

Micro-Bubble drag reduction with triangle bow and stern configuration using porous media on self propelled barge model

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Abstract. Drag reduction on ship to decrease fuel consumption and achieve higher speeds has become the topic since the last decades. One of the most attractive idea is micro-bubble, in order to reduce frictional resistance. The purpose of this research is to identify micro-bubble drag reduction effect on Self Propelled Barge Model at 1:28 scale. The influences of air injection ratio and speed will also be investigated. Five injection ratio were used in this experiments; 0,2; 0,3; 0,4; 0,5; and 0,6. Experiments were done in the towing tank, member of ITTC. Micro-bubble was injected on bow and midship using two configurations; triangle stern and triangle bow. The results show that triangle stern is the best configuration with 5% - 40% drag reduction at 0,2; 0,3; and 0,4 injection ratio.

1. Introduction

The resistance of a moving ship is a drag force that is opposite to the direction of the ship motion as it travels through the fluid at certain rate of viscosity. Drag on the ship can be categorized into frictional drag and residual drag. Drag reduction is divided into two methods: active and passive. The active is a method that adds substances continuously to the body of the ship, while the passive method using modification of the ship body in order to reduce resistances continuously.

Micro-Bubble Drag Reduction (MBDR) is an active method by injecting micro-sized air to the bottom of the ship. The use of micro-bubble is the most promising active methods to reduce frictional resistance. The first research on micro-bubble was done by McCormick and Bhattacharyya (1973) using electrolysis method. Madavan, *et al* (1985) injects the micro-bubble into the boundary layer layer using porous media in the water tunnel, resulting in 15-80% drag reduction.

Kodama, *et al* (2001) used tanker to determine the optimum location of air injection. They concluded that the most effective injection is at the bow of the vessel. Tanker and barge vessels have moderate L/B ratio, therefore the area covered by micro-bubble can become wider. This type of vessel also has a flat and wide bottom surface, making it suitable for micro-bubbles. Meanwhile, according to research of Yanuar, *et al* (2012) on the Fast Patrol Boat concluded that the best injection location is at 5 cm behind the midship. Another experiments, Kawabuchi, *et al* (2011) on container vessel injects micro-bubble on the bow and stern using CFD simulation, resulting up to 60% drag reduction.

In this research Self Propelled Barge Model was used with L=56m and scaled to ship model at 1:28 scale. Air compressor was used to inject air into porous media. The influence of speed and air injection ratio variations will be investigated. The effect of porous media location will also be



analyzed by comparing two different sets up. The final result will be the most effective configuration and air injection ratio at certain speed.

2. Experimental Setup

The experiments were done in Indonesia Hydrodynamic Laboratory (IHL), Surabaya, Indonesia. This towing tank is a member of International Towing Tank Conference (ITTC). The Specifications of this towing tank are presented in figure 1.

