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Comparison of Drag Reduction Effect on Barge Model Ship Using Ultrafine Bubble and Microbubble Injection

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ABSTRACT

Energy efficiency is a global goal in the fight against global warming. Research on reducing drag is one of the ways to improve energy efficiency. The research method used is the injection of micro-sized bubbles and ultra-fine bubbles used in the barge ship model. Microbubble Drag Reduction (MBDR) and Ultrafine Bubble Drag Reduction (UFBDR) are two methods that can play an essential role in reducing drag on the surface of the ship's hull. Factors that can affect the effectiveness of these methods are the injection ratio, location, and coefficient of drag produced by both methods. The injection method discussed the use of the method, which was reviewed on a 2-meter towing tank and compared the two injection methods. The results provided by this research are to determine the injection ratio and the optimum injection location on the model ship and compare the effect of reducing drag and drag coefficient. The increases total resistance reduction of 6.87% compared to the reduction in resistance by microbubble injection.

1. Introduction

Reducing drag on a ship is an effort made by shipowners to reduce emissions operating costs and increase the ship's ability to work at high speeds. Many studies have carried out developments regarding efforts to reduce ship resistance. The method helps know the effect other than ship operational activities, but physical phenomena are a big question for many researchers. The reduction in resistance can be affected by the viscosity and density possessed by the ship lubrication method and its interaction with the water surface. Mizokami *et al.,* [1] is the first attempt made on a bulk carrier ship by applying air lubrication. Based on the results provided by this large-scale research, there is a 12% reduction in energy consumption for vessels by using a blower with a power of 211 kW.

Academic developments regarding air lubrication using bubbles to reduce resistance near the surface of objects have been carried out by several studies such as (Madavan *et al.,* [2]; Madavan *et al.,* [3]. In both studies, this is the main driving force for the study of micro-sized bubbles to reduce

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resistance in turbulent flow, which is applied to the boundary layer with two investigative methods, namely numerical and experimental. However, this research is based on Soviet research from 1974 to 1976 (Migirenko and Evseev, [4]; Bogdevich and Evseev, [5], which used injection on a shaft medium measuring 254 x 102 mm. Madavan's research ends with two conclusions that the skin friction reduction effect is an effect that only appears at the location of the shaft, which is 35$\boldsymbol{\delta}$ (at low fluid velocity) and reaches 70$\boldsymbol{\delta}$ (at high fluid velocity) as well as the effect of the shaft size of the media used. Furthermore, the numerical test found that y+ is the distance to the wall in the inner variables. Therefore, the effect of bubbles on skin friction reduction is reduced in the two positions, namely the outer layer (y^+ = 200 to 300) and the sub-layer (y^+ = 0 to 10).

Madavan's research finally provided a significant step that opened the study and its application to lubricate ships' surfaces. The most significant reduction in drag on a ship recorded is a reduction of 80% of the skin friction generated by a ship, and this can be seen in several similar studies Hayder *et al.,* [6], Mohammad and Majid, [7], and Sindagi *et al.,* [8]. However, the application has its problems within the location of the injector pad on the surface that should have the highest effect. Second, with the presence of riblet as another method of lubrication applied to the surface of the ship, namely painting and the higher Reynolds number gives an effect that affects the use of air bubbles, and this effect increases with a broader surface area compared to experimental results in the laboratory Kodama *et al.,* [9]. Research [9] on a flat plate with array holes can reduce skin friction by 80%, but this is a problem with the system applied to the ship model. Blowers with high pressure and hydrostatic and dynamic pressure make this method inefficient so that the figure of 80% becomes a number that does not correspond to the actual situation. Silverstream Technologies, Lloyds Register and Shell, [10] on the other hand, it has successfully implemented this method on ships with 40,000 deadweight tons and reduced skin friction by 7.4%. However, research on skin friction reduction using bubbles does not end. Many discussions still need to be studied for this method Gunawan *et al.,* [11], Yanuar *et al.,* [12], Sindagi *et al.,* [13]. Some of these studies examine other methods such as modification of bubble size, position, and their effect on fluid flow experimentally and numerical analysis. These three studies are supported by the difference between bubble sizes conducted by Kawamura *et al.,* [14], who found that a bubble size of 0.5 mm was not as effective as a bubble with a diameter of 0.01 mm. Likewise, research Gunawan *et al.,* [11] found that 50 m bubbles produced by injection on carbon ceramics can have a skin friction reduction of 60.5% with n injection ratio of 0.4 to 0.6. The study is supported by research Kodama *et al.,* [15], which shows that the local friction coefficient ratio is strongly influenced by the air injection coefficient to the bubble injector and is known as the volume fraction in other studies Madavan *et al.,* [16]; Wu *et al.,* [17]; Kodama *et al.,* [18].

