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Assessing the Economic and Environmental Impact of Biofouling Management on Ships Using Remotely Operated Vehicles (ROV) Underwater Cleaning System: A Case Study in Indonesia

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***Abstract*— The maritime industry is currently facing challenges due to the increase of biofouling on ships, because it can potentially affect operational costs, fuel consumption, and exhaust emissions. Indonesia is in the tropics, biofouling growth on ships is faster than the Mediterranean region. The purpose of the observation is to find out the challenges and how Remotely Operated Vehicles (ROV) work in the underwater Cleaning system used to minimize biofouling growth on ships and the impacts it causes in Indonesia. Observations were carried out using a combined quantitative and qualitative methodology with an analysis method using triangulation methodology, and comparative analysis will be used. According to analysis findings to assess the environmental and economic effects of using ROV for biofouling cleaning, there are differences in fuel consumption results in the ship fuel usage data sample before and after cleaning using ROV. The Paired T test with the SPSS test tool was used to analyse the significance of the average difference from the sample data, and the average difference in fuel consumption is 1.11 MT, or 4.03 percent. The calculation of CO2 emissions in the sample fuel data resulted in a CO2 reduction of 139,400 tones, or 4.04 percent. With the positive assessment and benefits of using ROVs in Indonesia, surely in use there are various challenges faced and need to be properly addressed.**

Keywords*— *Ship Biofouling Management, Underwater Cleaning, Remotely Operated Vehicles (ROV), Economic and Environmental Impact.

I. INTRODUCTION

Biofouling on ship hull occurs due to microbial growth membrane surface and/or across the spacer-filled membrane feed channels to form a biofilm layer [1]. Biofouling is generally divided into two based on size, among others; microfilming is the attachment of small organisms such as bacteria and algae, while microfilming is the attachment of larger organisms such as barnacles, mussels, and polychaeta worms [2]. Biofouling grows and develops rapidly in various man-made structures that are submerged in water, one of which is the hull of a ship.

Indonesia consists of 5.8 million km2 of ocean area or 70% of its total area, making it the largest archipelago in the world with the second longest coastline [3]. As an archipelago, maritime transportation is essential to maintain connectivity between regions and islands and Indonesia's growing maritime sector has become a barometer of the country's development and growth [4]. Geographically, Indonesia is located in the equatorial and tropical region which causes faster biofouling growth compared to the Mediterranean region. [5] found that the mechanism of biofouling development is amplified by higher water temperatures and increased nutrient content in tropical seas.

Indonesia is a tropical country, so one of its main responsibilities is to deal with biofouling on ships. As an IMO category C member, Indonesia is part of an international strategy programmed called GloFouling, which was shown at the IMO 2023 session in London. As part of the International Maritime Organization's (IMO) larger plan to protect and maintain marine ecosystems from the damage caused by invasive species and the economic losses caused by ship biofouling, the UNDP and the Global Environment Facility (GEF) established the GloFouling partnership [6].

Marine biofouling has been found to cause disaster in ship operations for many years. The development of biofouling on a vessel will increase the hydrodynamic drag of the vessel. The immediate impact is a reduction in vessel speed at a fixed power - or an increase in power to maintain a fixed speed [2]. Both have negative economic and environmental impacts with increased fuel consumption and increased greenhouse gas emissions [7].

The economic aspect of biofouling on ships is detrimental to shipping businesses because the friction created by adhered organisms lowers ship performance and raises maintenance expenses [8]. The cost of ship fuel when the hull is lightly soiled by an average of 10% and when the hull is heavily soiled increases by an average of 35%, this was conveyed in a study by Munk et al (2009) [9]. According to Carmelita Hartoto, Chairperson of the Indonesian National Shipowners Association (INSA), fuel prices in Indonesia are significantly impacted by increases in the price of coal and crude oil on the global market. Because fuel is the biggest expense component in the ship's operating structure, this causes a 30 to 40% increase in the operational costs of commercial transportation [10].

