 2020 and 2021

6.1. Standard Testing

Until the first test season in 2020, Momentive Performance Materials GmbH and Fraunhofer IFAM each created 19 test systems. All were tested in the harbour of Norderney and replicates of five selected favorites of each partner were exposed additionally at the beachside eulittoral and sublittoral.

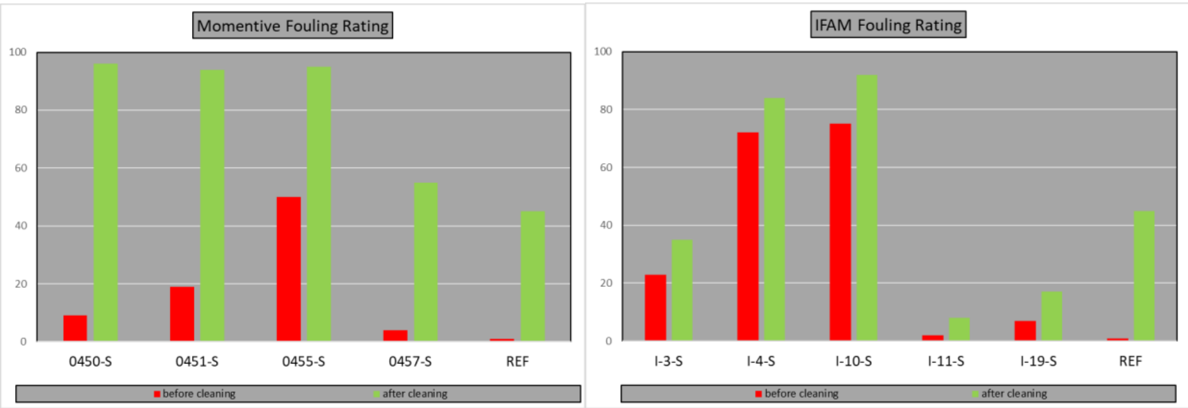

Fig.18: Results of Standard Testing of coatings by Momentive Performance Materials GmbH (right) Fraunhofer IFAM (left) at Norderney beachside eulittoral on October 20th, 2020, after 138 days of immersion. Green: before; Red: after 30 s HPW cleaning with yellow nozzle.

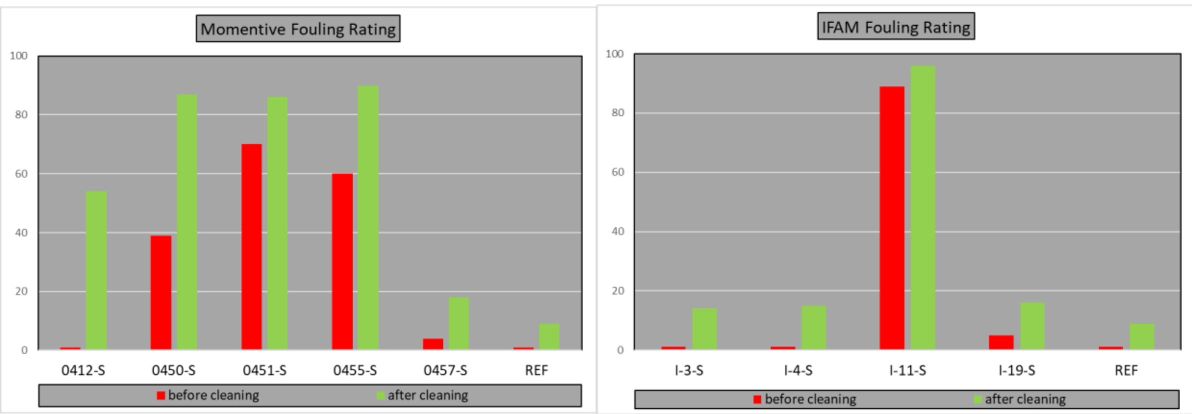

Fig.19: Results of Standard Testing of coatings by Momentive Performance Materials GmbH (right) Fraunhofer IFAM (left) at Norderney beachside sublittoral on October 20th, 2020, after 138 days of immersion. Green: before; Red: after 30 s HPW cleaning with yellow nozzle.

Figs.18 and 19 show the Fouling Ratings of these favorites before and after cleaning by high water pressure. Obviously, most test systems were heavily fouled before cleaning. HPW cleaning by white and green nozzle did not remove the fouling sufficiently. Using the yellow nozzle with an angle of 15°, especially the test coatings of MOM could be cleaned largely. The Fouling Rating increased distinctly on all MOM panels eulittoral and most panels sublittoral. For IFAM coatings there was also an increase but smaller.

6.2. Wear Testing

The five selected favourites of both companies have been selected also for Wear Testing in the harbour and at the beachside. The panels were exposed from May to October and cleaned five (harbour) respectively four times (beachside).

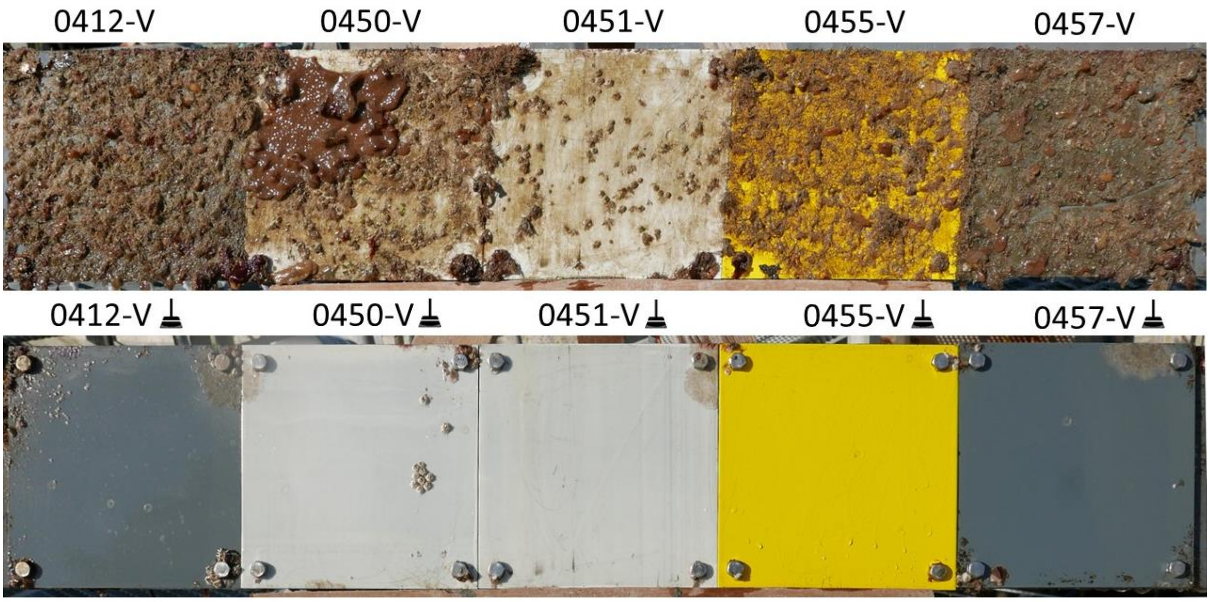

Fig.20: Wear testing of coatings (MOM) in Norderney harbour at 5th inspection on October 22nd, 2020, after 181 days: Top: before cleaning; below: after 30 s cleaning by soft brush.

