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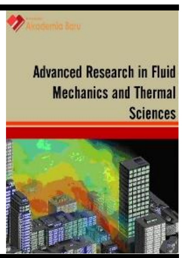

Micro-bubble Drag Reduction by Multi Discrete Hole Plate on Self Propelled Barge Ship Model

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ABSTRACT

Ship resistance is one of the main problems dealing with ship performance and fuel consumption. Microbubble Drag Reduction System (MBDRS) which is applied by injecting air onto the bottom of the hull is a promising technique of active method which it has been developing in various ways. The particular applications of these methods in relatively bottom displacement flat hull (self-propelled barge) are significant to support other available data. Moreover, the complex relation of the ship speeds, injection rates, and hull form take into account in this paper and need to be studied further in which show the optimization between the injection rate and ship speed at the particular cases as well as the bubble and air layer effects account for these results. The injected air bubbles to the bottom of the ships are supposed to modify the turbulent boundary layer properties in which can reduce the hull friction. The objective of this research is to identify the effect of microbubble injection on a self-propelled barge (SPB) model with main dimensions: L = 2000 mm, B = 521.6 mm and T = 52.5 mm. The optimum injector location and injection ratio at each ship speed can be obtained by conducting a towing tank test microbubble injection of self-propelled barge ship model at the after bow (0.35L) and after midship (-0.025L) sections at *Fn* range 0.11 - 0.31 and injection ratio 0.2 - 0.6. Bubble size distribution for each case describes the phenomena of the results obtained. There is the pilling-up effect of the microbubble during the propagation covering the bottom surface hull and so does in this experimental results visualization. Sometimes the size seems bigger in the after side due to the interaction between different injection rate and different model speed. The size of the microbubble in micro size while come out from the porous media as shown in the scale bar of bubble visualization. The test results show that after bow injection area gives the lowest drag reduction compares to the after midship injection with different optimum injection ratio for each case.

Keywords:
Self-propelled barge, resistance, MBDRS, injection ratio

1. Introduction

Ship resistance is one of the main consideration in the ship design process. The greater the resistance generated by the ship the greater the amount of power which must be given so that the

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ship can be operated in accordance with the expected speed. Recently, the concern of study in renewable energy become a trending topic like wave energy converter [1]. Another interesting topic is the energy conservation of the ship sailing at the sea which more specific area about the Reduction of ship resistances has attracted researchers in naval engineering, because with a reduction of 1 - 10% although might be small but has a significant effect, especially in saving the operational costs of the ships [2]. Over time, many researchers have searched for the most effective method of reducing the ship's resistance. There are two methods of reducing resistance to the vessel with active and passive methods. Usually, the ship designer reduces the ship's resistance to the use of the passive method by forming the shape of the ship so as to obtain the most efficient form with the smallest resistance value [3]. However, when using the passive method then it is often the case that there is a change in shape on the hull of the ship. With the change in shape on the hull of the ship, a frequent result is the reduction of the loading capacity of the vessel which can then reduce the economic value of the vessel.

Active resistance reduction methods are the most likely solution to be implemented. Several published studies such as the resistance reduction method using coating or polymerization [4], and micro-bubbles made by electrolysis method [5], water film [2], and also by using micro-bubbles made by injection of air to the bottom of the ship [6][7]. To reduce the resistance actively can be done in various ways, one of them is by injecting air to the bottom of the vessel which will then form a bubble of air with a micro size or commonly called the Microbubble Drag Reduction System (MBDRS) [8].

Microbubble drag reduction system is a tool that serves to minimize the friction resistance on the skin of objects moving in water by injection of micro-sized bubbles into the existing turbulent boundary layer formed on the skin of the object through a small opening on the bottom of the ship so that the micro-sized air bubbles enveloped the bottom of the vessel and can reduce the level of the touch surface roughness and surface shear stress that aims to control the velocity gradient in the boundary layer, thereby reducing the frictional resistance occurring [9]. The application of microbubble technology to ships is done by varying the viscosity of the fluid around the hull of the ship and making some modifications to the structure of the turbulent boundary layer. Previous research was studied MBDR for a high-speed vessel [10], and then investigated some variation of MBDR using porous media and provided the comparison between microbubble drag reduction and air layer drag reduction on a self-propelled barge [11][12].

