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Carbon Capture Storage System on the Ship

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KEYWORDS
Global warming, fossil energy, CO2, CCS.

ABSTRACT – Carbon Capture and Storage (CCS) is one of the global warming mitigation technology systems by reducing CO_2 emissions into the atmosphere. This system is a series of implementations of processes that are related to each other, starting from the separation and capture of CO_2 from the source of exhaust emissions (flue gas), transportation of captured CO_2 to storage (transportation), and storage to a safe place (storage). If these emissions are released in large quantities, it will certainly cause various problems such as Global Warming. In the maritime transportation sector, one of the emissions that is widely produced by ships is exhaust gas from the ship's main engine when operating which is released into the atmosphere through the Funnel (chimney). One method that can be done is to separate carbon dioxide gas (CO_2) contained in the exhaust gas with Membrane Technology placed on the Funnel. Technical analyzes is done by testing the vessel model then the results are developed with naval theories. This article will discuss how to filter carbon dioxide gas and membrane technology that can be used on ships.

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INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) emphasizes that, in order to meet the ambitions of the Paris Agreement and limit future temperature rise to 1.5°C (2.7°F), it is not sufficient to merely intensify emission reduction efforts—we must also deploy technologies capable of removing CO_2 from the atmosphere [1]. One such promising system is Carbon Capture and Storage (CCS), which can play a vital role in mitigating global warming [2]. On the other hand, ship operations are continuously associated with both economic and environmental challenges. The reliance on fossil fuels remains high, particularly in the use of fuel to power ship engines [3,4,5]. This fuel usage is not only economically inefficient but also environmentally unsustainable [6,7]. Currently, fishing vessels are still crucial in supporting and maintaining food security for billions of people worldwide [8]. The mission of these vessels is to harvest fish from the ocean with appropriate methods, ensuring quality catches and transporting them to shore or to other ships for further processing [9,10]. In their operations, fishing vessels must remain safe and functional even under harsh weather conditions, and they typically consume a significant amount of fossil fuel to stay operational [11].

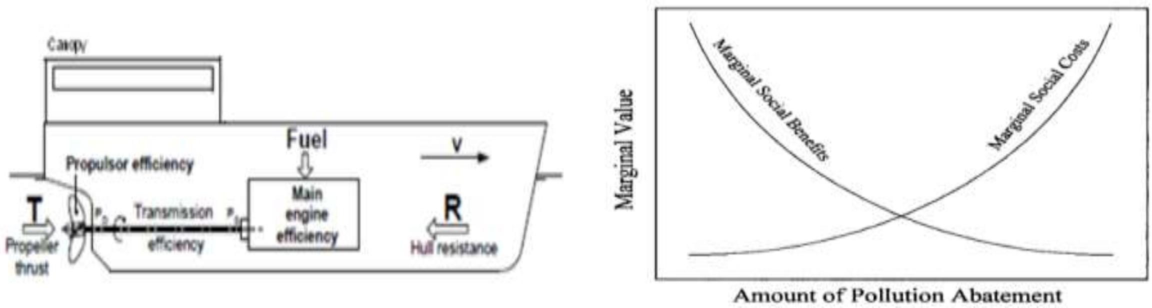

Figure 1. Motor Vessel Configuration and the Cost-Benefit Trade-Offs in Pollution Management [12]

The figure above illustrates the configuration of a motor vessel propulsion system. The basic concept of energy conversion involves transforming fossil fuel energy into the propulsive force required by the vessel through the use of a propeller. Such operational activities contribute significantly to air pollution—particularly emissions of CO_2, SO_2, and NO_x especially in fishing vessels powered by diesel engines using fossil fuels. These emissions negatively impact environmental marginal values in affected areas [12]. The subsequent figure presents the cost-benefit consequences of increasing air pollution, wherein rising emission levels lead to a decline in the social environmental marginal value and an increase in the marginal social cost that must be borne [13].