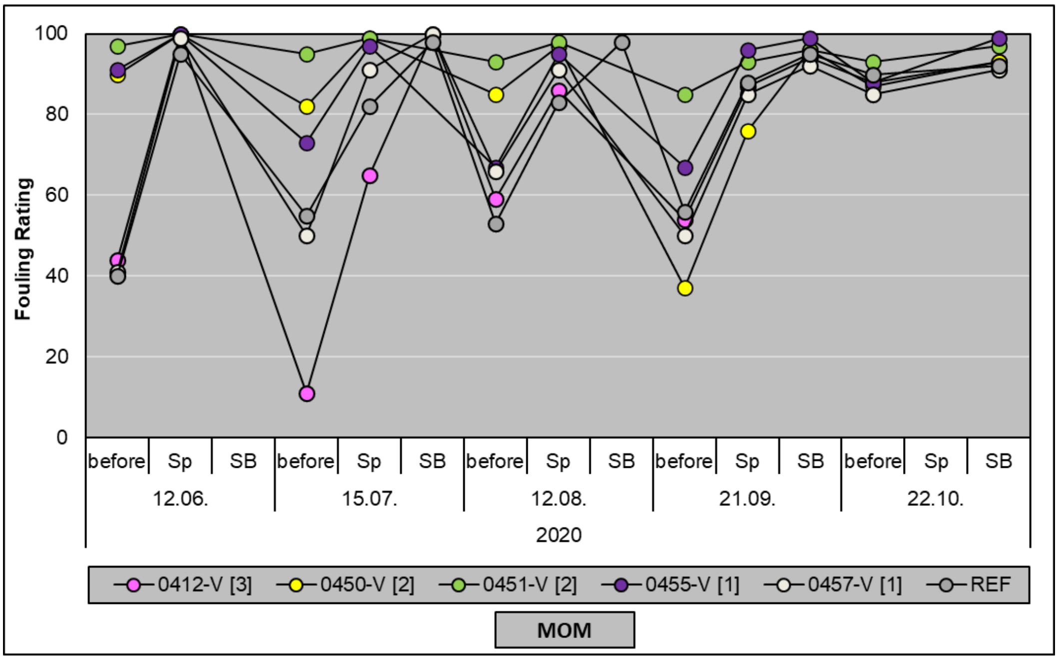

Fig.21: ASTM fouling rating at wear testing of coatings (MOM) in Norderney harbour at five inspections in 2020 before and after 30 s cleaning by sponge or soft brush.

Figs.20 and 22 show the panels at their last inspection at every test site before and after cleaning by brushes. The following diagrams show the course of the Fouling Ratings from first to last inspection in 2020. At the harbour station all test coatings showed Fouling Ratings mostly between 50 and 90 before cleaning and 80 and 100 after cleaning by sponge or soft brush, Figs.20 to 23. The soft brush could remove the fouling organisms without damaging the coatings.

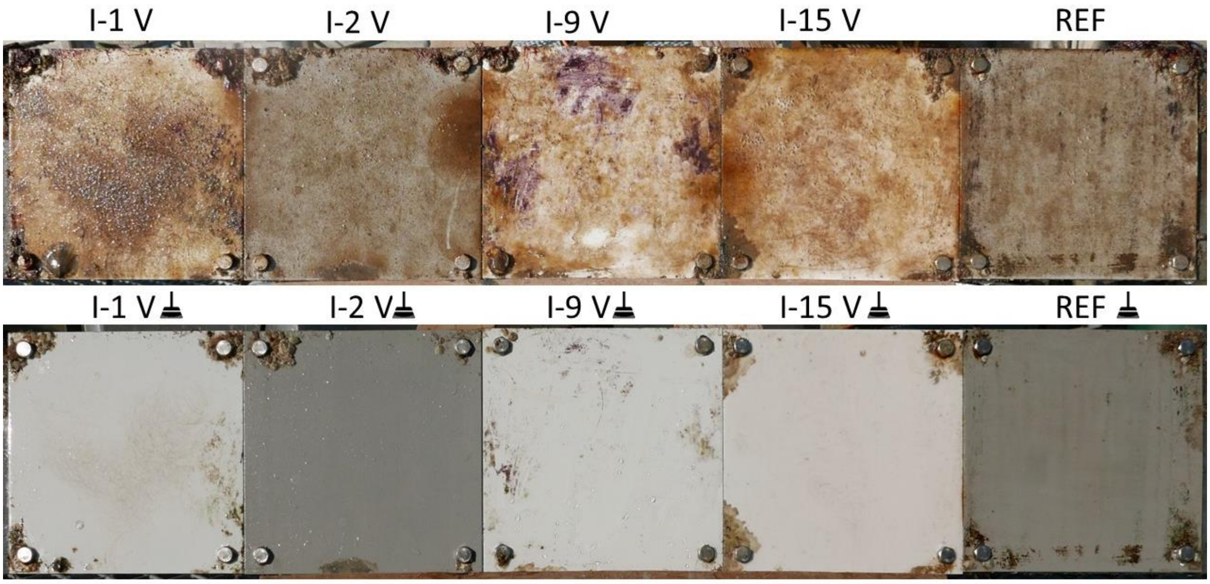

Fig.22: Wear testing of coatings (IFAM) in Norderney at 5th inspection on October 22nd, 2020, after 181 days: Top: before cleaning; below: after 30 s cleaning by soft brush.

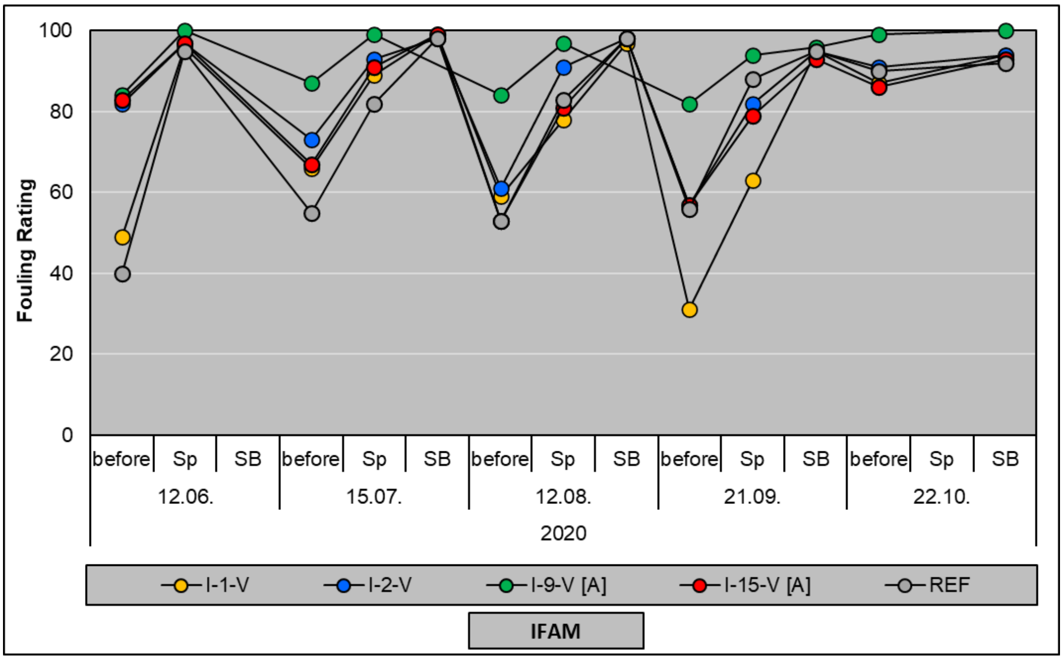

Fig.23: ASTM fouling rating at wear testing of coatings (IFAM) in Norderney harbour at five inspections in 2020 before and after 30 s cleaning by sponge or soft brush.

At the Beach Station the fouling community was strongly dominated by barnacles. In the eulittoral zone the panels were more or less completely covered by barnacles and obtained Fouling Ratings of zero to 40 at every inspection. Cleaning by hard brush could remove most of the barnacles even at fifth inspection, but all coatings have been abraded to a certain degree, Figs.24 to 27.

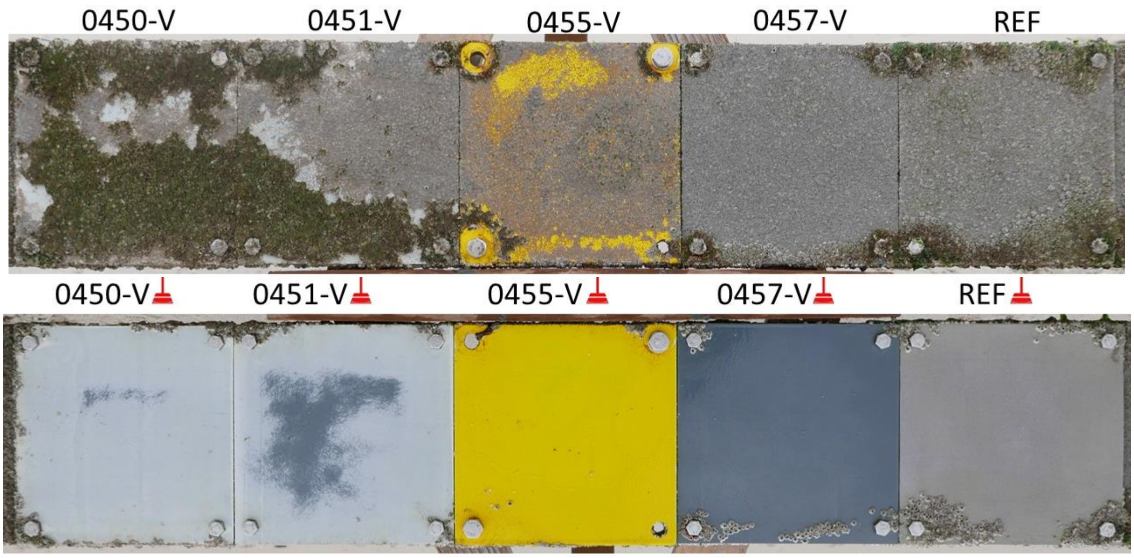

Fig.24: Wear testing (MOM) at Norderney beachside eulittoral at 4th inspection on October 20th, 2020, after 166 days: Top: before cleaning; below: after 30 s cleaning by hard brush.