The size of the injected bubble is more likely to be affected by the shear stress on the hull than the size of the hole used to inject air [13]. Therefore, this study used a porous plate with multiple discrete holes configuration due to easier to be manufactured [14].

The purpose of this research is to understand the ratio and location of the most effective and efficient injection to get the optimum resistance reduction value. To achieve the objective, the towing test procedure is conducted on the ship model to get the value of the ship resistance. Towing test method conducted by applying several variations of injection ratios, injection location, and towing speed on ship model.

2. Methodology

2.1 Experimental Set-ups

A set of test equipment used is the standard equipment commonly used in the procedure of testing ship resistance. The purpose of the towing test is basically a method to investigate the total resistance of the ship model to predict the speed to be applied. In practice, the towing test procedure is also used for the research of resistance reduction on ships with certain conditions that can be set on towing test devices. In the process, the towing test is performed using a model ship designed according to several scale parameters.

A 2 meters long model ship of self-propelled barge type made with fiberglass material used in the testing process. The model used strongly supports the research process in which the characteristics of the hull used is a type of displacement with the bottom area of the hull that tends to flat and shaped like a box with a groove in all four corners with a coefficient of block> 0.95. Air injection is given in two sections of the ship those are 0.35L and -0.025L from midship. Air injection is carried out through a plate having holes 0.2 mm in diameter. The holes spread is arranged in a position like a letter T. The source of the air flow is sourced from a compressor connected to a nylon hose of 6.35 mm diameter. The complete specification of the model ship used can be seen in Table 1.

Table 1
Model ship's specification

Dimension	Symbol and size
Model length	Lm = 2 (m)
Model width	Bm = 0.5216 (m)
Draft	Tm = 0.0525 (m)
Weight	Δm = 8.3 (kg)

While the basin used has ITTC standards with dimensions L = 234.5 m, W = 11 m and H = 5.5 m as shown in Figure 1. The towing speed is regulated through the electromotor used. To control the given airflow a flowmeter is used in a test with a range of 0-100 lpm.

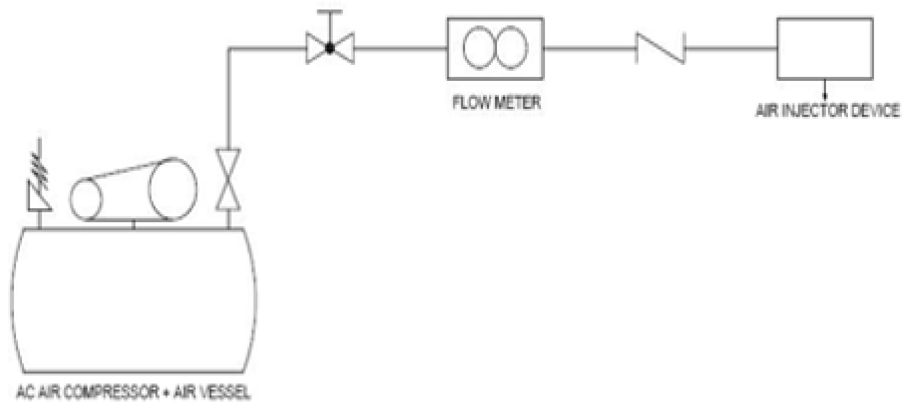

Fig. 1. Air Injection line diagram

To form a bubble at the bottom of the hull, the air is injected into the lower part of the hull through a series of holes in the plate inserted in 0.35L and -0.025L of midship as in Figure 2. The size of the plate used has 300 mm x 150 mm in dimensions. The transversal hole distribution has a distance of 5 mm and is longitudinally only in the middle of the vessel with a distance of 5 mm between holes as shown in Figure 3 with the injection scheme in Figure 4.

To obtain the total resistance value of the ship at the time of testing is used a set of DAQ tools that have a maximum reading of up to 10 kg. Loadcell transducer used on ships is located on the 0.3L from the midship area.