The investigation of ship biofouling management needs to be carefully evaluated since Indonesia is a tropical nation that biofouling growth will be quicker [5]. Generally, every 3-5 years commercial vessels undergo dry dock, but for some vessels, this period can be extended to 7.5 years [7]. During this period, a large biofouling growth can attach to the immersed part of the ship's surface [11]. Especially during longer immobile periods. In addition, ship biofouling can serve as a vector for the translocation and introduction of non-native organisms around the world [12].

Ship biofouling management, simply put, consists of measures to maintain hull cleanliness. Currently, ship biofouling management includes two main methods: Coating and Underwater cleaning system (UWCS) [13]. Underwater cleaning is the current approach applied to remediate biofouling accumulation during in-service and typically involves divers or remotely operated cleaning systems or cart systems. The UWCS reduced hull and propeller biofouling by 82-94% [14]. Biofouling underwater cleaning systems (UWCS) to maintain or restore submerged vessel surfaces to a hydrodynamically clean condition are a common approach to improving vessel performance and fuel efficiency in between dry-dockings [15].

With the dry-docking time to carry out maintenance of ships from biofouling which has been determined periodically and the dry-docking costs which are quite large, the underwater cleaning system is a good step in reducing biofouling on ships and can answer the challenge of losses caused by biofouling on ships from both economic and environmental aspects. The underwater cleaning system itself uses several methods and equipment, including cleanup using divers with existing equipment and Remotely Operated Vehicles (ROVs) with a remotely controlled robotic cleaning system. The cost of using Remotely Operated Vehicles in the underwater Cleaning system tends to be cheaper compared to cleaning using diving or dry dock and can be carried out in waters where cleaning is difficult with underwater diving. The purpose of the observation is to find out how the Remotely Operated Vehicles cleaning system works on the underwater cleaning system in minimizing the growth of biofouling on ships and the impact caused by it on the underwater cleaning system.

II. METHODS

A combination of quantitative and qualitative approach forms the basis of the research design, which integrates primary and secondary data from sources like academic publications, case study reports, interviews, and feasibility calculations. Paired T-test, comparative analysis, and triangulation methods will all be used in the data analysis process. In a literature review, triangulation refers to the process of validating or strengthening study findings through the use of multiple data sources, methodologies, or analytical approaches. When evaluating the impact of an intervention or anticipated change in the same sample, the paired t-test can be employed. When comparing the means of two or more groups or treatments to see if there is a significant difference between them, the average comparison analysis approach is used in statistic [16].

Obtaining the two sets of data will be the analytical stage. Quantitative analysis may involve statistical analysis, whereas qualitative analysis involves analysing interview responses to identify recurring themes and areas of concern. Additionally, the material is processed into a systematic and organised assessment of the available data.

III. RESULT AND DISCUSSION

The process of contamination on a surface begins with the attachment of microorganisms, especially bacteria and diatoms which grow many times over very quickly. Together with other particulate organic matter, these microorganisms will form a thin layer on the surface of the object. This stage is the primary stage where the microorganism acts as a pioneer of the next organism which is usually larger. Animals and plants that then stick to the surface usually come from animals and plants that naturally live attached [17].

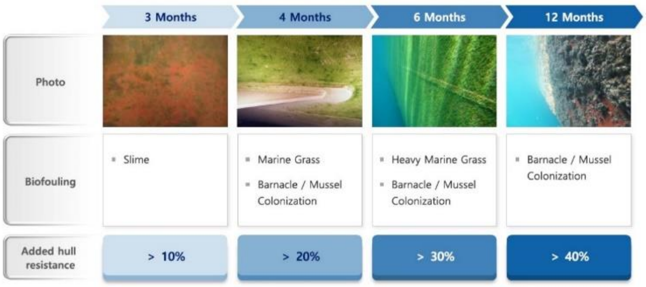

Figure 1. Biofouling Formation Process
Source: Glofouling (2022)

From figure 1 it can be seen that there is a period until the biofouling hardens and causes problems for the ship. Of course, the growth of biofouling on the ship's hull will have an impact on the ship's performance. It can be seen that cleaning and maintenance of ships from the effects of biofouling is very necessary. Based on current cleaning systems, underwater cleaning systems are considered effective, without damaging or wearing the underlying coating. Damage and wear can cause shortening of the coating's service life and lead to temporarily increased antifoulant release [18].