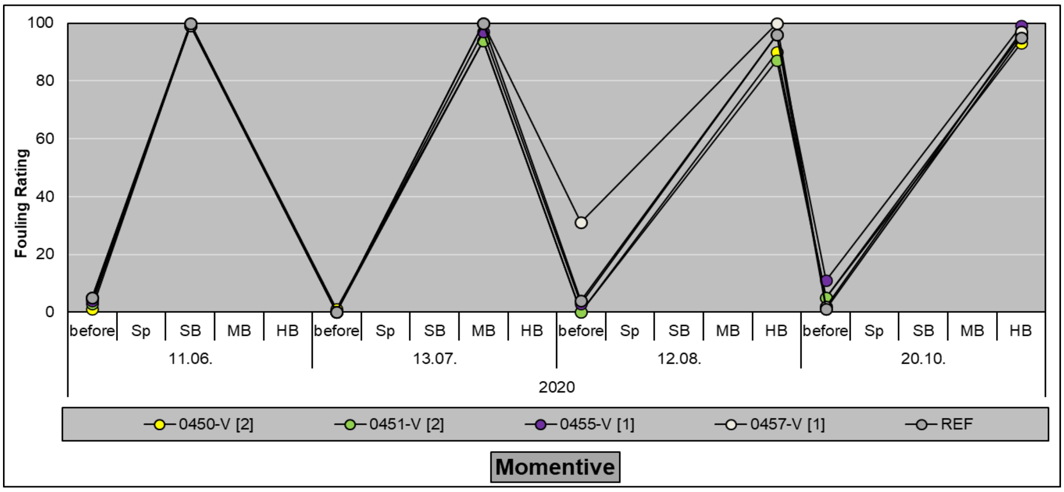

Fig.25: ASTM fouling rating at wear testing of coatings (MOM) at Norderney beachside eulittoral at four inspections in 2020 before and after 30 s by soft, medium, or hard brush.

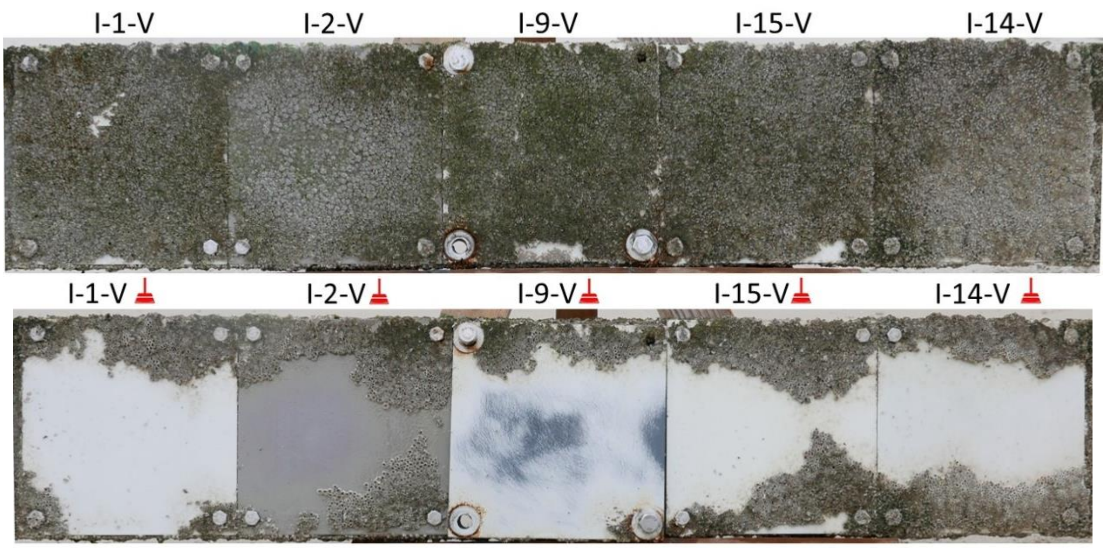

Fig.26: Wear testing (IFAM) at Norderney beachside eulittoral at 4th inspection on October 20th, 2020, after 166 days: Top: before cleaning; below: after 30 s cleaning by hard brush.

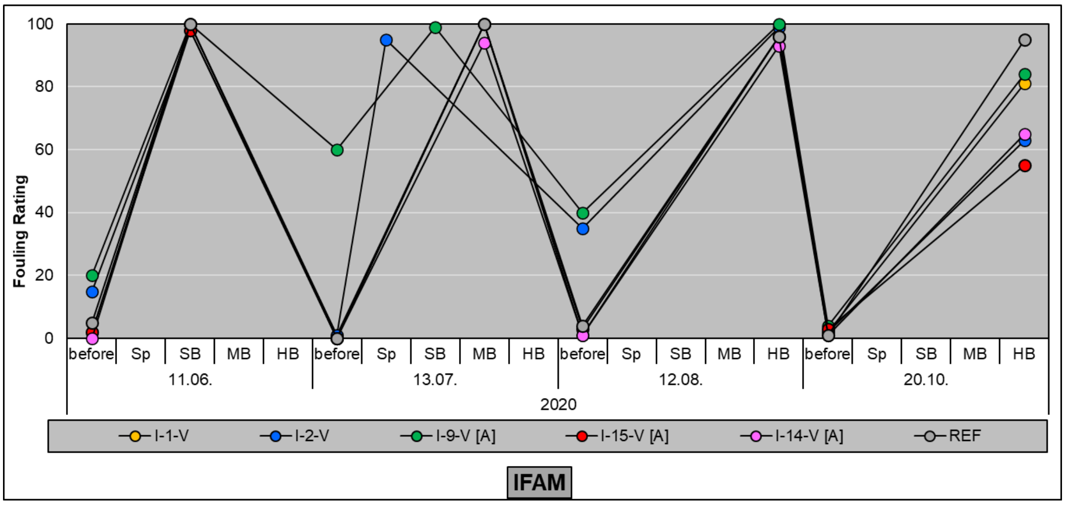

Fig.27: ASTM fouling rating at wear testing of coatings (IFAM) at Norderney beachside eulittoral at four inspections in 2020 before and after 30 s cleaning by soft, medium, or hard brush.

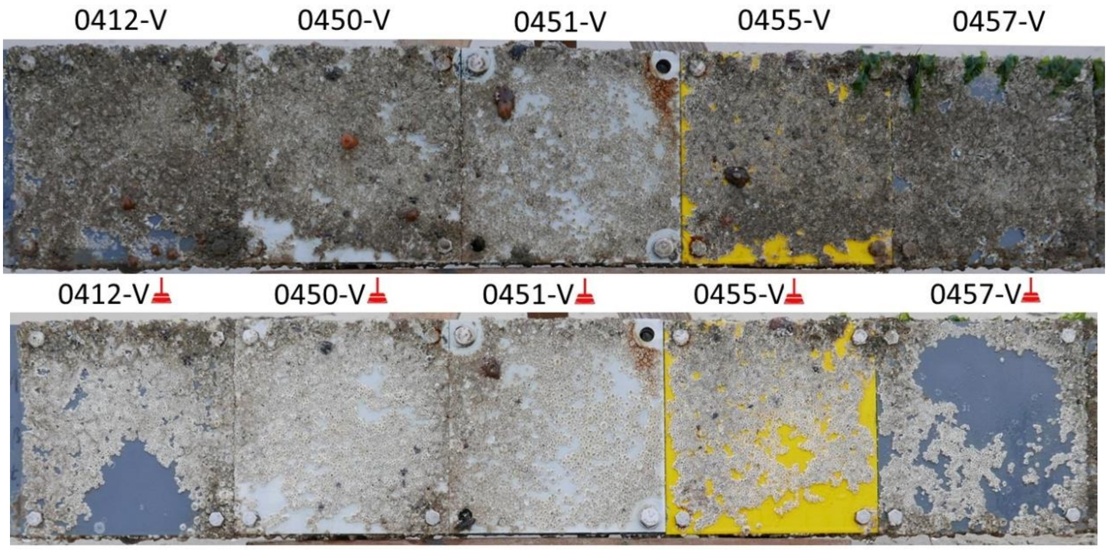

Fig.28: Wear testing (MOM) at Norderney beachside sublittoral at 4th inspection on October 20th, 2020, after 166 days: Top: before cleaning; below: after 30 s cleaning by hard brush.