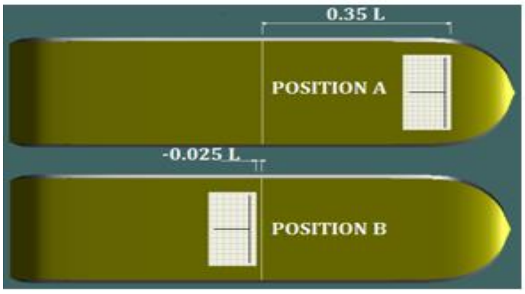

Fig. 2. Injector plate position below ship hull

Fig. 3. Injector plate

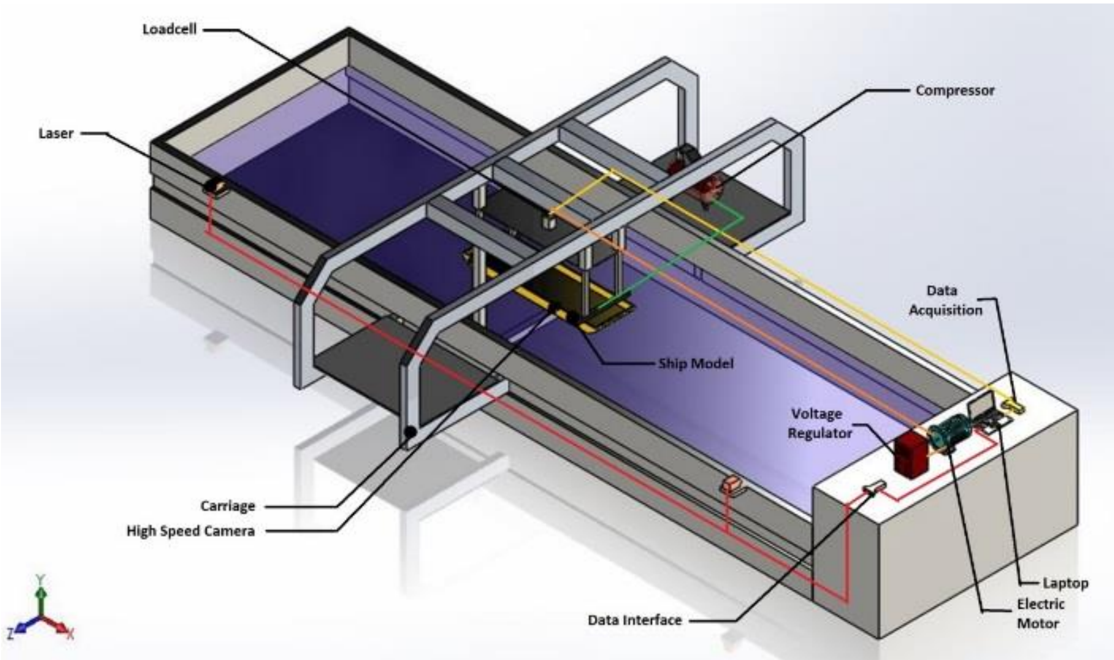

Fig. 4. Experimental set-up

2.2 Test Analysis

Before starting the process of data retrieval it is important to predict the amount of air injection given to the vessel. The inaccurate calculation can cause the vessel to lift and draft or trim changes at the time of the experiment, as it is essential to keep the draft of the vessel the same at the time of operation of this microbubble system.

To determine the amount of air injection is given, it can be calculated by using the ratio between the flow rate at the boundary layer and the flow rate of a given air flow (α) [14]. The ratio of α can be obtained by comparison [14]

$$\alpha = \frac{Q_a}{Q_w} \quad (1)$$

Where Q_a is the flow rate of the injected air and Q_w is the fluid flow rate in the boundary layer region. Based on the theory of turbulence in the boundary layer, Q_w obtained using the formula [14]

$$Q_w = 0.293 x L^{0.8} x \vartheta^{0.2} x V^{0.8} x W \quad (2)$$

where L is the length of the vessel, ϑ is the kinematic viscosity of the fluid, *V* is the velocity of the vessel, and *W* is the width of the vessel.

