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Analyses of Drag Reduction IPTEK

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Analysis of Drag Reduction Due to Hydrophobic Coating Application by Experiment

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Abstract **- Nowaday, at least 80% of the world's cargo is shipped via marine transportation modes, so with the amount of shipping activity, the shipping industry produces air pollution of at least 3.3% of global carbon dioxide emissions. The problem is trying to be answered by reducing a fuel use, one of which is through drag reduction. It is estimated that at least 80-90% of the drag that occurs on VLCC (Very Large Crude Carrier), comes from frictional drag that occurs on the surface of the hull. One of method to reducing frictional drag is by applying a hydrophobic coating. The hydrophobic coating has molecular physical properties to repel water. Similar as the water on a lotus leaf that can't wet the leaves even a little, this phenomenon is called the Hydrophobic effect. Applying the hydrophobic coating on the specimen is done by spraying hydrophobic coating paint. As It seen from the contact angle with value above 90^0 shows the hydrophobic effect on the coated surface. This research aims to prove whether the application of hydrophobic coating on the hull specimen would give a significant effect such as buoyancy increase and drag reduction characteristics. The research method used is the experimental method by pulling the ship model utilizing the free fall of the load mass to provide a pulling force to the ship model and hydrophobic evaluation of the surface. The experiment was carried out in the Diponegoro University's hydrodynamics lab with the assumption that the increase in acceleration is a drag reduction. From the test results, it was found that the drag reduction value has a percentage above 25% with the use of light mass variations. In the experiment, there is phenomenon of buoyancy increase characteristic appeared after the appliance of hydrophobic coating.**

Keywords— Frictional Drag, Hydrophobic Coating, Hydrophobic Effect, Drag Reduction, Experiment

NOMENCLATURES

LoA	: Length of all (m)
Lpp	: Length perpendicular (m)
B	: Breadth (m)
H	: Height (m)
Cb	: Block coefficients
WSA	: Wetted Surface Area (m)2
Δ	: Displacement (tons)
W	: Work (J)
ΔEk	: Kinetic Energy Difference (J)
HC	: Hydrophobic Coating Specimen
F	: Friction in the pulley
F	: Force (N)
g	: Gravitational acceleration (m/s)2
v	: Kinematic Viscosity (m2/s)
ρ	: Density (g/m)3
S_1	: Distance Traveled for acceleration calculation(m)
S_2	: Distance Traveled for speed calculation (m)
S_3	: Load drop distance (m)
l	: Towing Tank Width (m)
L	: Model Specimen Length (m)
a	: Acceleration (m/s2)
a_B	: Load Fall Acceleration (m/s)2
Rt	: Total resistance (N)
$\bar{V}$	: Average velocity (m/s)
t1	: Acceleration calculation Travel Time (s)
t2	: Speed calculation Travel Time (s)
t 3	: Travel time of falling object (s)
M_B	: Load Mass (kg)
M_K	: Specimen mass (kg)
Rn	: Reynold Number
DR%	: Drag Reduction (%)
aHC	: Acceleration of Hydrophobic Coating Specimen
aNon-HC Specimen	: Acceleration of Anti-fouling Coating/Non-coating
NC	: Non-coating
AFC	: Anti-fouling Coating
HC	: Hydrophobic Coating

I. Introduction

Shipping is one of the transportation modes that connects trade worldwide. At least 80% of the world's cargo is shipped via sea [1]. Hence, due to the significant ship activity, the shipping industry produces air pollution that affects the environment and human health with 33% of fossil fuel combustion emissions associated with all trade activities with at least 3.3% of global carbon dioxide emissions [2]. These problems are tried to be answered by saving the use of fossil-based energy in operation. Since then, research has focused on saving energy use, one of which is reducing the drag on ships. Drag is a mechanical force created by a solid object moving through a fluid, which is usually divided into two components, namely frictional drag and pressure drag. It is estimated that at least 80-90% of the drag that occurs on VLCC (Very Large Crude Carrier) comes from frictional drag that occurs on the hull's surface [3]. Therefore, several studies focus on reducing drag through the use of coatings on the hull [4].

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One method of Drag reduction with coatings is by using Nano-SiO_2 -TiO_2 /Dodecyl Trimethoxysilane which are known as Hydrophobic Coatings. In research by Meiman Peng and colleagues about superhydrophobic coatings, discoveries has been made that various capabilities of superhydrophobic materials shown able to effectively reduce the effects of water erosion, increase the contact angle of water with the surface >90^0 and reduce the possibility of contamination and sticking. In addition, the surface has several characteristics, such as self-cleaning, anti-icing, anti-fouling, and drag reduction [6].