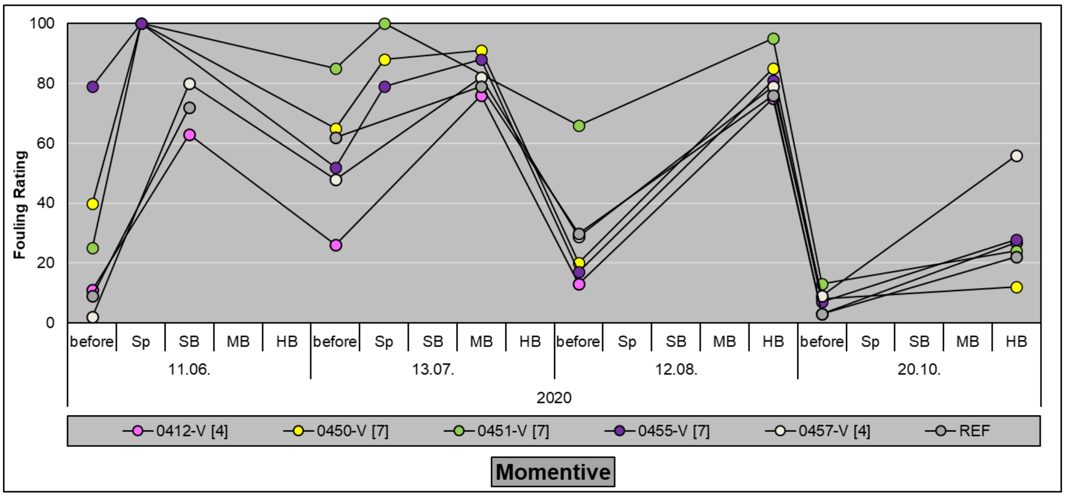

Fig.29: ASTM fouling rating at wear testing (MOM) at Norderney beachside sublittoral at four inspections in 2020 before and after 30 s cleaning by sponge, soft, medium, or hard brush.

At submerged immersion of the test panels at the beachside of Norderney, barnacle size and coverage were even higher. While eulittoral growth is interrupted for ~90 minutes two times a day at low tide, continuous submerged barnacles can filtrate plankton without interruption and grow up faster. And the adhesion of the barnacles also was stronger. Even the hard brush couldn´t remove the barnacles anymore, Fig.28 to 31.

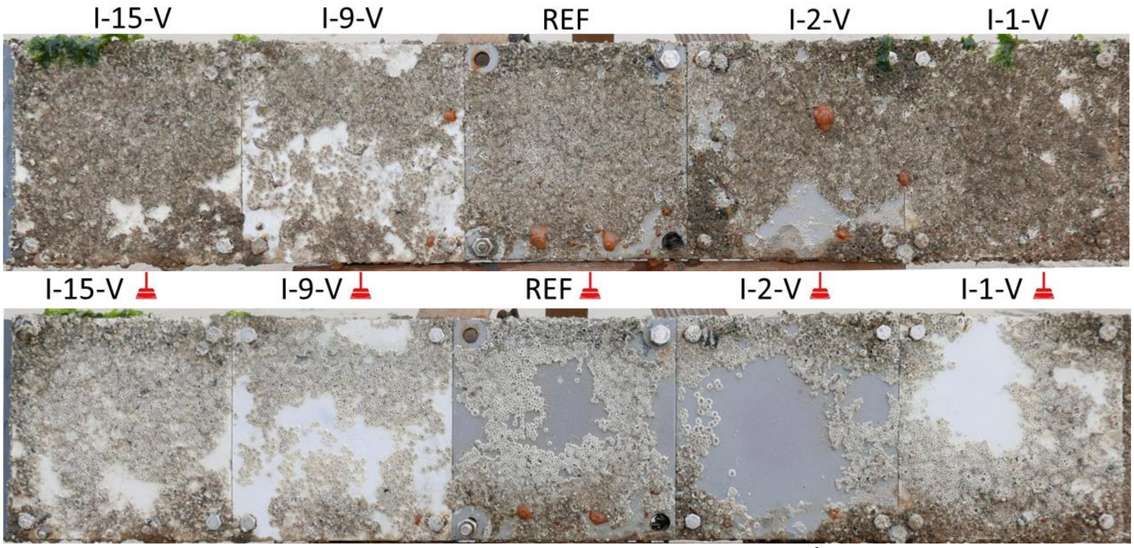

Fig.30: Wear testing (IFAM) at Norderney beachside sublittoral at 4th inspection on October 20th, 2020, after 166 days: Top: before cleaning; below: after 30 s cleaning by soft brush.

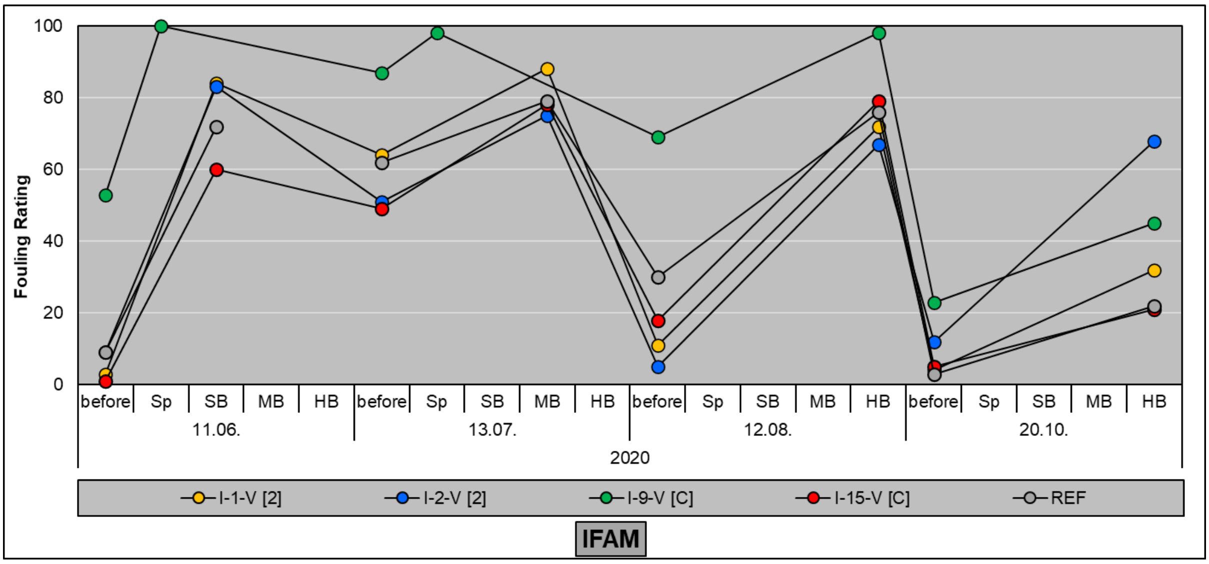

Fig.31: ASTM fouling rating at wear testing (IFAM) at Norderney beachside sublittoral at four inspections in 2020 before and after 30 s cleaning by sponge, soft, medium, or hard brush.