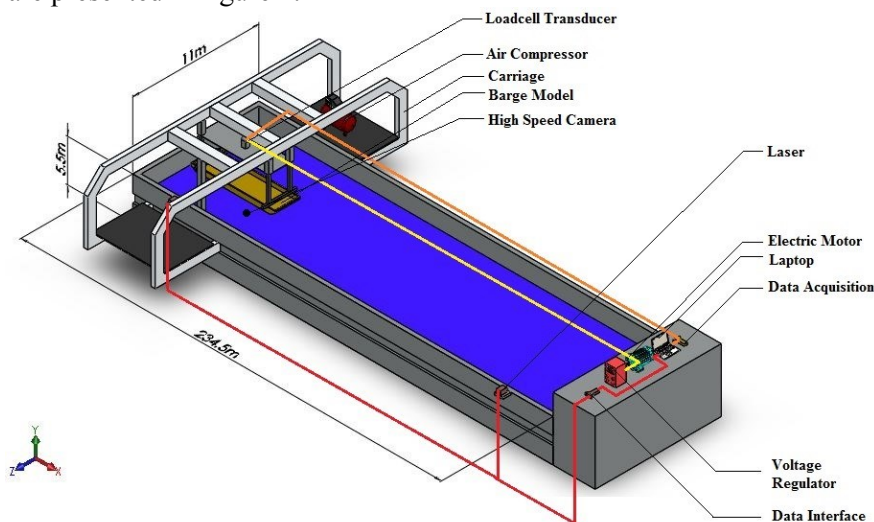


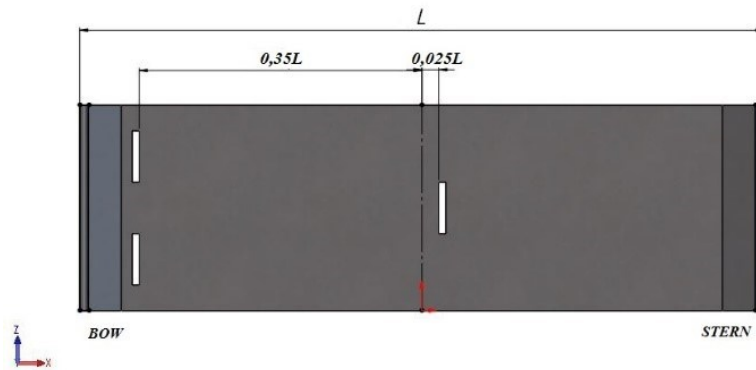
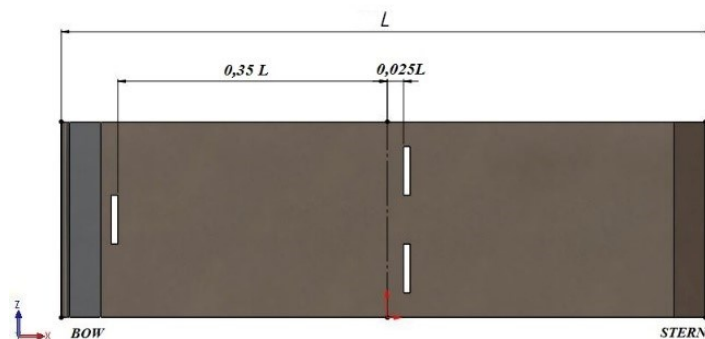
Figure 1. Experimental Set Up

A 2 m Self Propelled Barge Model has been constructed with fiber glass for experimental tests. The hull form of this model was straightforward, box shaped in the stern region and streamed in the bow, can be seen in figure 2.



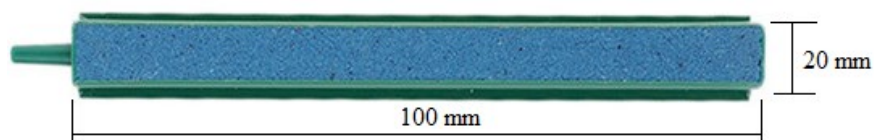
Figure 2. Scaled SPB Model at 2 m Length

Air injection was undertaken at two positions along the length of the model, bow and stern regions with length ratio. The length to position ratio for injection was $0,35L$ to the bow and $0,025L$ to the stern. The injector was located in triangled positions shown in figure 3 and 4. The first configuration was triangle bow, consisted of one injector at the bow and two injectors at the stern. Thus, totally in one configuration consisted of three injectors. Another configuration was reciprocal with two injectors at bow and one at stern. Further detailed specifications of ship model can be seen in table 1.

**Figure 3.** Triangle Stern Configuration**Figure 4.** Triangle Bow Configuration**Table 1.** Model Specification

Unit	Dimension
Length	2 m
Width	0.52 m
Height	0.12 m
Draft	0.08 m

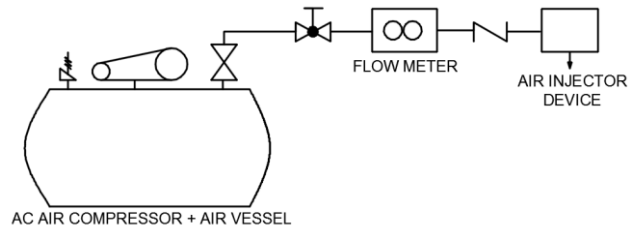
In order to form bubbles around the hull of the model, air was injected through a plate with array holes (porous plate). The width and length of this plate was 20 mm and 100 mm respectively. The injection plates were covered with holes along the width and length, which is shown in figure 5.