In general, vessel operations are intrinsically linked to both economic and environmental issues. From an economic perspective, fuel costs represent the largest portion of operating expenses, while from an environmental standpoint, emissions from fossil fuel combustion remain a critical concern [14]. High fuel prices are clearly disadvantageous for vessel operators. Moreover, the use of fossil-based marine fuels is not only economically inefficient but also environmentally unsustainable [15]. Therefore, assessing the environmental and economic impacts of vessel operations is essential for future policy development and sustainable marine transportation.

METHOD

Literature Review

a. Ship Moving Theory

The motion of a ship through water is governed by the balance between the thrust force generated by its propulsion system and the total resistance encountered during movement. Thrust (T) must be greater than the resistance (RT) caused by hydrodynamic forces such as wave-making, frictional, and form resistance. If the thrust fails to exceed the resistance, the ship will be unable to achieve forward motion or maintain its intended speed. Therefore, the propulsion system must be designed to overcome all resistive forces effectively [16]. The conditions for ships to move are as follows:

$$T > RT \quad or \quad T - RT > 0 \tag{1}$$

b. Resistance

Total vessel resistance (RT) refers to the sum of all hydrodynamic forces opposing the forward motion of a ship through water [17,18]. It is typically calculated based on empirical methods or model testing, taking into account components such as frictional resistance, wave-making resistance, and form resistance

$$RT = ½ . \rho \, C_T \, WSA \, V^2 \tag{2}$$

c. Trust

Thrust (*T*) is the propulsive force generated by the ship's propulsion system to overcome resistance and move the vessel forward [19]. It can be expressed as a function of propeller characteristics and operating conditions, such as:

$$\text{Thrust (T)} = RT/ (1\text{-}t) \tag{3}$$

Where: t is the thrust deduction factor for single screw, KR is 0.5 for thin rudder.

d. Powering

Powering refers to the calculation of the power required to produce the necessary thrust to overcome the ship's resistance [20]. It is typically expressed as the product of thrust and ship speed, adjusted by the propulsion efficiency:

$$\text{Effective power (PE)} = RT \times Vs \tag{4}$$

$$\text{Delivered power (PD)} = PE/ \eta D \tag{5}$$

$$\text{Quasi propulsive coeff } (\eta D) = \eta P. \, \eta H. \, \eta R \tag{6}$$

$$\text{Service power (Ps)} = PD/ \eta T \tag{7}$$

Where: ηT is 0.98 with gearbox, ηT is 0.95 without gearbox

e. Air Polution Quantification

Air pollution from ship operations, often measured by the CO_2 index or Energy Efficiency Design Index (EEDI), quantifies the environmental impact of emissions. This calculation follows established methodologies from previous research, which assess the amount of pollutants released per unit of transport work [21].

$$EI = Ki.SFR.Kw.T.\lambda \quad (8)$$

Where:
Ki = emissions per ton of fuel burned (Kg / Ton fuel),
SFR = specific fuel consumption (gm / kW.hr),
Kw = engine power (Kw),
T = operating time of ship engine (hr),
λ = CO_2 conversion (ton CO_2 / Kg).

f. Membrane Technology

The membrane functions as a filter to separate one or more gases from a mixed feed as in Figure 2. Two things that affect the ability of a membrane are permeability, which is the specific gas flux through the membrane, and selectivity, which is the ability of the membrane to accept specific gases and reject other gases. There are five possible mechanisms that occur in separation membranes, namely, Knudson diffusion, molecular sieving, diffusion separation, capillary condensation, and surface diffusion. In polymer membranes that do not have pores, the mechanism that occurs is solution diffusion. This is based on the solubility of specific gases with the membrane and the diffusion process through the membrane matrix. For CO_2 gas separation, the tools used are usually high-pressure hollow fibers and spiral-wound modules [22]. Separation does not only depend on diffusion but also on the chemical interaction between the gas and the polymer which determines the amount of gas accumulated in the membrane matrix. The Tool placement in Funnel

Experiment

The main dimensions of catamaran vessels serve as a critical reference in analyzing hull design, stability, and operational performance. Table 1 summarizes the typical main sizes of various catamaran vessels used in previous studies and real-world applications.

