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Determination the optimum location for microbubble drag reduction method in self propelled barge model; an experimental approach

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Abstract

Nowadays, the energy efficiency is the most important aspect to pay attention. Ship resistances are one of the most important factors in order to see the energy efficiency aspect in the marine transportation. Researchers have done a lot of researches to reduce resistance on ship. One of the method that can reduce the resistance on ship is Microbubble method or known as Microbubble Drag Reduction (MBDR). Ships such as barges play a major role in marine transportation. They are very large and move very slowly. They are proper for microbubble applications. Many factors can affect the effectivity of microbubble. One of them is the location of the microbubble injector. The purpose of this paper is to investigate the optimum injector location for microbubble on a barge ship model with 2 m long. Based on research that has been undertaken by the previous researchers, two locations were compared. The locations were after the bow and after the mid-ship. The test results show that the after the bow location is the most effective injector location on the barge ship model. Because this ship has wide flat hull bottom, microbubble can cover the whole bottom. It shows that effectivity of the injector location depends on the ship type. (© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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Keywords: Energy efficiency; Ship resistance; Microbubble; Injector location

1. Introduction

The most important problem in the marine transportation is the high use of energy. Energy consumption in the ship is depending on the resistance when the ship is operated. Ship resistance reduction is one of technology that developed by Naval Architect scientists for a long time in order to reduce the energy consumption. Hull resistance is considered as the paramount importance to the ships. There are several methods in order to reduce the ship resistance, either active or passive. Passive reduction is reduction of resistance by changing the shape of the hull design such as the addition of bulbous bow, multi hull, SWATH, micro-riblet etc. Active resistance reduction such as air layer, microbubble, air cavity, water repellent coating, etc.

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Microbubble Drag Reduction (MBDR) is one of the methods that have been researched by many researchers in order to reduce ship resistance. MBDR reduce the resistance by decreasing the friction resistance on solid body that moving through the fluid with injected bubble in hull surface.

Documented drag reduction techniques include electrolysis induced microbubble, reported by Mc. Cormick and Bhattacharyya [1]. Other techniques that can be use is injecting the air to the boundary layer usually with slot, porous material and hole plate. Elbing et al. [2] tested 2 types of injector which are porous material and slot. It is obtained from the experiment that the most effective between two injectors is porous material for microbubble method. That is why porous material is used as an injector for this experiment.

This method is successful enough in order to reduce ship resistance. Because it can reduce the resistance up to 20%. However, research for this method still can be developed to increase the effectively, such as analyze the factors that affect the reduction effectivity. Those factors are injector location, injected air flow rate, diameter bubble etc. H. Sayyadi et al. showed the best coefficient injection to determine injected air flow rate in catamaran ship model.

This study aims to compare injector location of microbubble. Injector location of microbubble is one of factor affecting drag reduction of ship. Yanuar et al. [3] showed that on Fast Patrol Boat ship model, it is obtained the optimum injector location for microbubble is 50 mm behind the mid-ship. Otherwise, many researchers [4–8] obtained that the optimum injector location on ship model is near the bow Therefore; it needed further study to know injector location for microbubble, especially application on barge ship. The application of barge ship is common in Indonesia to transport coal. However, barge has a flat hull surface that proper to use for microbubble method. On this experimental, researchers use barge ship model with 2000 mm in length. These experimental use two variables which are ship speed and air flow rate for both locations.

2. Experimental setup

The experimental model test is a fundamental tool utilized by naval architects and other engineering professionals for conducting physical model experiments within a controlled environment. This is one way of testing at a cheaper cost than large-scale testing. Towing tank test is accordance to ITTC Standard [9] and tested in Indonesia Hydrodynamic Laboratory with 234.5 m length, 11 m width and 5.5 m depth. Fig. 1 illustrated the test apparatus in this research.



Fig. 1. Experimental setup of the ship model.