By mimicking the lotus leaf structure, previous studies have developed hydrophobic surface coatings and found a reduction in drag on flat disks. In addition, surfaces with superhydrophobic coatings can be cleaned easily if there are stains that only need to be watered using water, can eliminate the formation of ice on the surface, and prevent the surface from contamination of bacterial biofilm microorganisms, dust, and dirt. Superhydrophobic coating technology has been used commercially in Indonesia for wood, stone, leather, and fabric materials protection.

Consequently, The research aim to examine the effects of using hydrophobic coatings that lead to the reduction of skin frictional drag on ships in order to increase the mileage and efficiency of ships.

In determining the drag reduction value, the towing experiment is carried out by applying the weight fallout adopting the gravitational type towing tank towing system [7]. The result is assessed from the acceleration and velocity value of the model specimen with comparison in which the higher the speed is assumed with a lower value of resistance occur between three coating variations that will be given the same tensile force. If there is a deceleration in one of the coatings with the same condition, it is assumed the model experiences a skin frictional drag that has been proven by empirical equation in **Equation 1-3**. The final assessment will be presented by percentage that come from assumption of Acceleration Increase as a drag reduction value.

II. Method

A. Experiment

This experiment aims to obtain the results of how hydrophobic coating affects drag reduction on a ship model made of grade A balsa wood with a thickness of 1.5 mm**.** The research was carried out with two tests to examine the effect of hydrophobic coating on the hull's model specimen.

2.1.Specimen Preparation

In this research, the research object used is the commercial ship model in **Figure 1-3**. with the main dimension as listed in **Table 1**.

TABLE 1.
MAIN DIMENSION DATA OF SHIP MODEL

Main Dimension	Value	Unit
LoA	0,8612	m
Lpp	0,8302	m
B	0,2350	m
H	0,11	m
T	0,8	m
Cb	0,732	
WSA	0,25963	m^2
Displacement (Δ)	0,01171	ton

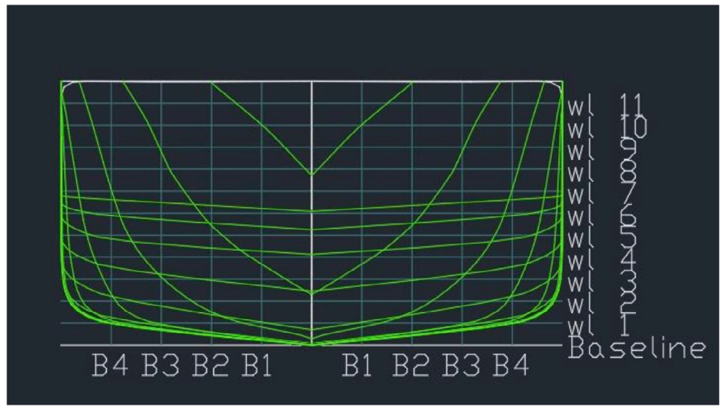

Figure 1. Body Plan of Hull Model Specimen

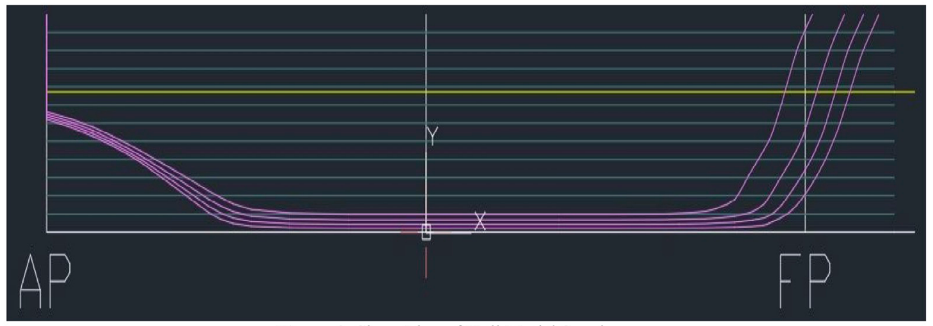

Figure 2. Sheer Plan of Hull Model Specimen

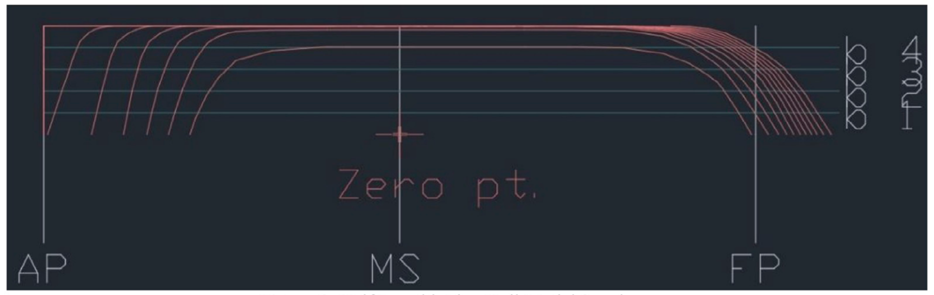

Figure 3. Half Breadth Plan Hull Model Specimen

The coating variations in this experiment used the three coating variations with the specifications of the coating variations and the application of the coating are described in **Table 2.** Specimen will undergo hydrophobic evaluation to determine the specimen's surface hydrophobicity. Which later will be tested by towing experiment under load mass and repetition mentioned in **Table 3.**