Furthermore, the position effect was also studied by Gunawan *et al.,* [19], who identified the best position so that the lubrication effect using microbubbles could give the best outcome. Based on the results presented in the study, [19-20] proposed that the best location for a 2-meter barge ship is placed after the bow and after the mid-ship. In this study, the way that will be used is injection using an ultra-fine bubble generator on a 2-meter-long model ship drawn on a towing tank and will analyze the optimum injection location and the difference in the effect of the injection given to the reduction of skin friction on the surface of the model ship. These two analyses are compared with the injection ratio delivered by the injector with and without the bubble injector. The research is appointed to compare the existing method of lubrication and differences in skin friction reduction an indication of increased lubrication throughout model ship hull as suggested by Ismail *et al.,* [21] that show cased the benefits of non-Newtonian fluid injection or transpiration.

2. Methodology

The experimental activity was carried out using a towing tank at the Department of Mechanical Engineering, the University of Indonesia, at the Naval Engineering Laboratory. The injection used is divided into two types of injectors. The first injector is a plate with a hole of 0.2 mm in diameter. Second, the injection used is an ultra-fine bubble generator, placing the generator in the same position. The injectors from both sources are connected to a compressor with a 60cc/minute ultra-fine bubble pressure and 120cc/minute for the microbubble injector. The airflow is monitored using an existing flow meter of 0-100 Ipm. Table 1 explains the specifications of the ship model used. The compressor used is used to inject pressurized air towards the injector from the injection chamber to the subsurface layer of the ship. Based on the position and parameter specifications of the hole distribution model owned by the microbubble injector, it is done by distributing the injector holes that have a distance between holes of 5 mm, which fits the plate of 150 mm x 300 mm. However, according to the previous description, the location of the appropriate injector has not been determined. Therefore, based on the function of this study, it would be better to know the effect based on the reduction of resistance on the ship's surface than analyze. Finally, suggestions for similar research in the future can be carried out. The body plan of the barge ship used in the study can be seen in Figure 1.

Table 1
Model Specification

Parameter	Barge Model
Lwl (m)	2 meters
Height (m)	0.5 meter
Width (m)	0.86 meter
Displacement (kg)	815 kg
Draft baseline (m)	0.21 meter
Block Coefficient	0.85
Injection position	0.35 loa & -0.025 mid-ship