Table 1. Main sizes of catamaran vessels

Parameter	Catamaran	Demihull
LWL (m)	14.5	14.5
B (m)	7.655	1.855
D (m)	0.65	0.65
CB	0.382	0.382
Displ. (ton)	11.8	5.9

These parameters provide fundamental input for further hydrodynamic calculations, resistance estimation, and propulsion efficiency analysis. Understanding these dimensional characteristics is essential for optimizing vessel performance and ensuring operational safety.

Figure 2. Testing of hull model [12]

Table 2 shows the value of the results of the test of catamaran resistance in the towing tank and this data's will be developed for determine the powering.

Table 2. Result of Resistance testing

Run No	V (knots)	Fr	Catamaran Resistances (kN)		
			S/L = 0.2	S/L = 0.3	S/L = 0.4
1	5.788	0.25	1.821	1.659	1.659
2	6.218	0.268	2.141	1.851	2.061
3	6.677	0.288	2.443	2.239	2.348
4	7.051	0.304	2.852	2.678	2.947
5	7.56	0.326	3.46	3.568	3.547
6	8.032	0.347	4.467	3.954	3.766
7	8.384	0.362	4.844	4.345	4.341
8	8.818	0.38	5.149	4.79	4.662
9	9.233	0.398	5.807	5.592	5.515
10	9.813	0.423	7.101	6.448	6.138

RESULTS AND DISCUSSION

Carbon Capture and Storage (CCS) is one of the global warming mitigation technologies by reducing CO_2 emissions into the atmosphere. This technology is a series of interrelated processes, starting from the separation and capture of CO_2 from the source of exhaust emissions (flue gas), transportation of captured CO_2 to storage (transportation), and storage to a safe place (storage). CO_2 separation and capture are carried out using absorption technology that has been known for a long time in the industry. CO_2 capture is commonly used in the hydrogen production process both on a laboratory and commercial scale. Meanwhile, transportation is carried out using pipes or tankers like gas carriers in general (LPG, LNG), while storage is carried out into rock layers below the earth's surface which can trap gas so that it does not escape into the atmosphere, or it can also be injected into the sea at a certain depth. According to the International Energy Agency (IEA), the volume of CO_2 emissions due to the combustion of fossil fuels reaches 56% of the total global emissions. This percentage comes from around 7500 large CO_2 emitting installations (large stationary point sources) that emit more than 1000,000 tons of CO_2 annually. The IEA study further concluded that of this amount, coal-fired power plants (PLTU) are the main source of emissions reaching more than 60%. Furthermore, PLTG reaches 11% and PLTD 7%. Meanwhile, other industries contribute around 3-7% (includes Transportation areas).Furthermore, in order to reduce CO_2 emissions in large quantities, it is logical to carry out control (capture of CO_2) produced in the exhaust gas from power plants.

Emission quantification in ships

Engine is prime mover of ship which works by converting fossil energy/fuels to rotate the propeller to produce enough thrust to resist the vessel resistance at a certain service speed [23].