TABLE 2.
COATING VARIATIONS SPECIFICATION

Variation	Brand	Coating Application
NC	*Without Coating*	Sanding to remove previous damaged paint.
AFC	*Polyurethane* Umeguard SX-HS *anti-foulingcoating*	Using a roller and dried for 72 hours and then smooth sanding to even out the paint.
HC	Talas Water Repellent -Anti air + Rain X water repellent	Direct spraying and dried for 24 hours

TABLE 3
TOWING EXPERIMENT SPECIMEN DATA

Specimen Variations	Label	M_B	Total Test
Non-coating	NC		
Anti-fouling Coating	AFC	1,125 kg 2,11 kg 3,14 kg	5x
Hydrophobic Coating	HC		

The coating process per coating variation is carried out in several stages, specifically:

1. The ship model was coarsely sanded to remove the damaged paint and form a variety of non-coating specimens.
2. The next variation was painted using a roller paint tool with a mixture of Polyurethane Umeguard SX-HS anti-fouling coating and hardener with a ratio of 0.6: 4.4 according to the recommended ratio and then dried for 72 hours.
3. The dried paint layer then will be sand with smooth sanding to even the paint.
4. The next variation is then will be applied with Rain x + talas Hydrophobic coating by spraying the talas hydrophobic coating at a distance of 8-10 cm with a slope of 45° and dried for 24 hours without direct sunlight.
5. After drying, it is continued by spraying the rain x hydrophobic coating with a distance of 8-10 cm with a slope of 45° and dried for 5 hours.

B. Experimental Set-Up

The test was conducted using fresh water with a temperature of 25° C. Therefore, the towing tank test was conducted with the physical conditions and size of the towing tank in **Table 4.**

TABLE 4.
TOWING TANK CONDITION & SIZE

Symbol	Value	Unit
g	9,81	m/s^2
v	8,93 x 10^7	m^2/s
ρ	0,9971	g/m^3
S_1	1,5	m
S_2	3	m
l	0,8	m

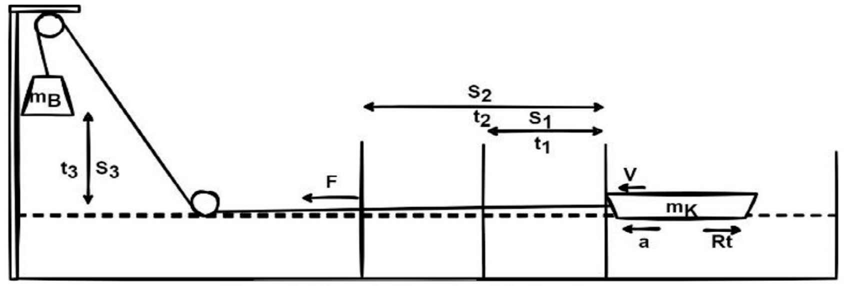

Figure 4. Schematic illustration of the Experiment

In the illustration depicted in **Figure 5**, the resultant acceleration force is linear with the direction of the velocity of the ship model, while the resultant total drag force is opposite to the velocity direction of the ship model.

Thus, in this experiment, the drag reduction effect is assumed to be the value of the acceleration increase of the ship model during the towing experiment. Therefore, it is assumed that:

$$\uparrow \Delta a = \downarrow \Delta R_T \quad (1)$$

The assumption is proven by the following formulation:

$$\sum F = m.a \quad (2)$$

$$W\text{-}f\text{-} R_T = m.a$$

Assuming the value of f is the same for all variations, which it wouldn't affect much.

$$W\text{-} R_T = m.a \quad (3)$$

$$W(1 - \frac{R_T}{W}) = m.a$$

$$\frac{R_T}{W} = 1\text{-}m.a$$

$$\frac{R_T}{W} = 1\text{-} \frac{m.a}{W}$$

$$(\uparrow R_T) \approx W\text{-}m.(a\downarrow) \quad (4)$$

Then, the drag reduction is determined by the acceleration value of the ship model through the equation:

$$a = \frac{2S_1}{{t_1}^2} \quad (5)$$

The assumed value of f is then proven by direct measurement of acceleration whether the acceleration of the fallout weight is equal to the acceleration of gravity to prove that there is minimal friction in the pulley using the equation:

$$A_B = \frac{2S_3}{{t_3}^2} \quad (6)$$

The acceleration was found to be 9.33 m/s^2, which is not much different from the acceleration of gravity of 9.78 m/s^2. In these experiment, the friction and air resistance occured when the weight is dropped happens to be very low.