Therefore, in order to minimize the adverse impact on coatings and the marine environment, it is recommended that the cleaning force be minimized, by matching the force with the fouling adhesion strength. Past research on underwater cleaning (reactive approach) and hull maintenance (preventive approach) of current coatings has basically focused on at least one of the following three aspects: (a) fouling adhesion strength, mainly for comparison between different FR coatings [19] ; (b) the effect of hull and propeller cleaning and maintenance on the constituent components of fouling communities and their hydrodynamic drag; and (c) impact of hull cleaning and maintenance on antifoulant environmental exposure of biocidal antifouling (AF) coatings [20].

One important thing before implementing an underwater cleaning system is to check with local authorities for regulations on Underwater cleaning of hulls and propellers and/or discharge of chemicals into the water column. Where practicable, use appropriate technology that can collect biological, chemical and physical debris so that it can be disposed of at a suitable onshore facility. When cleaning areas coated with biocide anti-fouling coating systems, use cleaning techniques that minimize biocide discharge to the environment [21].

As discussed in the opening, cleaning underwater uses several methods or methods of cleaning. Cleaning using remotely operated vehicles (ROV) underwater cleaning systems is considered to have advantages and efficiency compared to underwater cleaning using divers. The remotely operated vehicles (ROV) system can carry out cleaning underwater conditions and hull positions that are difficult for divers to reach.

Based on the results of interviews with stakeholders operating the remotely operated vehicles (ROV) system, it was conveyed that the cleaning time and cost of cleaning the ROV system is more effective than cleaning with divers and certainly cheaper than the cost of dry dock which has additional costs in the dry dock process. From the field, data obtained that the underwater cleaning process using remotely operated vehicles (ROV) systems is 50% more effective in terms of cost and time of use on sample ships with the same overall length, this is evidenced by documentation during implementation [22]. Of course, a comparison of time and cost efficiency can be seen and it becomes an attraction for shipping companies to choose a ship hull and propeller cleaning system using the Remotely operated vehicles (ROV) system for underwater cleaning.

A. Working Principle of Underwater Cleaning System

Marine pollution control coatings are currently used on the underwater surfaces of ships and stationary marine constructions to avoid biofouling. In addition to coatings, underwater cleaning, by divers or remotely operated vehicles (ROVs), may be required [23]. Various guidelines for both trial procedures and the use of the Underwater Cleaning System (UWCS) have been developed and adapted to international rules and regulations from the countries where this tool is used.

As of right now, the Underwater Cleaning System (UWCS) in Indonesia uses the brush unit approach, which involves cleaning immediately beneath the water's surface. The instrument used for cleaning is termed a remotely operated vehicle (ROV), and it is operated via a separate control system that allows it to be operated from above the water's surface. To locate and identify biofouling that has to be cleaned, the ROV is outfitted with lights and camera controls. The holding room, which is part of the ROV equipment series, will receive the cleansed biofouling that has been sucked up using the suction mechanism on this ROV. When compared to alternative techniques like sprinkling hot water or steam over the ship's hull, this brush system is thought to be more successful because, this hot water spraying system will only kill microorganisms but not physically remove them.

Figure 3. ROV Control Machine
Source: Kemenhub (2023)

In figure 2, you can see the ROV control equipment used to drive, direct and control the parts to be cleaned which are in the process of being checked by the Indonesian ministry of transportation team. In the ROV underwater cleaning system, divers are also accompanied by divers to control and ensure that the use of ROVs is in accordance with the rules and procedures for use. In its use, permission and assistance are also required by the local port authority to ensure that there is no adverse impact on the surrounding environment.

B. ROV Current Challenges in Indonesia

In Indonesia, the use of ROVs to clean biofouling on ships is a relatively new practice. In early 2023, ROVs arrived in Indonesia, and in March of the same year, ROVs received a license. In Indonesia, ROV underwater cleaning system is one of the methods used to prevent and remove biofouling on ships.