The ship model used in experimental based on the full scale ship that already made in one of Indonesia's shipyard. The ship used as a model is a barge with a scale of 1: 45 made of fiberglass. The ship model dimensions are as follows: LOA: 200 cm, B: 52.16 cm, H: 12 cm, T: 8.75 cm. The ship model is shown in Fig. 2.

The ship model was towed by an electric motor whose speed can be adjusted so the ship model can be towed at a constant speed. On the ship model there is a load cell transducer that located at 0.35L in front of mid-ship. Load cell transducer connected with electric motor to towing the ship model. The ship resistance data will be displayed by the data acquisition that has been connected to the load cell transducer. The porous media was used to form bubble on the hull surface. Porous media that used in the experiment is shown in Fig. 3a. Porous media was connected with air compressor by 1/4-inch pipe. The air flow rate will be measured by the air flow meter which is between the compressor and the porous media. The air injection system is illustrated in Fig. 3b.



Fig. 2. Ship model.



Fig. 3. (a) porous media; (b) air injection apparatus.

Experimental has been done with two conditions of injector location. First condition is located 100 mm after bow (location 1) and second condition is located 50 mm after mid-ship (location 2). One of the important things in application of Microbubble Drag Reduction method is the determination of injected air flow rate. Determination of the injected air flow rate described as coefficient injection (α). Coefficient injection is defined as the ratio of injected air flow rate divided by the water flow rate within the boundary layer.

$$\alpha = \frac{Q_a}{Qw} \tag{1}$$

Where Qa is variation of injected air flow rate, and Qw is the water flow rate within the boundary layer (mm). The water flow rate within the boundary layer can be calculated by the equation (2) (see Table 1):

$$Qw = 0.293L^{0.8}\vartheta^{0.2}V^{0.8}W \tag{2}$$

The total resistance of ship is most affected by both viscous and wave resistance. The viscous resistance is dominated by a portion of frictional drag which is influenced by form factor of the hull. Further, the wave resistance can be divided into two parts: wave-breaking resistance and wave-induced resistance. On low-speed range, the skin friction resistance is the biggest component.

]	Fr	0.11	0.13	0.15	0.19	0.23	0.25	0.28	0.29	0.30	0.31
	0.2	10	10	10	11	12	13	14	15	16	16
	0.3	11	12	13	15	18	19	21	22	23	23
α	0.4	13	15	18	20	24	26	29	30	31	31
	0.5	17	19	22	26	30	33	36	37	38	38
	0.6	21	23	26	31	36	40	43	45	46	46

Table 1. Air flow rate (lpm).

In the experimental model ship that has obtained total resistance (R_T) then the total resistance coefficient (C_T) can be calculated using the equation:

$$C_T = \frac{R_T}{0.5\rho SV^2} \tag{3}$$

Where S is the wetted area of the ship's surface hull (m²), V is the speed of the ship (m/s) and ρ is the water density. In the test model Injection flow rate (α) used ranges from 0.2–0.5. Due to the maximum DR obtained in the range.

Drag reduction can be obtained by:

$$DR(\%) = \left| \frac{C_T - C_{TO}}{C_{TO}} \right| .100\%$$
(4)

Where CT_O is the total coefficient resistance without microbubble injection and CT is the total coefficient resistance with microbubble.

3. Result and discussions

Total resistance (RT) to Froude number and comparison of total coefficient resistance (CT) to Froude number between ship model with and without injected microbubble at both locations can be seen in Figs. 4–7. As shown in Fig. 4, the total resistance (RT) of the ship model with microbubble injection at location 1 (after bow) is lower than the ship model without injection. Similarly, in the graph of the total resistance coefficient (CT) in Fig. 5 which shows that the ship model with microbubble injection has a lower CT than the ship model without injection. This indicates that there is a reduction in the ship resistance on microbubble injection at location 1 (after bow).



Fig. 4. Total resistance of ship model with injector in location 1.