The experiments were performed in addition to varying the injection ratio also variations on the velocity of the vessel in the range of froude number <0.3 obtained based on the formula

$$Fr = \frac{V}{\sqrt{gL}} \quad (3)$$

Ship total resistance value can be obtained from towing test data. The total ship resistance consists of the frictional resistance and residual resistance. However, the data obtained can not be used to obtain the value of the friction resistance and residual resistance specifically, so that only the total resistance value of the model vessel is obtained. From the data we can calculate the total resistance coefficient using the formula below

$$C_T = \frac{R_T}{0.5 \rho S V^2} \quad (4)$$

where R_T is total resitance value, ρ is water specific gravity, dan S is the wet area of the ship.

With the acquisition of a total resistance value of each variable test**,** then it can be calculated the percentage reduction of resistance in each condition using formula

$$DR(\%) = \left| \frac{C_T - C_{T0}}{C_{T0}} \right| .100\% \quad (5)$$

where C_T is ship total resitance coefficient value after being given an air injection and C_{T0} is ship total resitance coefficient value without given an air injection**.**

3. Results and Discussions

An exposure and comparison were made between the ship that was not given the injection and the vessel given the air injection as shown in Figure 5.

From a series of experiments that have been carried out using model vessels as shown in the experimental part of the experimental model, the raw data were obtained from the total resistance values of the model vessels with each of the given treatment conditions. The experimental data retrieval is done by giving the same speed at the vessel with a speed of 0.50 m/s; 0.56 m/s; 0.67 m/s; 0.83 m/s; 1.00 m/s; 1.11 m/s; 1.25 m/s; 1.30 m/s; 1.33 m/s; And 1.38 m/s.

Resistance generated by the model vessel and the injector placement in the front and rear sections. From Figure 5, it can be seen that the total resistance on the vessel with the addition of air injection in the 0.35L section of the midship or configuration A has a consistent decrease in each injection ratio. In contrast to vessels with the addition of injection at location B or -0.025L from midship tends to fluctuate at any given injection ratio. Even at some point, it has increased the total resistance value, yet generally, when given the medium-high speed the total resistance value tends to decrease compared to the ship model without injection.

However, the graph Alpha-1 when given low towing speed, the ship models with the configuration of the injector experienced a slight increase in the value of the total resistance, which is generated due to the value of the ratio of the injection is given still low, so that the effect of microbubble not effective and even tends to increase the value of total resistance. It happened due to at low speeds microbubble formed a less density bubble cluster on the bottom of the vessel so that the irregular distribution tends to quickly move out of the bottom of the vessel to the side of the ship. The moving air bubbles tend to coalesce as the velocity of the vessel is still low, so that when the injection ratio is still low the empty space left by the bubble is not immediately quickly filled by replacement air.

Figure 5 shows that when the low-speed vessel with injection ratio 4 has decreased the highest total resistance, although it can be said that the injection ratio of 3, 4, and 5 tend to be high when the vessel is given a low speed. However, when mid-speed vessels with injection ratios 4 tend to decrease and vessels with the highest injection ratios increase compared to the level of decrease in the ratio of other injections.

At an injection ratio of 0.3, when the vessel is given medium to high towing velocity there is a decrease in the total resistance value of the vessel to below the total resistance value of the vessel without air injection. However, when the vessel is given an injection ratio of 0.4 there is an increase in total resistance value when the vessel with injection configuration B is given medium to high towing speed compared to the vessel is given an injection ratio of 0.3. This indicates that on vessels with placement in the middle area of the ship (configuration B) the most effective injection ratio for medium to high speeds is at an injection ratio of 0.3.

Different results are obtained when the total resistance coefficient is used as a comparison parameter as shown in Figure 6. Total drag coefficient value of ship models with injection site in position B or -0.025L from midship still indicate no significant decrease in all ratios injection is given. In contrast to the vessel given the injection at position A, where there is a significant decrease in total coefficient resistance value throughout the existing injection ratio. This shows that the effectiveness of placing the most ideal location injector located at 0.35L from the midship position or in locations after bow compared to the location -0.025L or after midship.

When further reviewed the percentage value of the total resistance reduction as illustrated in Figure 5, we can see the effectiveness of the injection ratio to the speed applied to the vessel. To better focus, it can be seen on the graph depicting the percentage reduction of barriers on a given ship 0.35L injection on the part of the midship.