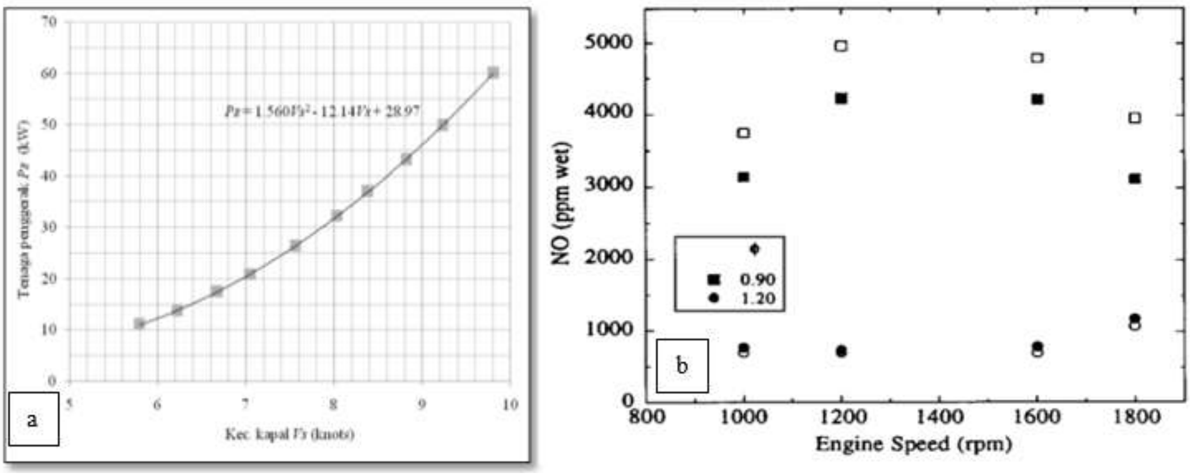

Figure 3. a) Graph of Vs – P and. b) Diagram of air pollution

Figure 3.a) shows the relationship between the speeds of the ship Vs with the propulsion power P with an increasing trend meaning that the increase in the speed of the ship Vs will increase the occurrence of RT ship resistance so that the driving force of the P ship produced will also increase. The ship with propeller propulsion when the higher engine speed (Engine Speed or Rpm), the speed will also increase (Vs), because engine speed (Rpm) is a function of ship speed Vs. Figure 3.b) shows the relationship between Engine Speed (Rpm) and air pollution (ppm wet), the higher the engine speed (Engine Speed or Rpm), the higher the amount of exhaust produced will increase the quantity of air pollution that occurs.

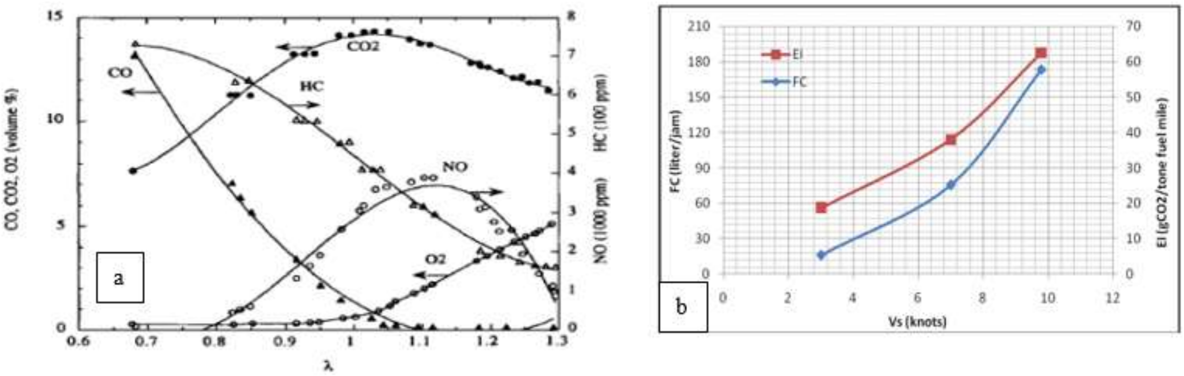

Figure 4. a) Relationship between Vs - FC-EI. and b) Various types of exhaust Emissions

Figure 4.a) shows the relationship between ship speed Vs, EI air pollution and FC fuel consumption from fishing vessels that have P 60 kW power. When fishing vessels operate with Vs 3 knots from the graph, the FC value is 5.4 liters / hour and EI around 56 g CO2 / tonne fuel mile. When the fishing boat operates with Vs 7 knots from the graph the FC value is 25.2 liters / hour and EI around 114 g CO2 / tonne. Likewise, when the ship operates with 9.8 knots, the FC value is 58 liters / hour and EI is around 188 g CO2 / tonne. Figure 4.b) shows a diagram of various types of air pollution exhaust emissions resulting from engine work. At present there are at least around 1.3 million commercial fishing vessels with a mechanical engine, and 40 thousand of them have a weight of 100 tons that participate in supplying daily food needs and sustaining food security for millions of people in the world. The fishing activities have an impact on the increase in air pollution levels (such as CO2, SO2 and NOX) in the atmosphere, especially on fishing vessels that use fossil fuel-fueled diesel engines.