III. RESULTS AND DISCUSSION

Based on the data that has been obtained, further Experiment and processing is held to acquire the results. The following are the results of the experiment.

3.1. Hydrophobic Evaluation

In testing the hydrophobicity of the Nano-SiO_2TiO_2 /Dodecyl Trimethoxysilane coating, a flat surface sample made from the same material used in ship model was slowly dripped with water and measured at room temperature. As shown in **Figure 5.**, the coated surface sample has 114° surface contact angle proving the surface to be hydrophobic while the uncoated surface has a 36° surface contact angle showing the hydrophilicity of the uncoated surface. In accordance with the Cassie-Baxter theory, this condition is caused by trapping air pockets on the surface which causes water to be unable to come into direct contact with the surface and form air bubbles with a contact angle of >90° . The higher the angle, the more hydrophobic the surface is with less water contact with the surface, resulting an increase in drag reduction characteristics on the surface [5].

Furthermore, the ship model which has been prepared and coated will be tested to evaluate the hydrophobicity of the surface visually by identifying the difference before and after the application of hydrophobic coating on the hull of the ship model to identify the slip condition of the surface, the surface is poured by glass of water. In **Figure 6.** It can be seen that the water has infiltrate the surface without hydrophobic coating as a result dampen the surface. Whilst the surface that has been coated with a layer of hydrophobic coating, cannot be dampen by water and immediately slips down and the remaining water tends to clot into water droplets on the surface like water on lotus leaves. These findings align with the statement in Kim Tae Min's research, where the condition due to the hydrophobic coating is described as a slip condition [4].

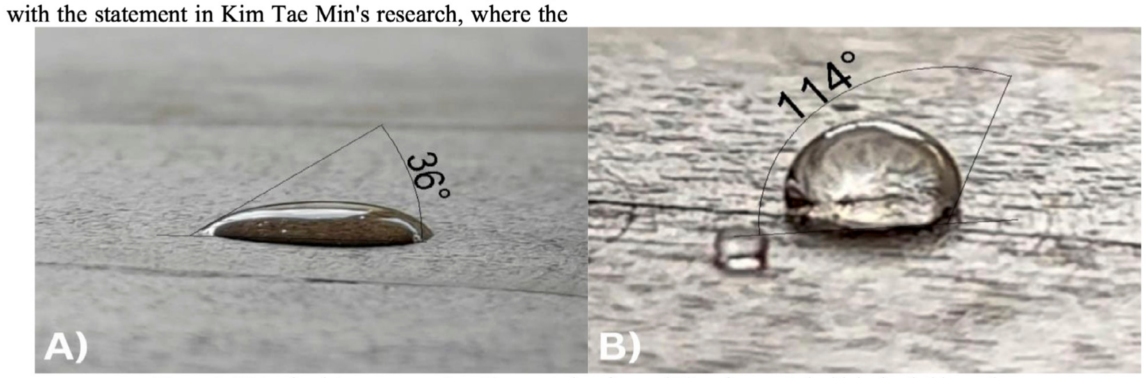

Figure 5. Water droplet measurement on **A)** uncoated surface and **B)** surface coated with hydrophobic coating.

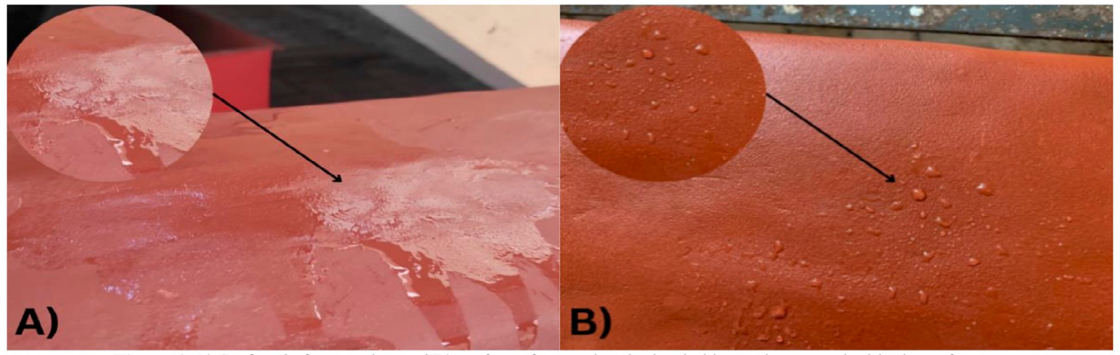

Figure 6. A) Surface before coating and **B)** surface after coating, hydrophobic coating poured with glass of water.