**Figure 5.** Porous Plate

To set and control the air injection rate, a flow meter was used. This flow meter shows the rate of air at Litre per Minute (LPM). The maximum rate could be measured at 100 LPM, which is shown in Figure 6. Thus, by using flow meter, air injection rate could be controlled at each step.

**Figure 6.** Air Flow Meter

In order to produce the injected air, an air compressor was used with 120 LPM maximum injection rate. This air compressor was connected to injectors using 6,35mm rubber tube. A division manifold was used to create equal flow rate at each injector. Thus, the air injection schematic was created and shown in figure 7.

**Figure 7.** Air Injection Schematic

To get varied data, 10 steps of speed were used and shown in table 2. These steps were based on the actual ships Froude Number at 0,15. Then, five air injection ratio were also used to determine optimum rate for Self Propelled Barge Model; 0,2; 0,3; 0,4; 0,5; and 0,6.

Table 2. Variation of Speeds

V (ms ⁻¹)	Froude Number
0,5	0,11
0,56	0,13
0,67	0,15
0,83	0,19
1	0,23
1,11	0,25
1,25	0,28
1,3	0,29
1,33	0,3
1,38	0,31

3. Test Analysis

Froude simialirity law is followed in the extrapolation of resistance test result. According to it, the resistance of ship can be divided into two components and one of them is proportional to the frictional resistance of a flat plate at the same length and wetted surface area, towed at the same speed.

In this experiments, air injection ratio was used to determine optimum injection for Self Propelled Barge Model. According to Sayyaadi and Nematollahi (2013), the air injection (Q_α) injected into porous media can be calculated as:

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

With air injection ratio (α) determined at 5 steps; 0,2; 0,3; 0,4; 0,5; and 0,6. Then, Q_w is water flowrate within boundary layer (Sayyaadi and Nematollahi, 2013), can be evaluated as:

$$Q_w = 0,293 \cdot L^{0,8} \cdot \nu^{0,2} \cdot V^{0,8} \cdot W \quad (2)$$

where L is the length of ship (m); ν is kinematic viscosity of the fluid (m^2s^{-1}); V is speed of ship (ms^{-1}); and W is the width of ship (m).

The first raw data obtained from the towing tank experiments were total resistances of ship (R_T), then it can be extrapolated into resistance coefficient (C_T) with the following equation:

$$C_T = \frac{R_T}{0,5 \cdot \rho \cdot V^2 \cdot S} \quad (3)$$

where ρ is fluid density (kgm^{-3}) and S is wetted surface area (m^2). From the MAXSURF software, the wetted surface area can be determined; 1,1292 m^2 . From the results above, then the results can be compared as:

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

where $DR(\%)$ is drag reduction percentage and C_{TO} is resistance coefficient without injection.

4. Results and Discussion

4.1. Total Resistance (R_T) vs Froude Number (Fr)

From the figure 8, it is shown that each configuration has the same trend, which is the total resistance of ship increases (R_T) as the speed increases. This corresponds to the resistance equation which the speed function is directly proportional to the resistance of the ship. When the injection process occurs, the triangle stern configuration tends to be stable, lower than without injection. Furthermore, in Figure 8 it can be seen as well that the total resistance of triangle stern configuration is lower than triangle bow. This is because in the triangle stern configuration consisted of two porous media located on the bow of the ship. The air that exits through the two porous media is more enveloped under the surface of the ship than the triangle bow configuration. Therefore, the ship resistance lowered, because the wet area is smaller.