The difference between ship model total resistances with microbubble injection in the location 1 to ship model without injection at high speed (starting from Fr = 0.23) tends to be greater than the lower speed. This is due to



Fig. 5. Total resistance coefficient of ship model with injector in location 1.

the pilling up effect. This at low speeds there is an excessive air injection that causes the air cavity. An excessive of air cavity size causes the air to break out. The phenomenon of the air cavity causes the disruption to its boundary layer and causes the wake range to enlarge. Wake range causes lower drag reduction or can even cause additional resistance to the ship model.

In the location 2, it can be seen in Fig. 6 that the total resistance (RT) with injection is generally lower than the ship model without injection. However, at Fr = 0.13 ship model with injected bubble has a higher resistance. At this Froude number occur the phenomenon of pilling up effect that can cause wake range. Therefore, it can cause the addition of friction resistance to ship model. Yet, after the speed increases drag reduction occurs. This is proven that the microbubbles succeeded in reducing total resistance on the ship model in both injector locations.



Fig. 6. Total resistance of ship model with injector in location 2.

Fig. 8 shows the total resistance comparison between the location 1 (after bow) and location 2 (50 mm after midship). Based on the graph, it can be concluded that in each injection coefficient (α), the ship model resistance at location 1 (after bow) is lower than the ship resistance at location 2 (5 cm after midship). However, in the coefficient injection (α) 0.6 starting from Fn 0.25 the resistance total (RT) in location 1 is greater than location 2. It can occur due to high speed and high injection rate causing the injected microbubble at location 1 (after bow) to leak out and could not stay on the boundary layer until the stern bottom surface. The results can be seen in the figure that showed in Table 2 with the injection coefficient (α) 0.6. Another case in the location 2 (50 mm after midship) tends to have a flow path. Therefore, at high speed and high injection rate microbubble does not leak out from the



Fig. 7. Total resistance coefficient of ship model with injector in location 2.



Fig. 8. Comparison of total resistance between location 1 and location 2.

boundary layer. In addition, it can be seen in the figure showed in Table 2 with the injection coefficient (α) 0.6 in location 2 occur microbubble built-up into water transition layer. This can lead to greater drag reduction.

Tables 2 and 3 show the microbubble visualization both for low speed and high speed. The bubble size of low speed is bigger than in high speed test. Resistance reduction is effected by the bubble generation and the mechanism is cut the boundary layer therefore the frictional resistance of ship is reduced.



Table 2. Microbubble visualization at Fn = 0.15 (representing low speed).

4. Conclusion

Based on the experimental ship model test, it can be concluded that the location of microbubble injection has an effect on the effectiveness of drag reduction. Microbubble applications in both experimental locations can reduce ship resistance. The results showed that the location 1 (after bow) was the most effective location for barge ship

Location 2 (50 mm behind midship) Location 1 (After the Bow) α 0.2 0.3 0.4 0.5 0.6

Table 3. Microbubble visualization at Fr = 0.29 (representing high speed).

model. This can occur because the barge ship model has a large flat hull bottom. Therefore, the injected bubbles can cover more hull bottom efficiently than in the location 2 (50 mm after midship).

Moreover, for the microbubble injection location, air flow rate and ship speed are the other factors that may affect microbubble effectiveness. It can be seen from Figs. 8 and 9 that at each speed and the injection coefficient of location 1 has lower total resistance and greater drag reduction. However, in the injection coefficient (α) 0.6



Fig. 9. Comparison of drag reduction between location 1 and location 2.

starts at a speed 1.11 m/s or Fn 0.25 the total resistance is greater and drag reduction at location 2 is lower than location 1. From the case, it can be concluded that the injector location depends on the ship speed and type.

At the injector location 1 (after the bow) proper for the ship with a relatively low speed. Because at the low speed microbubble will remain on the hull bottom surface and can cover most of hull bottom surface. In other case, location 2 (50 mm behind midship) is more proper for the ship with a relatively high speed with a high flow rate as well. Because the location 2 (50 mm behind midship) has a flow path below the hull bottom surface of the ship. Therefore, microbubble will not leak out from the boundary layer.

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