Furthermore, in **Figure 7.** the surface mdel was tested by placing it in towing tank to test the effect of hydrophobic coating on the buoyancy of the specimen model. The specimen model is placed in a fluid with the density and viscosity as listed in **Table 4**. As seen in **Figure 7.** the specimen model that has been coated with a hydrophobic coating obtain a bouyancy increase characteristic whereas it floating higher as can be seen from the draft line on the specimen model coated with a hydrophobic coating is above the bilge keel of the specimen model, while the uncoated specimen model as seen in **Figure 7.** the bilge keel submersed beneath the draft line. The application of hydrophobic coating on the ship model led to atleast 1.22 cm decrease of draft line caused by the hydrophobic coating that give a surface a buoyancy increase.

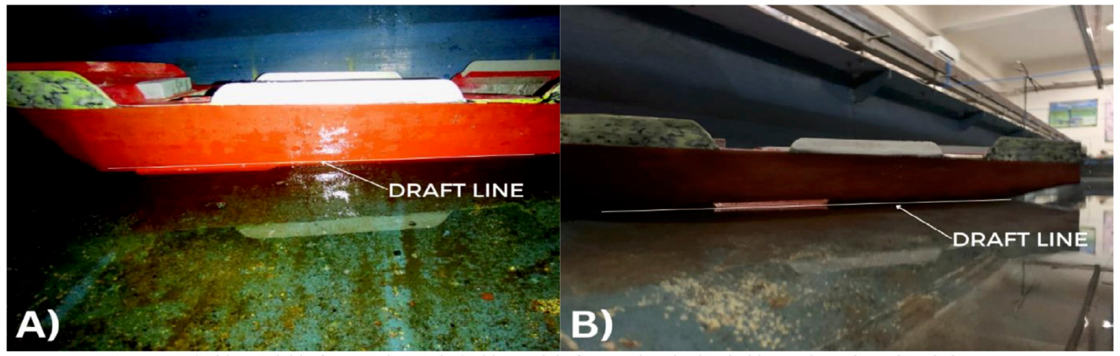

Figure 7. A) ship model before coating and **B)** ship model after coating, hydrophobic coating when placed above water.

This phenomenon happens due to air pockets trapped on the surface as shown in **Figure 7.** forming an air layer that prevents direct contact of the surface of the model specimen with the water surface, causing an increase in buoyancy following the findings in Wang's research results which mention the finding of a buoyancy increase of specimen due to the application of hydrophobic coating [16].

3.2. Towing Experiment Results

After conducting towing experiment on the ship model. The test results which displayed in **Table 5.** shown

that the specimen variation with hydrophobic coating is the fastest variation with the lowest travel time value followed by the specimen variation with anti-fouling coating and non-coating placed last in the three mass variations. The data in **Table 5.** has a finely distributed population as can be seen in **Figure 9**. The previous data with 5 repetions has been eliminated into 3 population using standard deviation to maintain the distribution of data population .

TABLE 5.
TOWING EXPERIMENT RESULT DATA ON EVERY LOAD MASS VARIATIONS

		1,125 kg			**2,11 kg**			**3,14 kg**		
Label	**Time**	**Experiment**			**Experiment**			**Experiment**		
		1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
NC	**t1**	1,001	1,034	1,018	0,801	0,834	0,817	0,667	0,7	0,684
	t2	1,802	1,902	1,818	1,568	1,585	1,602	1,201	1,318	1,185
AFC	**t1**	1,035	1,018	0,967	0,767	0,883	0,783	0,667	0,667	0,7
	t2	1,485	1,517	1,567	1,35	1,35	1,35	1,15	1,15	1,2
HC	**t1**	0,884	0,851	0,868	0,701	0,684	0,701	0,634	0,651	0,601
	t2	1,501	1,451	1,451	1,185	1,218	1,285	1,084	1,101	1,068

Based on the graph in **Figure 8.**, the population is distributed finely where the P-Value is >0.05. Therefore, based on the normality test results, the data can be tested with anova to see the significance of the experiment data.

The data was then subjected to a two-way ANOVA statistical test with a significance level of 95% or (alpha) = 0.05 to see how significant the effect of the application of coating variations affect the travel time. decision making is based on the F-value> F-Table (3.40) which indicates the significance of the variable on travel time. Based on the comparison of the Ftable value with the FValue, where the FValue>Ftable, coating variation can be stated to have a significant impact on travel time.