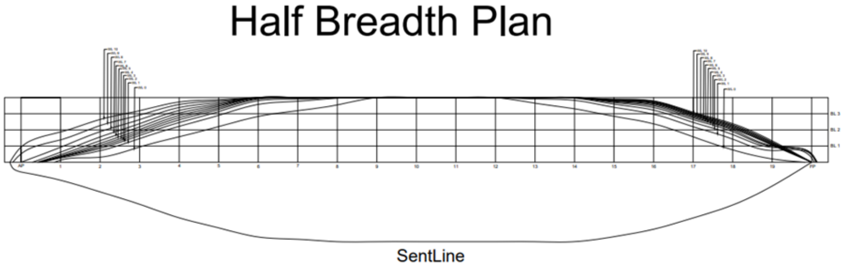


Fig. 1. Half Breadth Plan Model for 8900 DWT Barge

Similarly, the experimental model used was carried out following standard procedures standardized by the international towing tank convention, ITTC [22]. The owned towing tank is carried out with a length of 234.5 meters, a width of 11 meters, and a depth of 5.5 meters. Figure 2 illustrates a towing tank setup that was carried out for hydrodynamic testing. The towing tank used uses an electromotor to tow the model ship. When the vessel is pulled, the bubble injection releases bubbles that interact with the vessel's surface and the fluid in the tank—the fluid used in freshwater. The interaction between the fluid and the ship's surface is detected using a pressure transducer to see the difference in pressure between the fluids on the surface of the ship. Obstacles on the ship are seen using the DAQ application, which can see a maximum load of 10 kg. The interactions were read using a load cell transducer placed at 0.3 of the total LWL. Furthermore, the voltage regulator is connected to the rotation of the electric motor which can produce a Froude number of 0.11 to 0.31. Calculation between voltage regulators to adjust model ship speed.

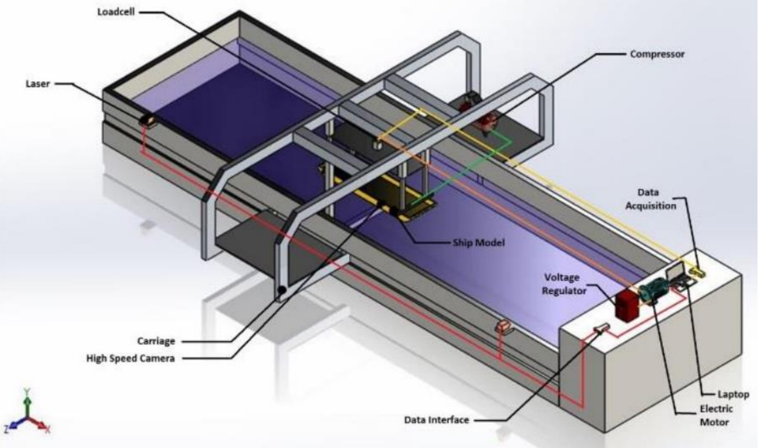


Fig. 2. Towing Tank Experimental Set-Up [12]

The study did not mix the air injected into the injectors because there was no difference between the bubbles produced. So that this research only adapts injectors divided into two types, namely through the shaft media and carbon ceramics. The resulting resistance reduction effect is based on the static pressure on the fluid flow. Furthermore, to increase the effect of reducing the operational bubble resistance, it is carried out in shallow water, which causes air injection to produce less energy to produce Mäkiharju *et al.,* [23]. The decrease in draft results in lower back pressure on the compressor. The effect is also shown in the Froude equation.

$$F_d = \frac{U}{(gDs)^{\frac{1}{2}}} \tag{1}$$

The bubble drag reduction technique can certainly be applied to ships on a full scale by reducing the amount of air injected into the injectors to increase the effect that wanted to be produced. However, large-scale tests are expensive, so the effects studied are carried out on smaller models, following a study that has been applied by Takahashi *et al.,* [20] who injected bubbles into the towing tank and a 50-meter-long flat plate. This review helps determine the optimum injection location that gives the most significant impact. In addition, the thickness of the boundary layer, which is beneficial as a cushion or boundary between the water surface and the ship's surface, is separated. Another experiment was also carried out by Kodama *et al.,* [15] on a plate with a length of 22-meters which observed the coefficient of friction on a flat plate surface with different injection positions. Based on the research results from both researchers, this effect will increase farther from the injection site. The conclusion of the effect can be seen in similar studies Jinho *et al.,* [24]; Gunawan *et al.,* [19], which saw that the coefficient of friction ratio on the injection surface would remain the same as the model used. Second, the residual resistance generated by the model does not significantly affect the injection of the resulting bubbles. So, based on the influence studied, the resistance coefficient equation generated using the ITTC 1978 method applies, where the wave generated from the model will be the same as on a large scale.

$$C_{TM} = R_T(0.5\rho SV^2)^{\frac{1}{2}} \tag{2}$$

$$C_{TM,Air} = C_{FM,Air} + C_R \tag{3}$$

$$\Delta C_{TM} = \left[\frac{C_{TM} - C_{TM,Air}}{C_{TM,Air}} \right] *100 \tag{4}$$