7. Conclusion and Outlook

Recently there has been a lot of research on proactive cleaning, e.g. *Morrissey et al. (2013), Morrissey and Woods (2015), Curran et al. (2016), Scianni and Georgiades (2019), Watermann (2019), Oftedahl (2020), Oliveira and Granhag (2016,2020)* and grooming of ship hulls, e.g. *Tribou and Swain (2015), Hunsucker et al. (2018). Hearin et al. (2015, 2016)* did simulated studies on grooming on large-scale panels. This test strategy has been pursued in the ROBUST project for static offshore structures. As it is much too laborious to do short-term inspections on such offshore structures, simulated conditions have been developed to facilitate tests of a high number of coatings in short time. Different exposure sites have been compared and different test campaigns have been applied to simulate the real offshore conditions with cleaning procedures every three years over a period of 20-25 years.

7.1. Exposure Sites

The fouling mass in the harbour of the islands Helgoland and Norderney were similar. At both sites the panels have been immersed on floating pontoons. Submerged in the harbour of Norderney the species richness was higher with barnacles, sea-quirts, moss-animals, hydroids, and sponges. In Helgoland less fauna but more flora has been registered.

The fouling growth at the beachside of Norderney in 500 meters distance to the harbour was much higher. On eulittoral as well as on sublittoral panels barnacles were very dominant and had covered the coatings surface completely at every inspection after a few weeks. Eulittoral, other species occurred only sporadically, sublittoral a lot of other fouling groups like mussels, hydroids, tunicates etc. occurred at the dolphins, but did not settle in wear-testing, where panels have been cleaned every 4-6 weeks. On long-term panels probably more species will be recorded at the only inspection after three fouling seasons in 2022.

As a conclusion, antifouling tests should be adapted to this different fouling growth: Tests for ship coatings should be conducted preferably at harbour stations, because the settlement on ship hulls predominantly takes place during berthing times.

In contrast, tests for offshore coatings are better placed at stations outside a harbour like the beachside station of DBP on Norderney, where currents, swell, dry periods, and especially the fouling growth resemble the conditions in offshore parks more realistically.

7.2. Test Simulations

The approach of three test campaigns has proven useful for the task, to simulate test methods for a long-term application. The Standard Test Method offered the opportunity of testing a large number of test formulations with one cleaning process at the end of the season.

Wear testing with four to five cleaning processes in 2020 has shown that a lot of test coatings were not robust enough for this cleaning intensity so far. Most coatings had been abraded partly or even completely. Thus, they had been removed unscheduled and replaced in 2021 by modified formulations which should be more robust. Again, they will be cleaned four times during the season 2021. Well performing formulations will be continued until end of 2022, worse performing coatings will be removed and replaced again in spring 2022.

7.3. Graduated Cleaning

The approach of graduated cleaning with soft brushes at the beginning and an increasing force by harder brushes if necessary has proven useful for testing several coatings with a different resistance. Coatings with high FR effect, but low resistance could be cleaned by soft brush without damaging the coating. Other coatings with lower FR performance, but higher resistance needed the middle brush, but they could stand this friction. If even the middle brush could not remove the fouling the hard brush was used. This graduated procedure allows capturing the differences between the test coatings.

Even the hard brush could not remove all barnacles at the sublittoral beachside station, although the friction was so high, that a lot of coatings showed significant abrasion. For locations with high barnacle fouling pressure at least either the FR performance or the resistance has to be improved in the remaining project time.

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The Need for an International Standard for Proactive Hull Cleaning and the Clean Hull Initiative (CHI)

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Abstract

This paper describes the need for an international standard for proactive hull cleaning and introduces the Clean Hull Initiative. It starts by outlining the biofouling challenge and current measures used to combat same. It goes on to define proactive cleaning and describe why proactive cleaning is needed in the biofouling management toolbox. Following a brief summary of the regulatory landscape and the need for an international standard, it concludes by introducing the Clean Hull Initiative and its work on same.

1. Introduction

Biofouling on ship's hulls pose a risk to the environment. Not only does biofouling serve as a vector for the spread of aquatic invasive species, it also increases the hull resistance and decreases the propeller efficiency, leading to higher fuel consumption and increased air emissions. According to the IMO, as much as 2.5 % of the world's Greenhouse Gas (GHG) emissions stems from marine shipping activities (IMO, 2015). 9% of these emissions is the direct result of biofouling on vessel hulls causing increased drag through water. Thus, combating biofouling on hulls can save ~9% of the global fuel consumption and thereby GHG emissions from shipping.

Marine fouling is typically classified in four stages of development. When a surface is submerged in seawater, an organic polymer film forms within minutes. During the next 24 hours, this layer allows bacteria to adhere, and they will form a biofilm (or slime layer). This stage is commonly referred to as microfouling. Within a week, algae and other single-cell organisms will have attached on the slime layer. After 2-3 weeks, organisms such as tubeworms, barnacles, etc, has attached. This is what is known as macrofouling.

Measures to combat biofouling are known as anti-fouling systems (AFS). AFS can generally be divided in two categories; prevention and removal. The most common preventive AFS today is antifouling coatings. These coatings usually contain one or more biocides, which are released into the sea during the coating's life span. A biocide is any chemical substance intended to destroy, deter, render harmless, or exert a controlling effect on any harmful organism.

Another preventive approach is the use of fouling release coatings, which surface properties makes fouling adhesion difficult. These coatings typically require higher speeds to be self-cleaning. Fouling removal (or cleaning) is done mechanically, and can be done in-water (in-water cleaning (IWC)) or in dry dock. Cleaning of the first two stages of fouling require minimal force, and is referred to as "proactive cleaning". Removing the last two stages of fouling require more force, and is commonly referred to as "reactive cleaning".

Inherent risks during fouling removal are erosion or damage to the coating and release of aquatic invasive species to the local marine environment. Erosion or damage to the coating can lead to excessive release of biocides and/or coating particles being released into the local marine environment. Furthermore, it can deteriorate the anti-fouling properties of the coating, leading to a potential increased risk of fouling during further operations.

IWC on macrofouling can cause release of aquatic invasive species to the local marine environment. To combat this, many technologies include mechanisms to capture the organic debris removed from the hull. However, requirements for capture vary between different ports and port states. Some countries have no requirements for capture, others have strict requirements such as 90% capture or higher. However, quantifying the accumulated and removed biomass is challenging. No standard methods exist to quantify and document amount of biomass removed or to verify capture rates. The recently published BIMCO standard for in-water cleaning requires that 90% by mass of captured debris shall be separated/treated but does not specify what share of total debris shall be captured in the first place, *BIMCO (2021)*.

2. Proactive In-water Hull Cleaning

Proactive cleaning is a new tool in the biofouling management toolbox. Instead of relying on antifouling properties in paint alone, paint is combined with cleaning at a sufficiently high frequency so as ensure any biofouling is removed before it becomes a problem.

Biofouling is removed before it causes a measurable reduction in hull performance and corresponding increases in both carbon intensity (grams of CO2 emitted per ton-mile) and fuel cost. Biofouling is also removed before it reaches the macrofouling stage and as such before it comes to represent a risk of transfer of invasive species. Note that slight/micro (very early stages) algae is included as microfouling. This as it is very difficult, and at today's technology boundary impossible, to visually distinguish between slight/micro algae and other microfouling and as slight/micro algae is generally considered not to represent a risk in terms of transfer of aquatic invasive species. Finally, the biofouling is removed before it has firmly attached to the hull surface and therefore before removing it results in a risk of damaging or eroding the hull coating and thereby also a risk of contaminating the water column.

For ships in challenging operations as viewed from a biofouling management perspective, conventional antifouling paints cannot (yet) offer fully reliable protection against fouling. Examples of what can make operations challenging from a biofouling management perspective are extended idling periods, major changes in ship's operating profile (e.g. a major increase or decrease in seawater temperature or operating speed) and unplanned extensions of dry-docking intervals. Proactive cleaning is, at the current technology boundary, the only solution that can reliably keep the hull clean in such situations.

In principle cleaning can be done proactively using any technology platform; divers, brush carts, swimming or crawling ROVs. In order to fall under the definition of proactive cleaning, however, the cleaning must be done at a sufficiently high frequency so as to remove any fouling before it becomes a problem and must be done with a sufficiently gentle force so as not to damage or erode the hull coating.

As long as the cleaning is proactive, capture of debris should not be necessary. By definition, fouling is removed before the macrofouling stage (excluding slight/micro algae) and as such before the debris is generally considered to represent a risk in terms of transfer or aquatic invasive species. Also by definition, the fouling is removed with sufficiently gentle force so as to ensure no damage to or erosion of the coating. The debris will therefore not represent a risk in terms of contamination of the local water column.