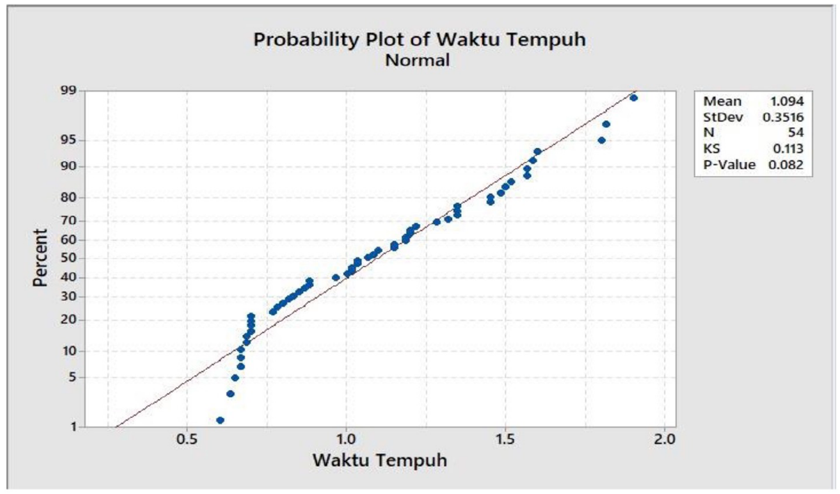

Figure 8. Graph of Normality Test Results

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Factor Information

Factor    Type   Levels  Values
load      Fixed       3  11 N, 20.64 N, 31.71 N
Coating   Fixed       3  AFC, HC, NC
Distance  Fixed       2  1.5, 3.0