From the above equation, the reduction of frictional resistance that can be done is based on the reduction of the friction coefficient resistance and the reduction of the working fluid density, and the reduction of the surface area of the model used. The formation of a flow containing air and water bubbles can undoubtedly produce a fluid density and viscosity that is useful for influencing the flow structure and causing a reduction in resistance. Other factors also influence this effect, such as the interaction between the fluid and the surface based on multiphase flow. The effectiveness of the density will change along with the void ratio between the injected air and the volumetric flow rate in the boundary layer of the ship's surface Elbing *et al.,* [25] in the following equation.

$$\alpha = \frac{Q_a}{Q_a + Q_w} \tag{5}$$

Qa, in this case, is the flow rate of the air injection. While Qw is the fluid flow that exists in the boundary layer, affecting the volumetric flow rate (α). The fundamental difference between microbubbles and ultra-fine bubbles can be seen in two previous studies Gunawan *et al.,* [19]; Yanuar *et al.,* [12]. Therefore, the fluid flow equation at the boundary layer applies to different coefficients.

$$Q_{\text{w, micro}} = 0.293(L^{0.8} \vartheta.^{0.2} V^{0.8} W) \tag{6}$$

$$Q_{\text{w, ultra fine}} = 0.82912(L^{0.8} \vartheta.^{0.2} V^{0.8} W) \tag{7}$$

Based on the theory that there is a bubble that is injected produces a development effect and the distribution of momentum that makes the fluid flow in a different direction. An increase in the velocity of the injected air also causes bubbles to form faster and at a faster rate. Research Moriguchi and Kato *et al.,* [26]; Sanders *et al.,* [27] resulted in research that the greater the value of this ratio, the more bubbles that will stick to the vessel wall. Thus, reducing turbulent flow has a direct effect on the existing surface of the ship that causes the effect of reducing frictional resistance. However, this effect will exist if a given boundary layer is produced continuously [13].

3. Results

In this study, the resulting different injection ratios between microbubble injection and the use of ultra-fine bubbles. The effect is because the injection power given between one injection device is different, adjusted to the dimensions of the media and carbon shafts for ultrafine bubbles. Table 2 and Table 3 show the difference between the injection ratio and the airflow produced by each device. In this study, the microbubble had a bubble diameter of 200-500 m, which was more significant than the ultra-fine bubble injected with a bubble size of 50-100 m. It is significant in the discussion below that theoretically and practically. The diameter certainly affects the interaction between boundary layers on the ship's surface. A load cell with a 500-gram SWCM model detected the difference between these effects.

Table 2
Air Flow Microbubble Injection(lpm)