Some have argued that one may as well require capture of debris anyway. At the current technology boundary, however, collection of debris significantly increases cost and complexity and a requirement to do so would likely represent a barrier to greater proactiveness. This is problematic. As long as available capture technologies remain imperfect a proactive strategy (focusing on greater proactiveness) should yield a lower risk of transfer of aquatic invasive species and / or contamination of the local water column than a capture strategy (reactive cleaning with focus on capture).

All else being equal, a proactive strategy should also result in improved energy efficiency and reduced carbon intensity as compared with a capture strategy. When cleaning is done reactively hull performance is allowed to deteriorate before fouling is removed. This results in an average over period performance loss as compared with keeping the hull always clean. The higher level of abrasiveness needed to remove fouling that has firmly attached increases the probability of damage to and erosion of the hull coating. We observe that hull performance is seldom fully restored, and that new biofouling growth tends to accelerate following each reactive cleaning. Over a full dry-docking interval, the average over period performance loss associated with reactive cleaning is therefore often substantial.

A real-life example of changes in hull performance on a reactively cleaned vessel is provided in Fig.1. Note accelerated drop in performance and that starting point for hull performance is lower following each cleaning event. Average over period speed loss, as per ISO 19030-2, was 6.2%. As compared with keeping the hull always clean, decrease in energy efficiency and increase in carbon intensity was around 18.6%.

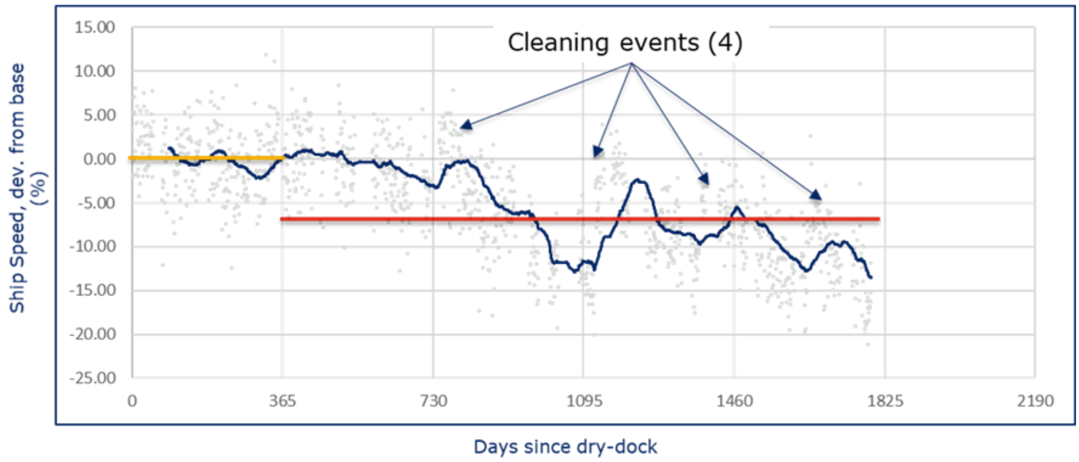

Fig.1: Real-life example of changes in hull performance as per ISO 19030-2 on reactively cleaned vessel

The availability of reactive cleaning with capture is still important. On ships where a proactive cleaning strategy has not been adopted or fails, reactive cleaning with capture is less risky than reactive cleaning without.

The best strategy from a risk reduction perspective, therefore, is to stimulate both greater proactiveness as well as improvements in capture technologies. For ships in challenging operations where conventional antifouling paints cannot (yet) offer fully reliable protection against fouling, proactive cleaning should be seen as part of the 1st line of defense. Cleaning with capture is the 2nd line of defense for the event that the 1st fails, Fig.2.

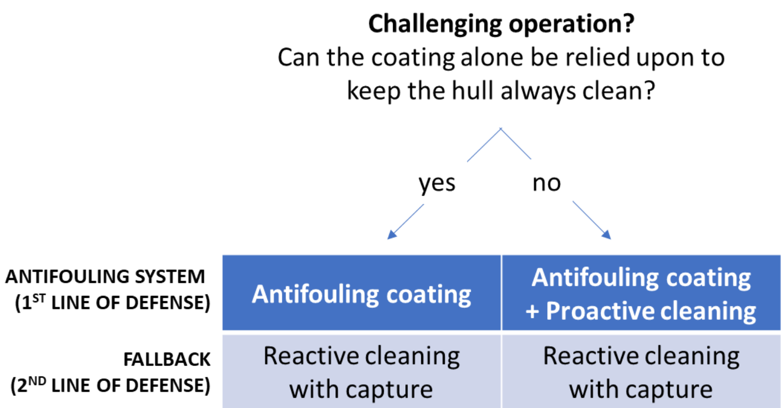

Fig.2: Defense options

Simply prohibiting cleaning altogether is not a good solution. In addition to the obvious negative consequences in regard to energy efficiency and carbon intensity, a hull with severe fouling idling at a port or at an anchorage pose a risk in terms of transfer of aquatic invasive species also in the absence of any cleaning action. Once present, assuming the local eco-system is habitable, there is a risk such aquatic invasive species "jump ship". It is in everyone interest that fouling is removed before it comes to represent a risk of transfer of aquatic invasive species. The more ports and anchorages that allow responsible cleaning to take place (proactive or reactive with capture), the lower the likelihood that ships will be heavily fouled. For this to be possible, decision makers with jurisdiction in ports and at anchorages must first agree what constitutes responsible cleaning.

3. The need for an international standard

The regulatory environment in ports and at anchorages is complex. There is no international governing body and often multiple overlapping jurisdictions (e.g. national, regional and local as well as more than one agency at any one level).

In addition to commercial and operational issues, regulations tend to focus on managing risks to environment, personal safety and/or asset security. Under environmental risks, focus tends to be on risk of transfer of aquatic invasive species and/or risk of contamination of local water column on account of release of biocides or paint particles. There is no general agreement on what level of risk is acceptable and how best to manage either of these risks, however.

For in-water cleaning activities, current regulations and guidelines, if any, tends to be focused on reactive cleaning and associated challenges. There is limited regulatory precedence within the area of proactive cleaning. A decision on whether or not to grant permission to proactively clean therefore typically involves determining whether or not the proposed proactive cleaning activity delivers on either very general requirements and/or more detailed requirements developed for other purposes. Such decisions are therefore often very difficult – even more so given overlapping jurisdictions.

There are signs this is now changing. Reflecting and increased awareness of the benefits of including proactive cleaning as a tool in the biofouling management toolbox, as national and international regulations and guidelines on biofouling management and in-water cleaning are being updated, support for proactive cleaning is included.

The Australian Department of Agriculture's "Antifouling and In-water Cleaning Guideline" published in 2015 states that "Microfouling, regardless of origin, may be removed without the need for full containment of biofouling waste, provided the cleaning method is consistent with the coating manufacturer's recommendations. Where microfouling is removed using a gentle, non-abrasive cleaning technique, the contamination risk is likely to be acceptable", *ADA (2015)*.

Along the same lines, US EPA's proposed rules on "Vessel Incidental Discharge National Standards of Performance" published in 2020 states that "EPA expects that regular cleaning of biofouling consisting of FR-20 or below, in combination with the potential for controlled cleaning of biofouling exceeding FR-20 through IWCC devices, represents best available technology…", *EPA (2020)*. FR20 is a reference to the fouling rating scale in US Naval Ships Technical Manual and refers to fouling limited to microfouling.

Also the Canadian Ministry of Transportation's "Draft Voluntary Guidance for Relevant Authorities on In-water Cleaning of Vessels" published in 2021 state that microfouling can be removed without capture. It furthermore states that "if a vessel only has microfouling on the hull but has macrofouling on niche areas, cleaning without capture can still happen if there is a low chance that the niche area will be affected by the cleaning system", TC (2021).

Finally, the IMO is also considering including proactive cleaning as a part of their updated Biofouling Guidelines – the first draft including a separate chapter on same.

While support for proactive cleaning is increasingly included in national and international regulations and guidelines, what is required to bring environmental and other risks to an acceptable level differs. Furthermore, it is part of the nature of proactive cleaning that it must be allowed pretty much everywhere for it to deliver on its full potential. There is a need for generally agreed upon definition of proactive cleaning, and what is required to bring environmental and other risks to an acceptable level. There is a need for an international standard.