The ratio of load to fuel consumption is 47% (see table 3), meaning that to get a catch of 1000 kg of fish requires fossil energy of 470 kg of fuel. From these results it can be used to determine the measurement of the technical and economic value of fishing vessels. By measuring fuel consumption and air pollution that occur on fishing vessels that are operating (as shown in table 4 below), it can be seen the level of efficiency and economic value.

Table 3. Operational Efficiency and Economic Value

No	Ship Speed *Vs* (knots)	Power *P* (kW)	Thrust *T* (kN)	Fuel Consumption *FC* (liter/hour)	Emission Index *EI* (g CO_2/tonne fuel mile)
1	3	8	1.994	5.4	57.55
2	7	31	4.059	25.2	134.29
3	9.8	60	6.685	57.9	188

Table 3 shows the relationship between Powering (P), Thrust (T), Fuel consumption (FC) and Emission index (EI) when the fishing vessel operates with service speed (Vs) in accordance with its operational profile and obtained economic value of fossil energy as follows: First, for the price of the speed of the ship (Vs) of 1 knots is equivalent to the fuel value of 5.9 liters / hour. Second, for the price of boat propulsion (P) of 1 Kw is equivalent to the fuel value of 0.965 liters / hour. Third, Thrust of vessel (T) of 1 kN is equivalent to fuel consumption value of 8.7 liters/ hour.

Membrane Technology Concept

Membrane Technology is a separation process using a membrane as a contact tool. There are two types of membrane contactors, namely gas-liquid membrane contactors and liquid-liquid membrane contactors. The contactor used for exhaust gas control is a gas-liquid membrane contactor. Gas-liquid membrane contactors are divided into 2 processes, namely the process where gas or vapor moves from the gas phase to the liquid phase, and the process where gas or vapor moves from the liquid phase to the gas phase. In general, the membrane used in gas-liquid membrane contactors is a porous membrane (microporous membrane) where the membrane functions as a boundary between the two phases. If a hydrophobic membrane is used, the liquid will not wet the pores so that the pores will be filled with gas (non-wetted membrane). Conversely, if a hydrophilic membrane is used, the liquid will wet the pores so that the pores will be filled with liquid (wetted membrane).

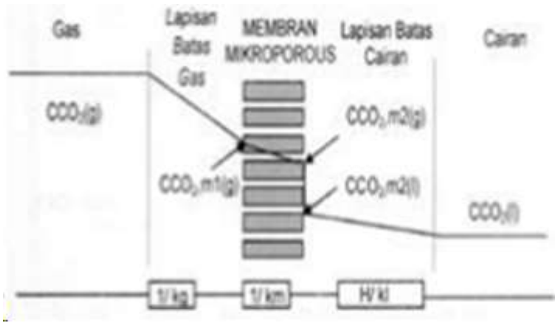

Figure 5. Mass transfer and resistance areas in a membrane tool

The mass transfer area and resistance of the membrane contactor can be seen in Figure 5. The process of moving a molecule or particle in the membrane is caused by the force acting on the molecule or particle. In the contact process, the driving force that occurs is caused by the difference in concentration. In a membrane contactor, if component i moves from the gas phase to the liquid phase, there are three stages of transfer that must be passed, namely transfer from the gas phase to the membrane, diffusion through the membrane, followed by transfer from the membrane to the liquid phase.

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Due to the three stages of transfer, the CO_2 flux in the membrane contactor is also divided into three mass transfer areas, namely the gas film layer, the microporous membrane, and the sorbent film layer. The Membrane Technology Paradigm is that the porous fiber membrane as a liquid gas contactor in the absorption process with a wet solvent (NaOH) has a high absorption capacity (flux) for CO_2 gas originating from ship engine exhaust gas (Funnel) when compared to conventional methods.