Analysis of Variance

Source         DF   Adj SS    Adj MS   F-Value  P-Value
  Load          2  1.26678   0.63339    107.24    0.000
  coating       2  0.36416   0.18208     30.83    0.000
  Distance      1  4.63819   4.63819    785.31    0.000
Error          48  0.28350   0.00591
  Lack-of-Fit  12  0.23932   0.01994     16.25    0.000
  Pure Error   36  0.04418   0.00123
```

Figure 9. Anova Test Results with Minitab Software

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TABLE 6.
AVERAGE DATA OF EXPERIMENT RESULTS AFTER NORMALITY TEST

		AVERAGE		
Label	**Time**	**1,125 Kg**	**2,11 Kg**	**3,14 Kg**
NC	t1	1,018	0,817	0,684
	t2	1,841	1,585	1,235
AFC	t1	1,007	0,800	0,675
	t2	1,523	1,358	1,167
HC	t1	0,868	0,695	0,629
	t2	1,472	1,229	1,084

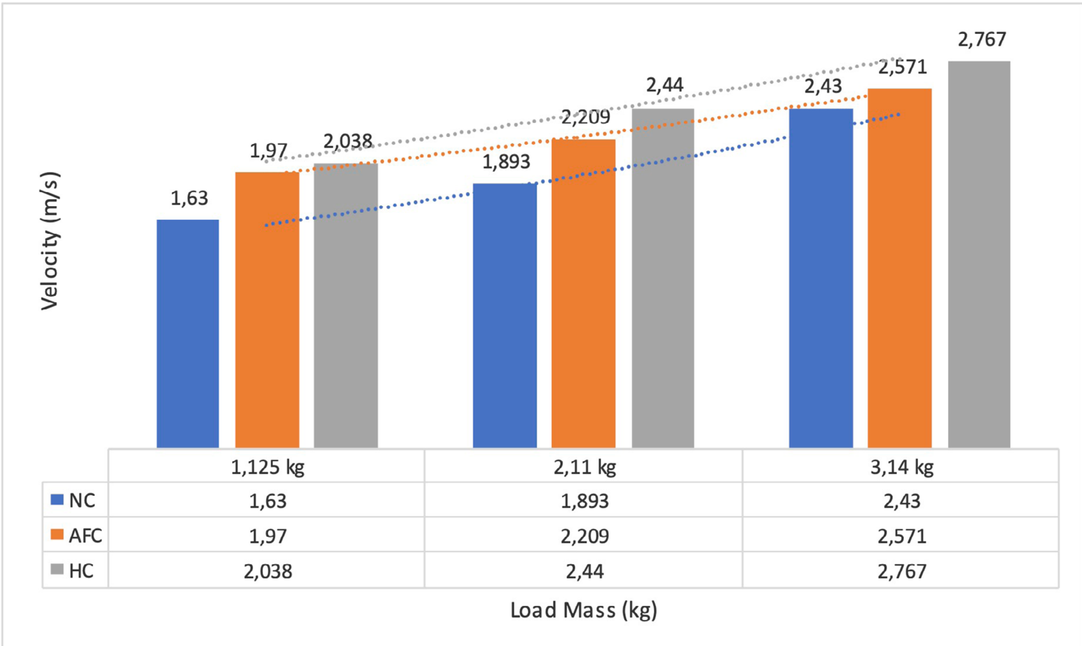

Figure 10. Graph of Velocity Values

3.3. Data Analysis of Towing Experiment Results

The results of the average speed of the ship in **Table 6**. obtained from the value of t_2 in **Table 5**. And the track distance S_2 which is then calculated with **Equation 7.**

$$V = \frac{S_2}{t_2} \quad (7)$$

As can be seen in **Table 9.** The highest speed in each mass variation is specimen model with a hydrophobic coating followed by anti-fouling coating and non-coating which has the lowest speed value. This proves that in traveling a distance of 3 m, the specimen model with a hydrophobic coating layer is experience a lower force of resistance, causing the specimen model to run effectively and travel faster. In **Figure 11.** above, it is found that the velocity increases with the use of larger mass variations. The specimen coated with hydrophobic coating has a higher speed due to the slip condition that occurs on the hull of the ship model which causes drag reduction effect. Thus, the specimen with hydrophobic coating has a higher velocity due to less total drag.

This phenomenon is proven again with the calculation of acceleration in **Figure 11.** Whereas the acceleration on specimens coated with hydrophobic coating has the highest acceleration followed by anti-fouling coating and non-coating with the similar value**.**

The acceleration values in **Figure 11.** are theoretically calculated through **Equation 8.** using the t_1 values in **Table 5.** and S_1 values.

$$a = \frac{2S_1}{{t_1}^2} \quad (5)$$

The increase in acceleration is assumed to be a reduction in drag, which has been proven in **Equations 1-3.,** by ignoring other resistance force, especially pulley friction, which has been validated by the calculation in **Equation 6**. The acceleration increase, which is assumed to be a drag reduction, is then compared between the hydrophobic coating and the non-hydrophobic coating to determine the percentage of drag reduction with the application of the hydrophobic coating using **Equation 9**.

$$DR\% = \frac{aHC - aNonHC}{aNonHC} X100\% \quad (9)$$

Figure 12. shows that the maximum drag reduction occurs at a lowest mass variation as the value slowly decrease following heavier of the mass used. This is

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because the use of heavier mass variations has an impact on the higher speed of the specimen model which also affects the flow turbulency which is assessed through the Reynold's number value.

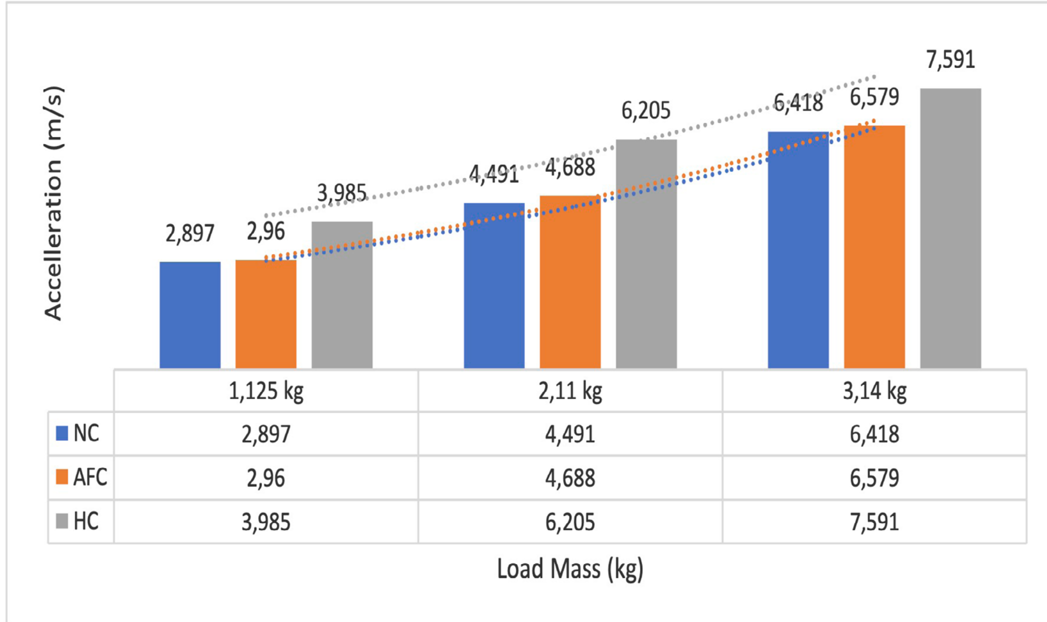

Figure 11. Graph of Acceleration Value

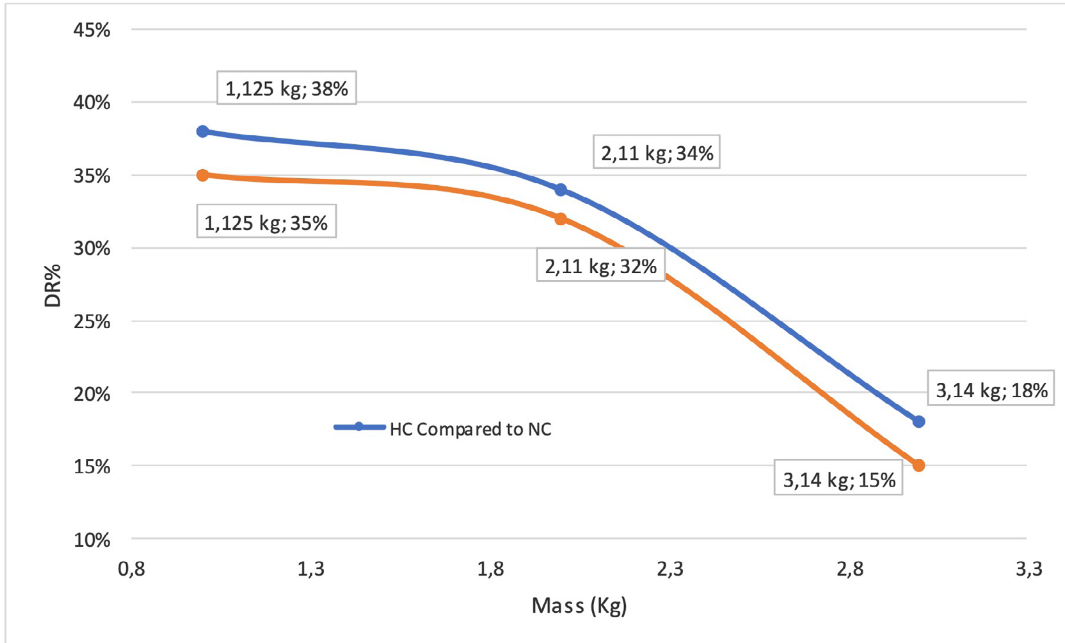

Figure 12. Drag Reduction on every mass variation

The use of variations with higher mass leads to higher velocities, as evidenced in **Equation 10.** by conducting a review through Lagrangian mechanics.

$$V = \frac{\sqrt{2m_B.g.S_2}}{(m_K+m_B)} \quad (10)$$

The speed of the specimen model affects the fluid velocity causes an increase on flow turbulency, as evidenced in **Equation 11.**

$$Rn = \frac{V.L}{\nu} \quad (11)$$