4. Clean Hull Initiative

The Clean Hull Initiative (CHI) is led by The Bellona Foundation, a Norwegian non-profit environmental NGO, and is supported by Jotun. The objective of the work towards "development and implementation of an industry-wide recognized and accepted standard for proactive hull cleaning".

The CHI aims to bring together key stakeholders from the industry, public sector and civil society, to "build a multi-stakeholder platform". The platform shall act as a forum where stakeholders can come together and discuss, with a goal to reach consensus on a standard for proactive hull cleaning. All work carried out under this initiative is pre-competitive, meaning that we do not promote any specific company or product, but instead help accelerate the development of a new greener shipping industry by creating a level playing field for new innovations to be used in the proactive cleaning of ship hulls.

Key success factors for the platform will be to ensure collaboration and consensus in the industry, and communication and awareness raising of the importance of proactive hull cleaning from both an environmental and a financial perspective.

One activity of the CHI is to develop a set of guidelines for pro-active hull cleaning in ports. The guideline will contain minimum requirements and procedures for proactive hull cleaning that ports can apply in their local setting. The completion of the proactive hull cleaning guideline will ultimately lead to the development of a global industry standard.

5. Summary and conclusions

Biofouling on ship's hulls pose a risk to both the marine environment and to the environment. It serves as a vector for the spread of aquatic invasive species and it also increases the hull resistance and decreases the propeller efficiency, leading to higher fuel consumption and increased air emissions. Combating biofouling on hulls can save roughly 9 % of the global fuel consumption and thereby GHG emissions from shipping.

Proactive cleaning is a new tool in the biofouling management toolbox. Instead of relying on antifouling properties in paint alone, paint is combined with cleaning at a sufficiently high frequency so as ensure any biofouling is removed before it becomes a problem. Biofouling is removed before it causes a measurable reduction in hull performance and corresponding increases in both carbon intensity (grams of CO2 emitted per ton-mile) and fuel cost. Biofouling is also removed before it reaches the macrofouling stage and as such before it comes to represent a risk of transfer of invasive species. Finally, the biofouling is removed before it has firmly attached to the hull surface and therefore before removing it results in a risk of damaging or eroding the hull coating and thereby also a risk of contaminating the water column.

For ships in challenging operations as viewed from a biofouling management perspective, conventional antifouling paints cannot (yet) offer fully reliable protection against fouling. For these ships proactive cleaning is a part of the 1st line of defense. Cleaning with capture is the second line of defense for the event that the first fails.

It is part of the nature of proactive cleaning that it must be allowed pretty much everywhere for it to deliver on its full potential. Reflecting and increased awareness of the benefits of including proactive cleaning as a tool in the biofouling management toolbox, support for proactive cleaning is increasingly being included in national and International regulation and guidelines. However, a generally agreed upon definition of proactive cleaning, and what is required to bring environmental and other risks to an acceptable level, is still needed.

In an effort to contribute towards such general agreement, The Clean Hull Initiative (CHI), led by The Bellona Foundation and supported by Jotun, is working towards development and implementation of an industry-wide recognized and accepted standard for proactive hull cleaning.

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In-Transit Cleaning of Hulls

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Abstract

A new method allows In-Transit Cleaning of Hulls (ITCH) by "grooming". ITCH at commercial speeds avoids the need of idling vessels in harbor for cleaning operations. The effluents from the cleaning operations with ITCH are disposed in deep waters offshore, with an objective of avoiding costal pest invasions. The ITCH method has been successfully utilized commercially and for tests on vessels with speed of between 9 and 19 knots at sea. The paper will discuss the learnings from the initial tests. The overall objectives of the ITCH are to clean the hull while maintaining the vessel schedule, to have very low costs per hull cleaning and to avoid damages to the hull paint.

1. Introduction to In-Transit Cleaning of Hulls

The commercial motivation for cleaning vessel hulls under water is to reduce the fuel consumption related costs, which is a large part of the total operating costs of commercial vessels. The hydrodynamic surface roughness caused by biofouling is reduced, and the viscous resistance is lowered. The environmental motivations are to avoid transport of invasive species and reduce greenhouse gas emissions due to a lower fuel consumption.

The cleaning methods has traditionally involved divers or dry docking, but underwater cleaning techniques are nowadays much more common due to the lower cost and shorter off-hire durations. Some challenges with the methods are:

- Off-hire time of vessel because
    - travel to port with cleaning facilities or to a cleaning location
    - waiting for cleaning and the cleaning operation
- Disruption of the schedule of the vessel causing cleaning to be deferred
- Rough methods degrade the antifouling paint, increasing marine growth for the future
- Low-cost In-Port Hull Cleaning treatments disperse waste such as invasive species and antifouling residue

Fig.1: Winch on forecastle deck with rope via fairlead

As an alternative to in-port cleaning, frequent brushing with low forces were attempted (grooming), *Hunsucker et al. (2019)*. Grooming provides a superior surface, however, its limited commercial popularity may be due to the logistics of frequent treatments. To overcome these challenges, the ITCH system was developed.

2. In-Transit Cleaning of Hulls

Except for port calls for cargo operations and fueling, a ship is an independent unit. Crews takes pride in maintaining and running the ship uninterrupted and in shipshape. Traditional hull cleaning does not allow the crew to maintain the underwater hull. It has been performed by third-party specialists.