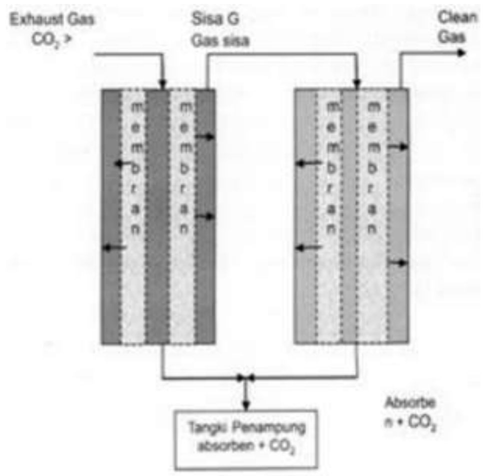

Figure 6. CO_2 Separation in Funnel via Membrane

CONCLUSION

It can be concluded that this study contributes significantly to technological innovation aimed at reducing the environmental impact of ship operations, particularly by enhancing the absorption capacity of CO_2 emissions from marine diesel engine exhaust. The proposed solution demonstrates potential in supporting decarbonization efforts in the maritime sector by integrating emission control with energy efficiency considerations. The results indicate that this technology not only holds promise for small-scale applications but can also be scaled up for commercial vessels operating under increasingly strict emission regulations. Furthermore, the implementation of such systems aligns with global climate targets and maritime sustainability goals. Therefore, it is essential to promote further development, testing, and socialization of this technology within the global maritime industry to accelerate its adoption and maximize its environmental benefits.

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REFERENCES

[1]. Wilhere GF. A Paris-like agreement for biodiversity needs IPCC-like science. Global Ecology and Conservation. 2021 Aug 1;28:e01617.

[2]. Osman AI, Hefny M, Abdel Maksoud MI, Elgarahy AM, Rooney DW. Recent advances in carbon capture storage and utilisation technologies: a review. Environmental Chemistry Letters. 2021 Apr;19(2):797-849.

[3]. Suardi MU, Alamsyah AM, Nugraha AM, Pawara MU. Experimental analysis of castor oil and diesel oil mixtures in a 4-stroke compression combustion. Int. J. Mech. Eng. Technol. Appl. 2023;4(5):167-76. Doi; https://doi.org/10.21776/MECHTA.2023.004.02.6

[4]. Tasrief M, Nurcholik SD, Wulandari AI, Setiawan W. Testing the Inclination of an Industrial Diesel Engine Under Static Conditions According to the International Convention for the Safety of Life at Sea (SOLAS) Regulations. International Journal of Marine Engineering Innovation and Research. 2023 Feb 27;8(1). Doi; 10.12962/j25481479.v8i1.15749

[5]. S. Suardi, M. U. P. Uswah, A. Alamsyah, M. A. B. Arham, and F. Mahmuddin, "Analysis of Diesel Engines using Biodiesel Blended from Waste Cooking Oil and LDPE Plastic Waste Pyrolysis Oil", *J. Adv. Res. Fluid Mech. Therm. Sc.*, vol. 130, no. 1, pp. 64–76, Apr. 2025. doi: 10.37934/arfmts.130.1.6476.

[6]. S. Suardi, M. U. . Pawara, W. . Setiawan, F. . Mahmuddin, and S. . Klara, "Alternative Fuel Mixture Waste Cooking Oil (WCO) and Corn Oil: Transforming Hazard into Renewable Energy", *J. Adv. Res. Fluid Mech. Therm. Sc.*, vol. 122, no. 1, pp. 244–257, Oct. 2024. doi: 10.37934/arfmts.122.1.244257.