Based on the calculations described earlier, it can be seen that in general the total resistance value generated by the vessel model with the addition of air injector with the configuration A has more significant impact compared to the model vessel added air injector with configuration B. It can happen on a vessel with an air bubble injector configuration A can last longer at the bottom of the ship because the location of the injector is far from the stern, so that the vessel can be covered by the larger air bubbles coverage. While the injector is at amidships, the bottom of the vessel area affected by the microbubble lesser than configuration A that is only at amidships to the stern as shown in Figure 7. Thus, a configuration with injector locations 0.35L or after the bow is the best placement location than the location -0.025L or after midship.

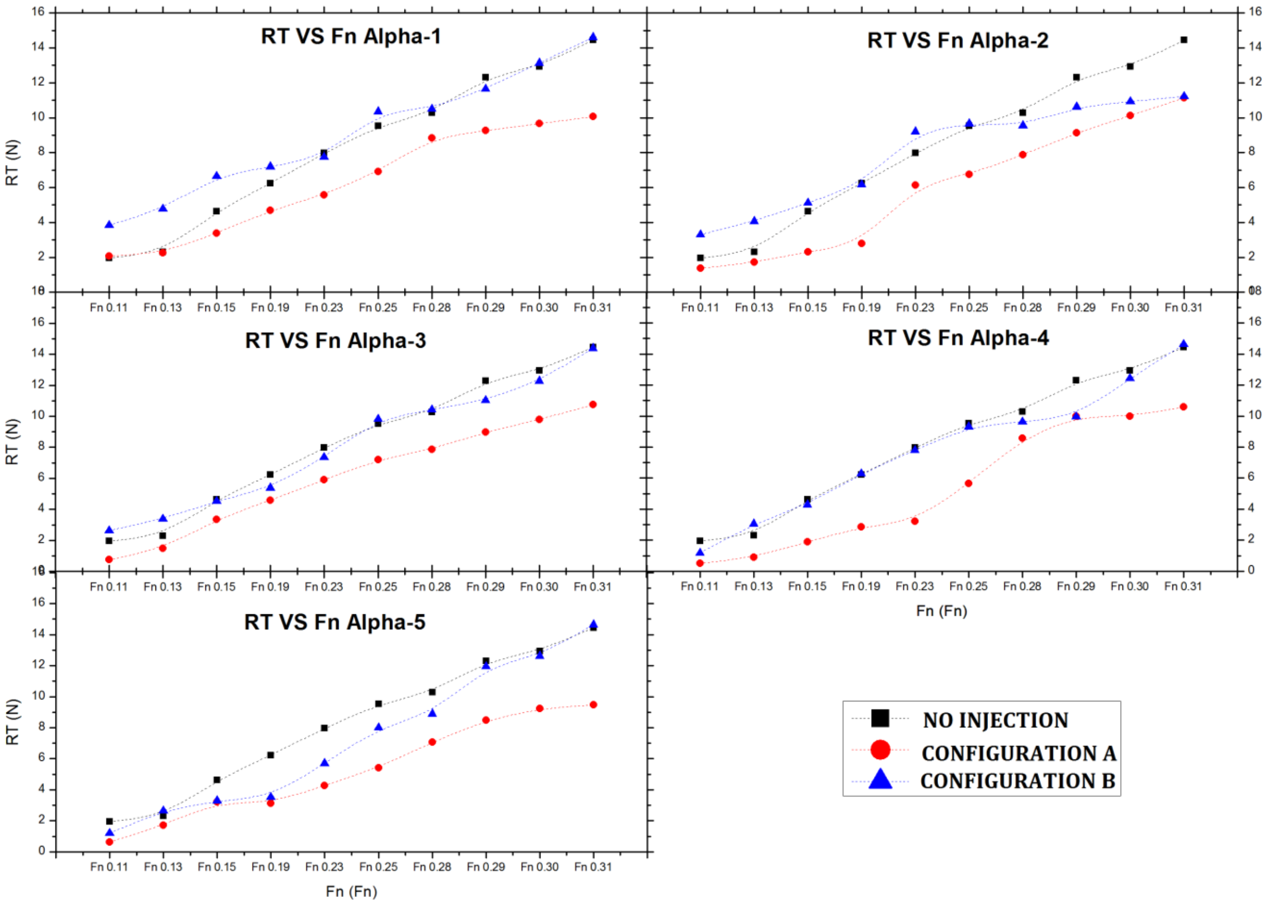

Fig. 5. Relationship between the total resistance (RT) of the Froude number at each injection ratio