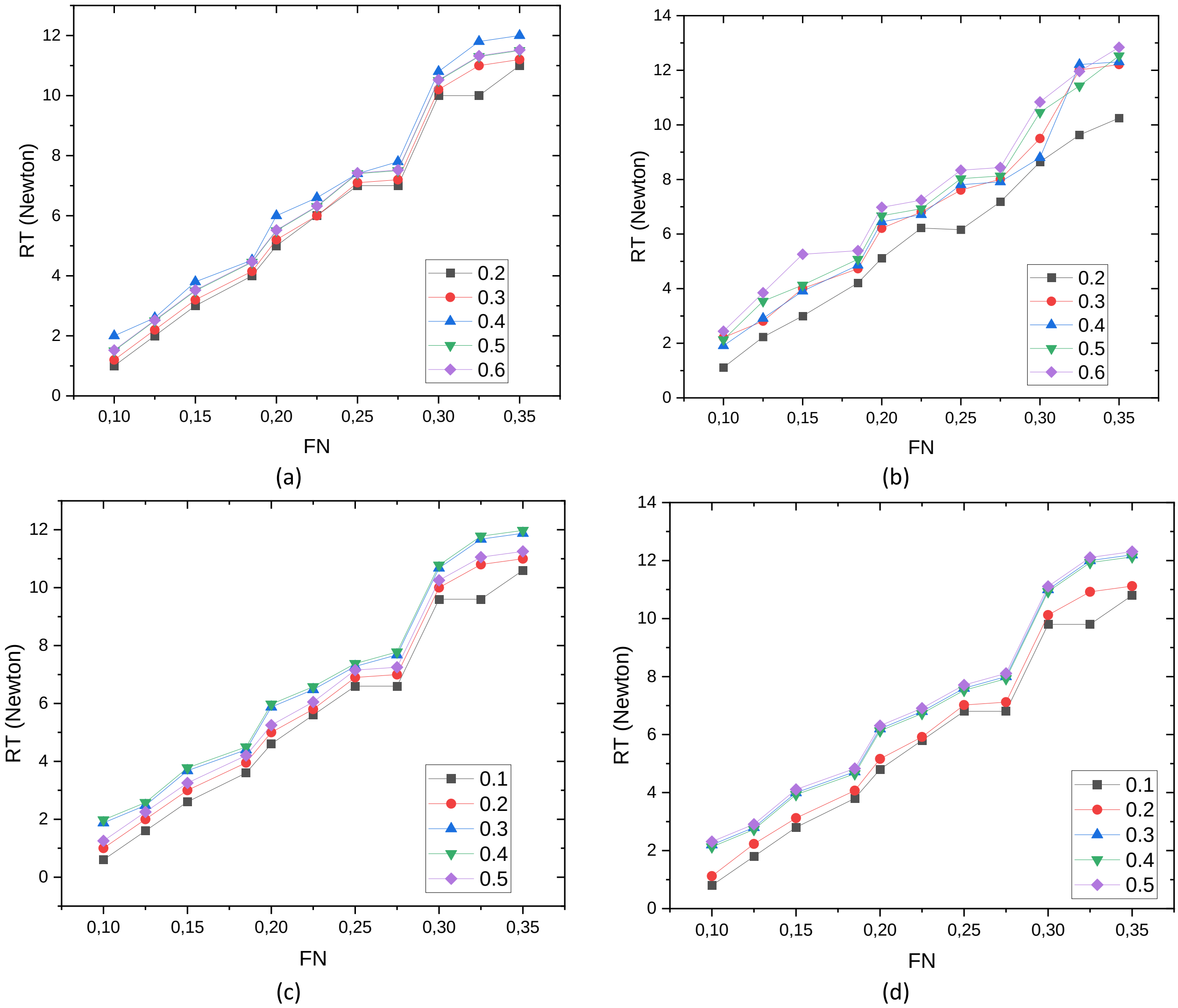
Fr	0,11	0,13	0,15	0,17	0,19	0,21	0,23	0,25	0,27	0,29	0,31
α 0,2	10,00	10,00	10,00	10,00	11,00	11,60	12,00	13,00	14,00	15,00	16,00
α 0,3	11,00	12,00	13,00	14,00	15,00	18,60	18,00	19,00	21,00	22,00	23,00
α 0,4	13,00	15,00	18,00	18,00	20,00	23,00	26,00	26,00	27,00	30,00	31,00
α 0,5	17,00	19,00	22,00	23,00	26,00	28,00	31,00	33,00	35,00	37,00	38,00
α 0,6	21,00	23,00	26,00	28,00	31,00	36,00	38,00	40,00	41,00	45,00	46,00

Table 3
Air Flow Ultrafine Bubble Injection(lpm)

Fr	0,11	0,13	0,15	0,17	0,19	0,21	0,23	0,25	0,27	0,29	0,31
α 0,1	9,80	9,91	10,02	11,40	11,50	11,80	12,00	13,00	13,80	14,85	17,96
α 0,2	10,20	11,80	12,40	13,46	14,85	17,60	18,00	19,08	21,00	23,06	27,05
α 0,3	11,40	14,20	16,80	17,86	19,20	21,05	24,00	24,88	27,00	31,00	32,00
α 0,4	16,80	18,70	21,20	22,31	25,00	27,15	30,02	32,50	35,00	37,00	38,00
α 0,5	19,50	22,40	25,20	27,50	29,00	32,06	34,60	38,00	39,00	40,05	42,80

In this experiment, the ship's speed did not give a considerable disruption by providing a large drag force. The low speed also gives a more significant effect than micro and ultra-fine bubbles injection. In the turbulent layer, there is a vital exchange of fluid particles so that the thickness of the boundary layer increases. The alignment of fluid particles provides a laminar boundary layer by minimizing energy dissipation compared to turbulent motion. When calculating the frictional resistance of moving objects, there are things to consider, such as the length of the model ship, the height of the draft, and the flow's characteristics along the hull's surface.