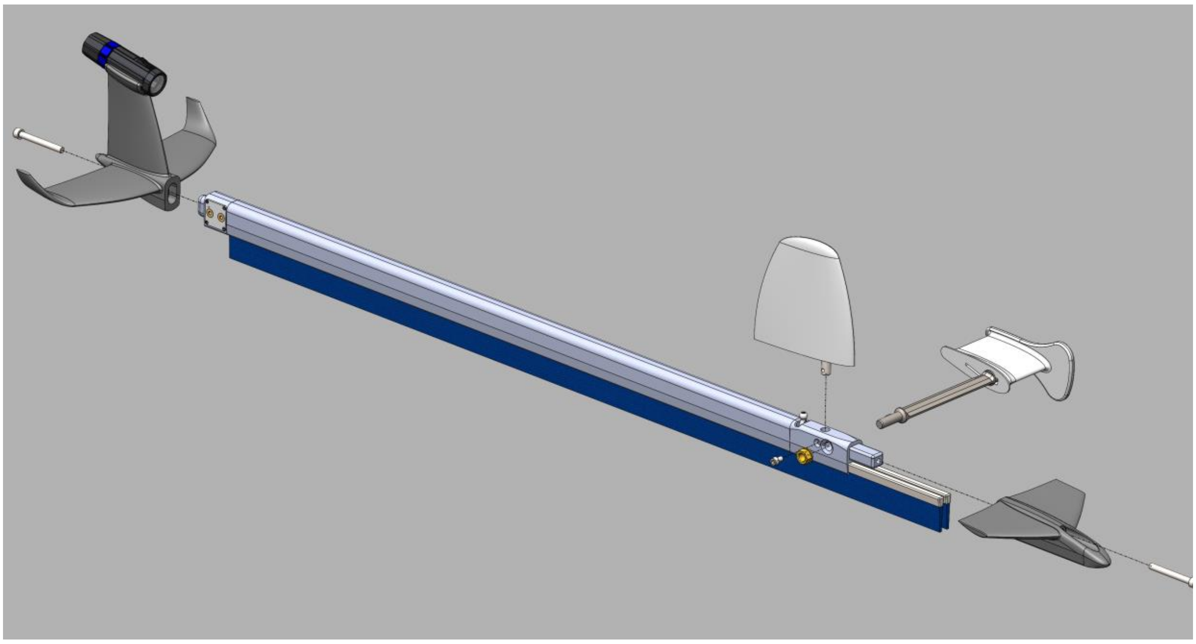

Fig.2: ITCH robot

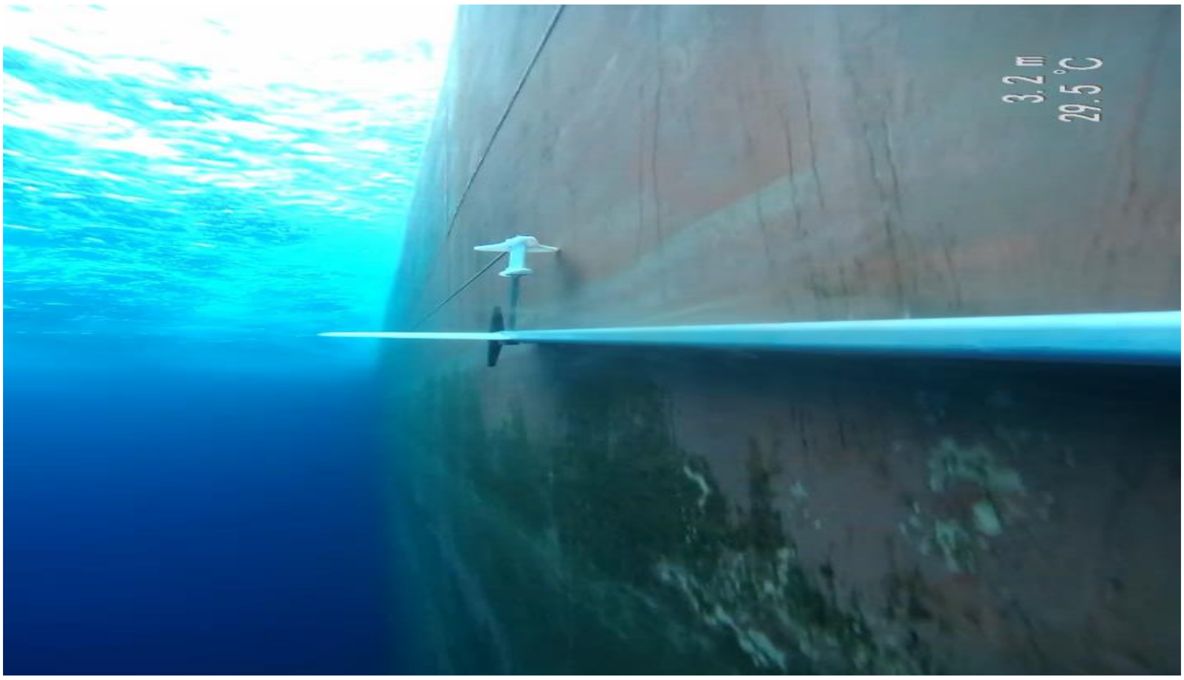

Fig.3: The robot is pulled forward by the winch in an overlapping pattern

The ITCH solution shall enable the crew to gain control over hull performance. A portable winch is positioned on the forecastle deck. The ITCH robot is lightweight and hydrodynamically efficient, enabling easy manual deployment. The rope is led out via one of the foremost fairleads together with an ITCH robot. The ITCH robot has a rudder to maneuver and use the energy of the waterflow around the vessel to clean the hull. The robot automatically senses its position and conducts a vertical movement up and down on the hull sides while soft brushes are forced against the hull. The number of sweeps on each location can be defined through the combined settings of the winch and the settings on the ITCH robot software.

The method uses non-rotating, soft brushes in a swiping motion with controlled hydraulic forces and a controlled number of strokes. A camera is attached to the ITCH Robot and can visually display videos with the effects of cleaning and the condition of the hull.

The technology development has focused on basic functionality, robustness and user friendliness.

3. Testing and commercial use

Till date the ITCH system has been tested at 26 different vessels from 60 m coasters up to a 340 m long container vessel. The ITCH system has been used up to 28m/s winds. It has been used between 9 and 19 knots boat speeds. 28 m/s wind and 19 knots boat speed appear violent, but still the equipment operated well and survived. Both are outside the recommended operating limits.

8 systems have been delivered to vessels whereof 3 systems have so far been in operation by the seafarers. The equipment has been operated down to 12 m depth so far, though the system has not reached its limit. Several crews have been successfully operating the equipment without onsite induction or specialist supervision. The equipment has in all cases visibly removed fouling, however established fouling may not be completely removed. In the cases of established fouling, slower winch speed results in repeated cleaning strokes, leading to more complete fouling removal. Clouding because of removal of depleted surfaces of self-polishing antifouling is sometimes seen, but antifouling damage is not seen.

4. Hull performance measurement

It is notoriously difficult to get accurate and quantitative data on fuel consumption in shipping.

One hull cleaning test was executed on a Platform Support Vessel (PSV) that had no hull cleaning for about 3 years. The ship was sailing with 2 out of 4 engines on full throttle back and forth in the same waters and the averages taken. The increase in boat speed was 5.6%, indicating a theoretical vessel power reduction of 17.6%.

One ship owner was utilizing the ITCH over 4 months on a 238 m long combination carrier mainly trading in tropical waters. The ship was utilizing a fuel efficiency software that indicated reduced overconsumption of approximately 5%. After this pilot, the ship owner invested in two ITCH systems for other vessels.

5. Hull condition inspection

Many researchers advocate visual monitoring of hulls before cleaning to minimize paint wear and cleaning cost. The hull may be inspected by divers or ROVs to determine the need for an in-port cleaning operation. Qualitative information can be had, but quantitative is hard to get accurate as it depends on light, diver training, and other factors. The ITCH system may exhibit a cleaning cost for a hull that is lower than the survey cost. The soft brushes will likely eliminate paint cleaning damage. With a low-cost, neglectable damage cleaning method, inspections with high relative cost may provide less value.

Furthermore, the ITCH system has a video camera showing the cleaned surface before, during and after cleaning on the same screen picture. Because of the rapid flow during transit, released biofouling plumes may be seen, but the vision is unimpaired. One does not only get a regular hull cleaning, but also a regular hull inspection.

6. Invasive species and antifouling disposal

Hull fouling leads to the transportation of invasive species. Cleaning in port, dock or slipways contributes to such pests when ships are cleaned without complete capture and destruction of effluent. The antifouling polymeric components and its included biocides may also be released to accumulate in harbor sediments. IMO and others target to develop global regulations to avoid geographic variations to protect near shore aquatic environments. Researchers also point to the technical complexity of full effluent capture of in-port cleaning systems. From an environmental perspective, hull cleanings should be performed at locations where pollution and pest cannot spread, such as well controlled dry docks or the open ocean.

7. Cleaning frequency

Commonly hull cleanings are performed during scheduled dry docking and with in-water cleaning in between dry docks. In trials, the users of ITCH have applied in varying frequency when it fits in the vessel schedule. With the low cost and limited wear of the antifouling ITCH enables as high frequency of cleaning as desired.

8. Hull cleaning cost

The variable cost components of ITCH hull cleanings are estimated to:

Cost element	
Idling of vessel and crew	No cost
Crew hours	Less than one shift
Disruption of Trading schedule	No cost
Service crew and equipment rental	No cost
Scheduling and management	No Cost
Added fuel in operation	Drag power may be 1-4kW. With 5 hours of operation for one cleaning with 0.20USD per kWh, the cost is 1-4USD per cleaning
Consumables	Less than 300 USD per clean

There is an upfront investment in the ITCH system.

9. Further work

The method and tools are new, and the information presented is “hot off the press”. The testing till date verifies tool functionality and visually shows the efficacy of cleaning. Quantification of fuel efficiency benefits depends on trade, vessel, parameter control and data quality. Despite of testing in many different ships and working environments, further qualifications may be required for specific applications such as high seas, high speeds, silicone antifouling systems and calcareous fouling. Users needs to optimize on scheduling of cleaning so that the hull does not get overgrown between cleanings.

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Index by Authors

3rd In-Port Inspection & Cleaning Conference (PortPIC)

Hamburg / Germany, 12-14.9.2022



Topics: Aquatic Invasive Species / Diver operations in port / Next-generation antifouling technologies / Operator perspective on cleaning / Performance-based cleaning / Regulations & Guidelines / Robotic cleaning & inspection

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Venue: The conference will be held at the “Katholische Akademie” in central Hamburg

Format: Papers to the above topics are invited and will be selected by a selection committee.
The proceedings will be made freely available to the general public.

Deadlines:

anytime	Optional “early warning” of interest to submit paper / participate
02.05.2022	First round of abstract selection (1/2 of available slots)
15.06.2022	Second round of abstract selection (remaining slots)
21.08.2022	Final papers due (50 € fee imposed for late papers)

Fees: **700 €** – early registration (by 21.08.2020)
800 € – late registration

Fees are subject to German VAT
Fees apply also to presenting authors
Fees include proceedings, lunches, coffee breaks, and the conference dinner

Sponsors: Jotun, Tutech Innovation, Fleet Cleaner, Hasytec, HullWiper
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