In Figure 5 it can also be seen that the model ship with configuration B has a minimal decrease or even increase in total resistance value that occurs when the injection ratio is low. This is because at the time of low-speed air bubbles will be easy to unite so it tends to move more easily due to high buoyancy. When one part of the air bubbles come up the edge of the ship's body or the stern of the vessel, the unified air bubble will immediately move easily out of the bottom of the hull due to the high buoyancy factor and the replacement air supply of the lost bubble does not directly replace the empty space which left the bubbles in motion due to the low flow rate factor. In addition, when a unified air bubble can form a layer of air that is thick enough, so that it can cause phenomena such as piling up effect that usually occurs at the time of injection rate is too high at low speeds, so as to cause a rise in total resistance at some point at low speed.

In the graph the results of the data presented can be seen when the ship is given a low towing speed and simultaneously given the injection with a low ratio, then the following happens is the small change in the value of ship resistance or even the addition of total resistance on the ship. This happens because when the low-speed air bubbles are formed, it will easily move to the side of the ship and then disappear and at low speed the resulting bubble tends to unite, so it is easier to move to the side of the ship and cause the distance between bubbles too loose as seen in Figure 8. So, to overcome this required more air injection so that the number of air bubbles under the vessel will be more and more air bubbles that stay on the bottom of the hull as shown in Figure 9. However, excessive air injection as shown in Figure 10 may also result in an increase in the total resistance reduction value as it may lead to piling up effect where a fragile air cavity forms and damages the built-up space of the existing boundary layer and may make the boundary layer thicker.