There are several challenges to employing ROVs in Indonesia. The picture below depicts the challenges of using ROV underwater cleaning in Indonesia, based on existing literature data that was analysed using Atlas.ti to obtain a mapping of word groups and word frequencies.

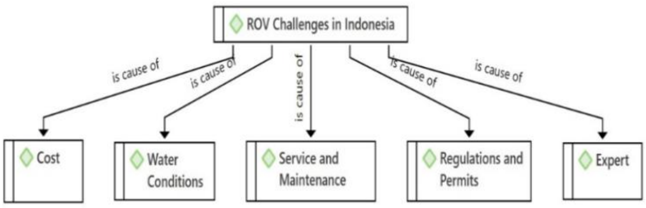

Figure 2. ROV Challenges in Indonesia
Source: Atlas.ti analysis (2024)

The results of the literature review on the present challenges to the use of remotely operated underwater vehicles (ROVs) for cleaning and preventing ship biofouling in Indonesia. Some of the current challenging factors are:

I. Cost
ROV technology is costly to purchase, maintain, and operate. This could be a hurdle to widespread use in Indonesia, especially for businesses or groups wishing to invest.

II. Water Conditions
Poor water and environmental conditions are common in Indonesian waterways, and they can be brought on by debris, marine pollution, strong currents and waves, and low visibility. It is necessary to build and equip ROVs to deal with these problems.

III. Service and Maintenance
At present, ROVs in Indonesia are manufactured in other countries. In Indonesia, the maintenance of ROVs and the provision of spare parts, support apparatus, and skilled technicians can be a challenge.

IV. Regulations and Permits

In order to ensure environmental conservation and maritime security, the operation of remotely operated vehicles (ROVs) for underwater washing must adhere to government regulations and obtain permits. Currently, there are no regulations that specifically address the application of underwater biofouling removal licenses; the current regulations pertain to generic underwater work activities.

V. Expert

Specialized training and specialist operators are necessary for ROV operations. The absence of human resources who are proficient in the operation and maintenance of ROVs may pose a challenge for ROV operations in Indonesia.

C. Economic Aspects

The risk of biofouling is determined by calculating the probability of its development and by analyzing the impact of its growth on construction and operations [24]. As we are aware, the pace and fuel consumption of a ship will be affected by biofouling that adheres to the hull or propeller. The economic impact of the ship after biofouling cleaning using ROV underwater cleaning will be analyzed to determine whether there is a difference in fuel consumption between the pre- and post-cleaning periods. An analysis of the average fuel consumption before and after cleaning will be conducted using a test tool that employs the Paired T test on SPSS in order to observe this difference. In this study, the hypotheses consist in :

- H0 will be accepted if Sig (2-tailed) > Probability 0.05, which indicates that there is no difference in fuel consumption between before and after the use of ROVs.
- H0 will be rejected if Sig (2-tailed) < 0.05 probability, indicating that there is a difference in fuel consumption between before and after ROV use.

A probability value of 0.05 is a frequently used threshold in hypothesis testing to assess whether or not there is sufficient evidence to reject the null hypothesis. The null hypothesis is often rejected and it is determined that there is a significant difference between the two conditions or measurements being evaluated if the p or sig (2-tailed) value is less than 0.05. Nonetheless, fail to reject the null hypothesis and determine that there is insufficient data to demonstrate a significant difference if the p or sig (2-tailed) value is higher than 0.05.

A paired T-test study was performed to compare the fuel usage of the MV Chandra Kirana before and after cleaning utilizing a remotely operated vehicle. From the analysis conducted, the result is rejecting H0 because the paired t-test's Sig (2-tailed) value of 0.000 is less than the probability of 0.05. In other words, the average fuel consumption before and after the use of ROV differs. The difference in the average fuel consumption before and after cleaning with a remotely operated vehicle (ROV) can be observed in the SPSS analysis findings, in addition to the P Value. The table below shows the outcomes of the variation in use.