[7]. Suardi S, Suanggana D, Said B. Biodiesel Potentials of Waste Cooking Oil (WCO): Production, Content of Fuel Properties, and Effects on Engine Performance. Int. J. Mar. Eng. Innov. Res. 2023 Jun 16;8(2):213-21. doi; 10.12962/j25481479.v8i2.16679

[8]. Manik A, Arifuddin AM, Pawara MU, Nurcholik SD, Ikhwani RJ. Analysis of Gross Tonnage (GT) Capacity Installed On Traditional Wooden Ships In Penajam Paser Utara. Indonesian Journal of Maritime Technology (ISMATECH). 2023 Dec;1(2). doi; https://doi.org/10.35718/ismatech.v1i2.1059

[9]. Pawara MU, Arifuddin AM, Tobing AY, Hidayat T, Nurcholik SD, Syadzali AM. Numerical Evaluation of Transversal Strength of Traditional Fishing Vessel in Penajam Paser Utara, East Kalimantan, Indonesia. Indonesian Journal of Maritime Technology. 2023 Dec 20;1(2). doi; https://doi.org/10.35718/ismatech.v1i2.1070

[10]. Setiawan W, Kyaw AY. Plan for the Power Requirements of The Lights in the Fishing Boat Room Using LED Lights. Indonesian Journal of Maritime Technology. 2023 Jun 27;1(1). doi; https://doi.org/10.35718/ismatech.v1i1.877

[11]. Pramudya IS, IKAP Utama, Wasis DA, 2017, Catamaran Fishing Vessel: An Overview of the Energy, Functions and Performance Aspects of Environmentally Friendly Vessels, Dissertation - MT093350

[12]. Molland AF., Turnock SR., Hudson DA., 2011, Ship Resistance and Propulsion – Practical Estimation of Ship Propulsive Power, ISBN: 978-0-521-76052-2 Hardback, CUP, USA.

[13]. Eran Sher, 1998, Handbook of air pollution from internal combustion engines pollutant formation and control, Academic Press.

[14]. Paribang FS, Setiawan W, Wulandari AI, Pawara MU, Arifuddin AM, Alamsyah A. Experimental Study on The Performance Characteristics of 4 Stroke CI Engine using Biodiesel Blend from Coconut Oil. Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering). 2024 Feb 13;13(1):188-96. doi; http://dx.doi.org/10.23960/jtep-l.v13i1.188-196

[15]. P I Santosa, 2019, the Configuration of Engine-Sail Catamaran Fishing Vessel, IOP Conf. Ser.: Mater. Sci. Eng. 462 012008, doi:10.1088/1757-899X/462/1/012008, The 1st International Conference on Advanced Engineering and Technology, IOP Publishing

[16]. Extrada E, Pranatal E, Santosa PI. Analisa Penyebab Poros Kemudi Kmp. Nusa Jaya Abadi Patah. InProsiding Seminar Teknologi Kebumian dan Kelautan (SEMITAN) 2021 Aug 23 (Vol. 3, No. 1, pp. 253-256).

[17]. Akbar R, Suastika IK, Utama IK. Effects of Homogeneous and Inhomogeneous Roughness on the Ship Resistance. CFD Letters. 2025 Mar;17(3):77-94.

[18]. As'ad, M. S., Pawara, M. U., Ikhwani, R. J., & Wulandari, A. I. (2024). Impact of Hull Breadth Modification on Tugboat Resistance: A Comparative Analysis Using Holtrop and CFD Methods. *Indonesian Journal of Maritime Technology*, *2*(1). doi; https://doi.org/10.35718/ismatech.v2i1.1062

[19]. Utama IK, Suastika IK, Sulisetyono A, Hermawan YA, Aryawan WD. Resistance Analysis of Rescue Boat in Calm Water Condition. InIOP Conference Series: Materials Science and Engineering 2021 (Vol. 1052, No. 1, p. 012062). IOP Publishing.

[20]. Dinariyana AA, Deva PP, Ariana I, Handani DW. Development of model-driven decision support system to schedule underwater hull cleaning. Brodogradnja: An International Journal of Naval Architecture and Ocean Engineering for Research and Development. 2022 Jul 1;73(3):21-37

[21]. Lee SS. Analysis of the effects of EEDI and EEXI implementation on CO2 emissions reduction in ships. Ocean Engineering. 2024 Mar 1;295:116877.

[22]. Korol I. and Latorre, R., 2010, Development of Eco-Friendly Fishing Vessel An ecological vehicle powered by renewable energy, EVER Monaco.

[23]. Olsen AA. Introduction to Ship Engine Room Systems. Routledge; 2023 Apr 6.