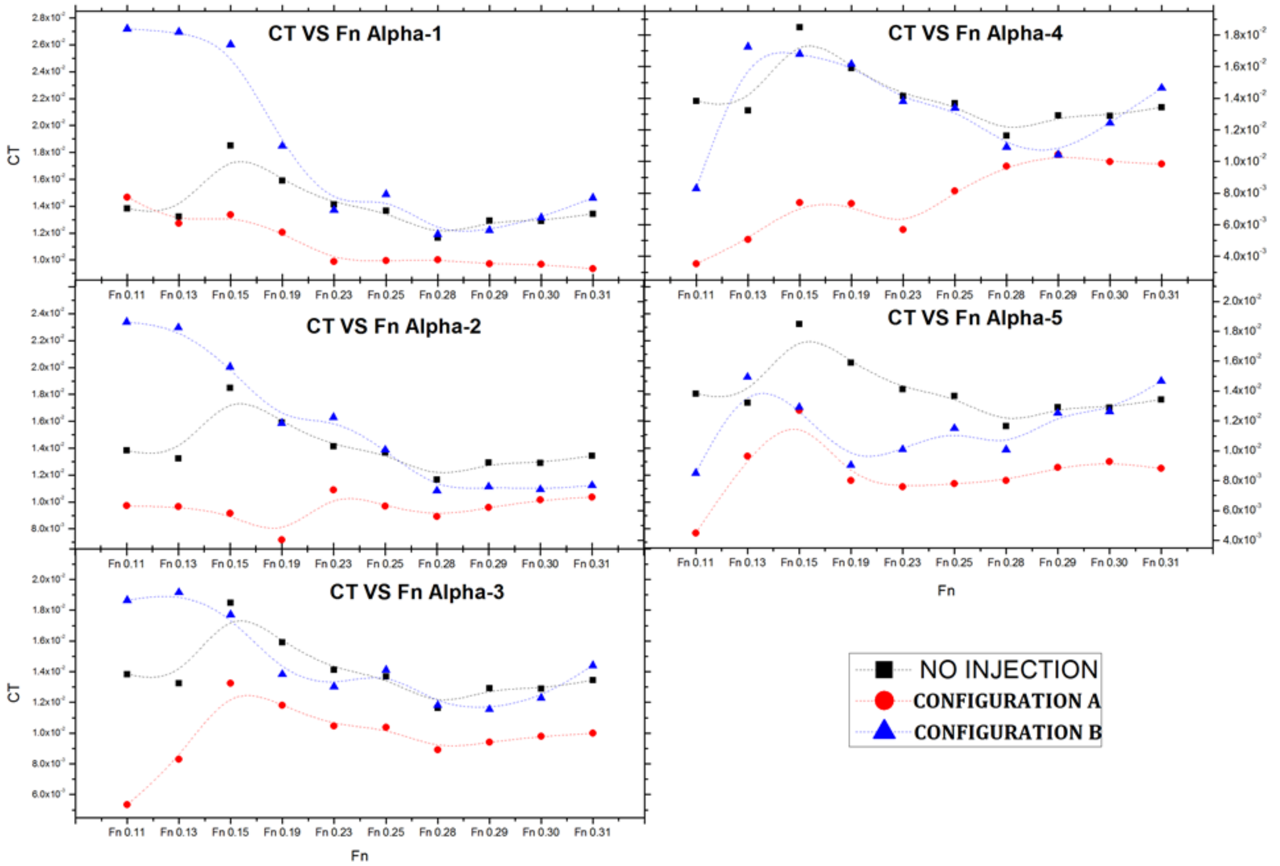

Fig. 6. Relationship between the total drag coefficient (CT) against the Froude number at each injection ratio

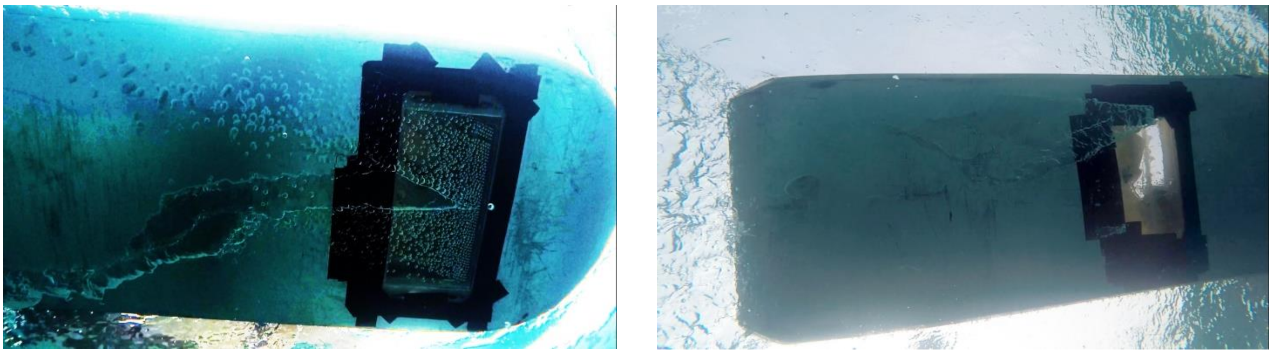

Fig. 7. Location of the injector configuration A (left) and configuration B (right)

In addition, the difference in the decrease in total resistance generated can also be influenced by the large factor of the small air bubbles produced and also the density of the air bubbles located at the bottom of the vessel. Where air bubbles, though of small size, can have significant block-breaking effects when they are large and dense compared to when the air bubbles are large but small and have low bubble density [15]. This is because with the number of bubbles are large and dense then the interference results from the turbulent flow was successfully cleaved by the air bubbles that exist will increasingly have destructive properties against turbulent flow which then moves to the back.

This is in line with the results of research that has been processed where at the time of bubbles produced air is not distributed adjacent the resulting reduction of total resistance obtained is smaller than when the resulting air bubbles are distributed evenly and more tightly. In addition, when the resulting air bubbles become large because the bubbles formed start to blend due to the piling-up effect the total value of the total resistance reduction is also smaller than when the bubbles at the bottom of the ship are evenly distributed and more tightly.