Table 1. Paired Samples Statistics
Source: SPSS Analysis (2024)

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Before Cleaning	27.54250	10	.482334	.152527
	After Cleaning	26.4280	10	.60911	.19262

The fuel usage before cleaning in the current 3-month data sample is 27.54 MT, as can be seen in the above table, while the fuel consumption after cleaning is 26.43 MT. Based on these findings, it can be observed that the amount of fuel used after clearing the ship's biofouling utilizing ROV was reduced by 1.11 MT, or 4.03 percent. Based on the price of marine fuel oil in Indonesia as of May 13, 2024, which is $868 per metric tonne (Mega Anugerah energi, 2024), the shipping company gains $10,373 economically from the decrease in fuel consumption following cleaning based on sample data.

D. Environmental Aspects

The amount of CO2 gas emissions generated before and after the ship is cleaned by the ROV will be computed using the fuel usage sample data. This is to determine whether the fuel usage samples obtained have an increase or decrease in CO2 gas emissions. Table 13 displays the total amount of fuel used, which is derived from the fuel sample. The amount of CO2 emissions before and after biofouling cleanup will be calculated using a remotely operated vehicle (ROV) once the sample ship's total fuel consumption has been determined. The steps involved in the calculation are as follows.

The product of two factors, DA (ship fuel usage activity data) and FE (emission factor) determines the ECo2 value in the computation of ship CO2 emissions [25]. The real fuel consumption of the ship, or DA, is directly proportional to the quantity of CO2 emissions produced over a specific time period. Unfortunately, the dataset used for this study only included fuel consumption information for the three months before cleaning. This data was extrapolated to provide an annual view under the assumption that the vessel's fuel usage pattern remains mostly constant throughout the year. The annual fuel use was thus estimated by multiplying the three months of data by four. By making this assumption, the study hopes to estimate yearly CO2 emissions from the existing three-month data, which will enable a thorough examination of the effects of ship operations on the environment. The calculation of the amount of CO2 emissions based on fuel consumption sample data before and after cleaning using ROV includes:

ECO2 (Before Cleaning Using ROV)
= Data Activity (DA) x Factor Emission (FE)
= 44,5087 Tj/Year x 77,400-ton CO2/TJ
= 3.444,972-ton CO2/year

ECO2 (After Cleaning Using ROV)

= Data Activity (DA) x Factor Emission (FE)

= 42,7.76 Tj/year x 77,400-ton CO2/Tj

= 3.305,572-ton CO2/year

The findings of the computation of the ship's CO2 emissions before and after cleaning indicate that 3,444,972 tons of CO2 are released annually prior to cleaning, and 3,305,572 tons are released after cleaning. The drop, which amounts to 139,400 tons of CO2, or 4.04 percent, is a significant contributing factor to lessening the negative effects of ship operations on the environment. Not only can lowering emissions have a positive environmental impact, but some nations have started taxing CO2 emissions. In Indonesia this taxation currently only applies to emissions from coal-fired power plants, but it is possible that emissions from the transportation sector may also be subject to taxation.

IV. Conclusion

The analysis of the economic impact of ROV underwater cleaning on shipping companies and the environment reveals a difference in fuel consumption, as evidenced by a sample of ship fuel usage data collected before and after ROV cleaning, which is evaluated for significance using the Paired T test. The statistics indicate that cleaning with ROV affects fuel usage, resulting in a more economical average of 1.11 MT or 4.03 percent, while overall fuel consumption has decreased by 11.95 MT. The decrease in fuel consumption after cleaning, according to sample data, provides the shipping company with a financial benefit of $10,373. The analysis of ship CO2 emissions prior to and following cleaning demonstrated a decrease in CO2 emissions subsequent to ROV underwater cleaning. The reduction is 139,400 tonnes of CO2, representing 4.04 percent, which is a significant contributor to mitigating the environmental impact of maritime operations.

The presence of ROV underwater cleaning in cleaning ship biofouling in Indonesia undoubtedly presents challenges in its application. The analysis of the literature research showed that ROV underwater cleaning is one of the methods for cleaning and maintaining ship biofouling in Indonesia. However, in addition to its benefits, the operation of ROVs presents challenges, including the high cost of using and investing in ROV equipment, various problems with water conditions in Indonesia, the ineffective process of repairing and maintaining equipment, inefficient adherence to regulations and licensing processes, and a lack of experts in the use of ROVs.

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