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Therefore, the drag reduction effect is getting smaller as the flow become more turbulent. The phenomenon is in line with the results obtained on research by Moaven [5]. Reynold's number is influenced by three components: specimen width, fluid velocity (influenced by specimen model speed), and kinematic viscosity of the fluid in the test.

IV. Conclusion

Based on discussion of the experimental research results and data analysis, the following conclusions has been obtained that the surface experiences a hydrophobic effect after being coated with a hydrophobic coating, as it was seen from the angle of water contact with the surface, which is >90°. It was found that there is a slip condition & buoyancy increase phenomenon with the application of hydrophobic coating on the model specimen. It was found that there was an increase in acceleration, which was assumed as a drag reduction on the ship model with value shown the hydrophobic coating by 31% compared to the non-coating and by 27% compared to the anti-fouling coating. The reduction in drag gets smaller as the load variation gets higher, which gave a higher pulley force that affecting a ship model's velocity influencing a flow to become more turbulence.

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Reducing a ship's drag by 25% through a smoother hull can lead to notable improvements in both speed and fuel efficiency.

Impact on Speed

In maritime engineering, the power required to propel a ship typically increases with the cube of its speed. This means that a 25% reduction in drag doesn't directly translate to a 25% increase in speed. However, it does allow the ship to achieve higher speeds with the same power output.

Using the cubic relationship between power and speed, a 25% reduction in drag could theoretically allow for approximately a 9% increase in speed without additional power. This is because:

So, the ship could travel about 9% faster for the same power expenditure.

Fuel Consumption Reduction

Fuel consumption in ships is closely tied to the power required to overcome drag. With a 25% reduction in drag, the power needed decreases, leading to fuel savings. Assuming the ship maintains its original speed, the fuel consumption could decrease by approximately 25%.

This estimation aligns with findings in other transportation sectors. For instance, in heavy trucks, a 20% reduction in aerodynamic drag has been shown to result in about a 10% reduction in fuel consumption at 80 km/h, with greater savings at higher speeds . While ships operate under different conditions, the principle that reducing drag leads to fuel savings remains consistent.([tc.canada.ca][1])

Considerations

Hull Maintenance: Maintaining a smooth hull surface is crucial. Biofouling (the accumulation of microorganisms, plants, algae, or small animals) can increase drag, negating the benefits of a smoother hull.

Operational Practices: Implementing practices like slow steaming (operating at reduced speeds) can further enhance fuel efficiency. For example, reducing a ship's speed by 25% can lead to a 58% reduction in fuel consumption per ship year .([rivieramm.com][2])

Technological Enhancements: Incorporating technologies such as air lubrication systems or rotor sails can provide additional drag reduction and fuel savings .([theicct.org][3])

In summary, a 25% reduction in hull drag can enable a ship to travel approximately 9% faster at the same power level or achieve up to 25% fuel savings at the same speed. These improvements contribute to more efficient and environmentally friendly maritime operations.

[1]: https://tc.canada.ca/en/programs/non-funding-programs/ecotechnology-vehicles-program/review-aerodynamic-drag-reduction-devices-heavy-trucks-buses?utm_source=chatgpt.com "Review of Aerodynamic Drag Reduction Devices for Heavy Trucks ..."

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