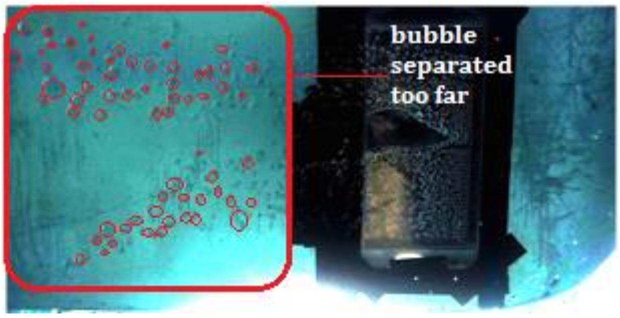

Fig. 8. Visual air bubbles that form on the vessel with the Fn 0:13 and injection ratio 0.2

Fig. 9. Visual bubbles formed on the ship by 0:13 and the ratio Fn injection 0.5

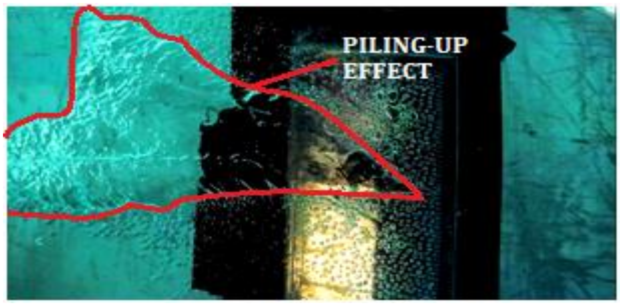

Fig. 10. Visual air bubbles that form on the vessel with the Fn 0:13 and injection ratio 0.6

As the towing velocity is given higher, the percentage reduction of the resistance occur actually shows that between the vessel given the injection with the low and high ratio has slightly different as seen in the Figures 11, 12, and 13, so that at the given speed medium to high then the injection given does not need to be too large to save the energy needed when injecting air.

Fig. 11. Visual air bubbles that form on the vessel with the Fn 0:29 and injection ratio 0.2

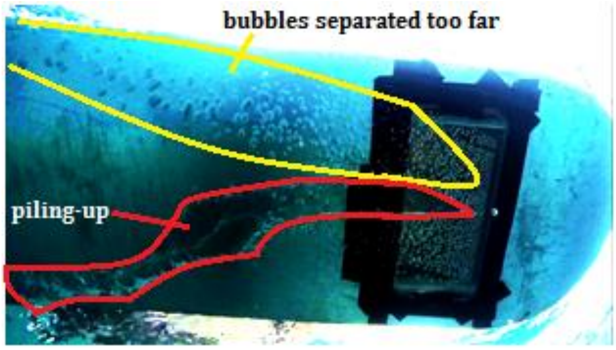

Fig. 12. Visual air bubbles that form on the vessel with the Fn 0:29 and injection ratio 0.5

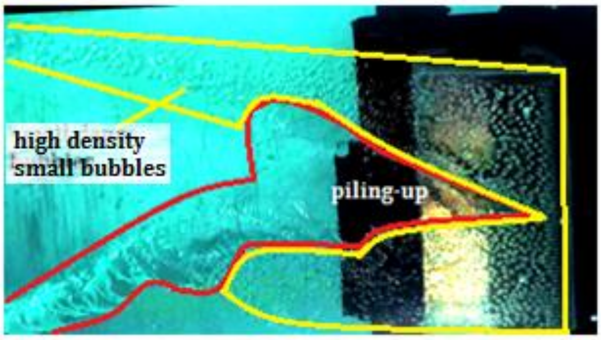

Fig. 13. Visual air bubbles that form on the vessel with the Fn 0:29 and injection ratio 0.6

4. Conclusions

From this research can be concluded several things. The most efficient injector placement location is at the 0.35L location of the midship compared to -0.025L from the midship for all speeds provided at the time of testing. While the most optimum injection flow rate ratio at low speed for the most effective position (configuration A) is in the range 0.4 to 0.6 with a decrease in resistance value in the range 25%-75% due to different air bubble characteristics the bottom of the vessel. Where at low flow rate bubbles that occur tend to gather and rarely, whereas at high flow rate bubbles that occur tend to cause piling up effect, and for high speed all given ratios tend to give results that do not vary much where the value of the decline is in the range of 20% -30%. Hence, the use of microbubble as a resistance reduction method is more effectively used on low-speed vessels making it suitable when applied to self-propelled barges.

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