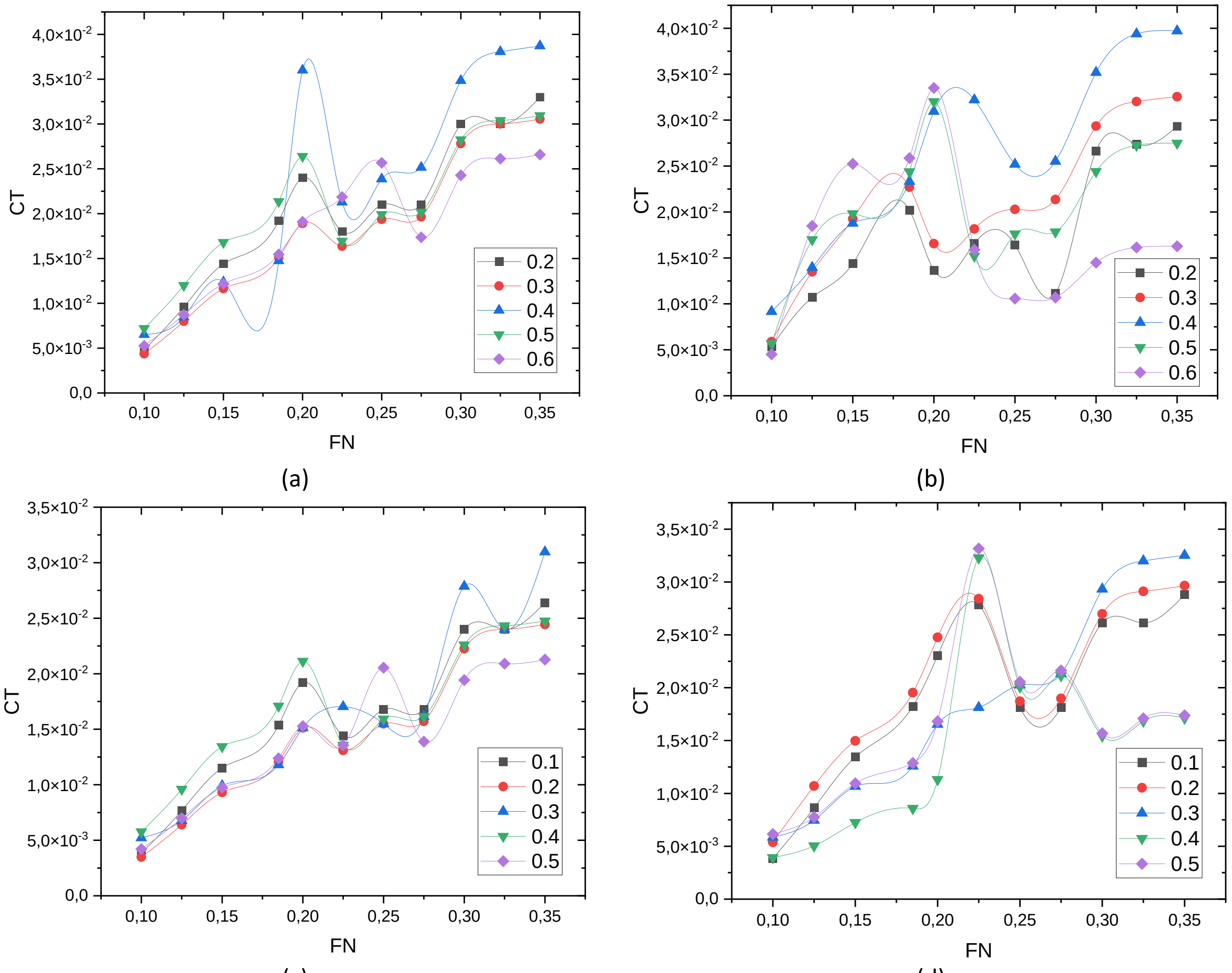
Based on the experimental results, the total resistance compared with the total resistance coefficient produces a significant change in effect. The change can be seen in Figure 3, namely the injection of microbubbles at two different locations. In the results obtained, the correlation between the injection ratio and the inhibition results obtained correlates with 97.54%. With a maximum total resistance value of 11.52, Newton with a Froude number of 0.35 and an injection ratio of 0.6. In contrast, the average total resistance at the first injection site is 6.55 Newton. It has an average total resistance of 7.26 Newtons compared to the second location. The effect is because the function of the microbubbles is only in the middle to the end of the vessel's surface. So, the injection location affects the resistance reduction results.



(a) (b) (c) (d)

Fig. 3. Total Resistance of Ship Model with Different Injection Ratio; (a) MBDR Method in Location 1, (b) MBDR Method in Location 2, (c) UFBDR Method in Location 3, and (d) UFBDR Method in Location 4

Both injection results can be seen in the ultra-fine bubble injection method at two different locations. However, the location placement is the same as the placement of the microbubble injector. Ultrafine bubble injection has a more significant impact than micro, which in the first location, the total resistance generated is 6.1 Newtons. The increases total resistance reduction of 6.87% compared to the reduction in resistance by microbubble injection. Furthermore, the average total resistance at the second location is 6.3 Newtons. Nevertheless, the reduction in resistance was still more significant than the microbubble injection at the second location, with an increase of 13.2%. Resistance reduction can be explained in previous research Gunawan *et al.,* [11], which showed that the effect of ultra-fine bubbles gave a more prolonged effect. This effect is supported by the nature of the bubbles that do not burst easily during movement and remain functional for a longer time. The bursting of micro-sized bubbles is caused by external effects such as light, sound, and the interaction between one bubble and another that can even become one giant bubble or burst. Meanwhile, ultra-fine bubbles have a more consequential impact by reducing the possibility of interactions between bubbles due to a better surface tension balance than micro-sized bubbles.



(a) (b)

(c) (d)

Fig. 4. Coefficient Resistance of Ship Model with Different Injection Ratio; (a) MBDR Method in Location 1, (b) MBDR Method in Location 2, (c) UFBDR Method in Location 3, and (d) UFBDR Method in Location 4

Finally, the drag coefficient graph in figure 4 shows that the ship model with injection using microbubbles is higher than the drag coefficient on the ship model equipped with injection with ultra-fine bubbles. The two methods have differences, namely an increase in the coefficient at the second location because the wetted surface is impactful because the location allows the surface layers of the hull to interact with the fluids. Based on the given effect, the drag coefficient between the ultra-fine bubble method is smaller than the coefficient of the microbubble method. The accumulation phenomenon is not easy to occur in micro-sized bubbles due to the equilibrium possessed by bubbles in turbulent flow conditions.

4. Conclusions

The purpose of the study is to analyze the best possible place for bubble and air lubrication method along the ship's hull. The analysis helps to investigate further effect of lubrication method that decreased skin friction and improve fluid flow in various Froude Number speed. Bubble injection at location 1 is highly effective in reducing resistance and lowering the drag coefficient. The injection ratio also influences this effect by selecting 0.4 as the optimum injection ratio at Froude number speeds of 0.2 to 0.25. For ultra-fine bubble injectors, this has a more negligible effect due to the nature of the ultra-fine bubbles already discussed. However, if it is seen that the injection ratio of 0.2

can provide optimum results. The results are supported by the drag coefficient results generated based on the ultra-fine bubble injection method. Second, based on the results of the interaction between bubbles and the boundary layer on the hull's surface, the effectiveness will be better if the surface is flat and wide so that the bulk carrier is suitable as a user of lubrication methods based on microbubble injection or ultra-fine bubbles. This effect can also be extended by increasing the operational depth of the vessel. Results in a long upward movement of the bubbles to the surface and the bubbles are pumped with less force and under more stable environmental conditions.

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