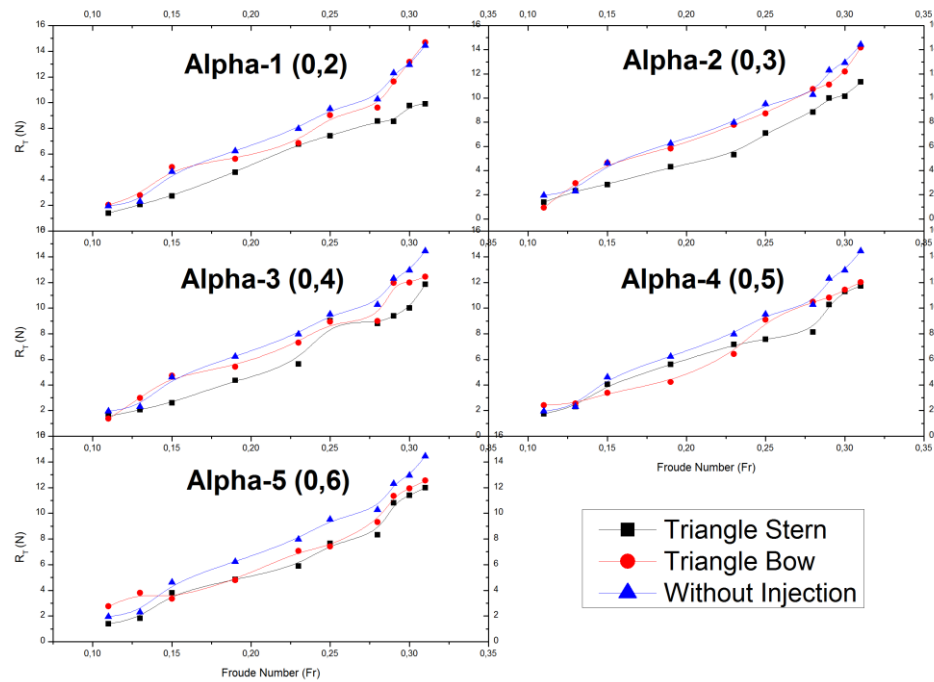


Figure 8. Total Resistance (N) vs Froude Number

4.2. Total Resistance Coefficient (C_T) vs Froude Number (Fr)

The next step is breakdown the total resistance into coefficient using equation 3. Wetted surface area (S) can be calculated precisely using naval software; MAXSURF and resulted a value of $1,1292 \text{ m}^2$. The graph trend in figure 9 has the same characteristics as the graph in figure 8 because each component has a comparable value.

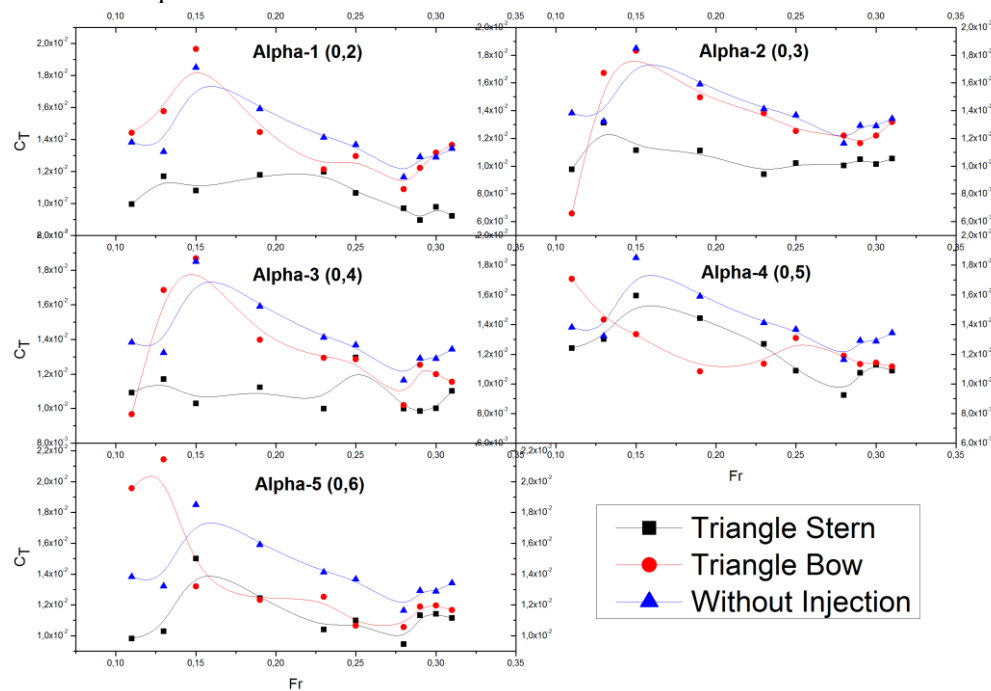


Figure 9. Total Resistance Coefficient vs Froude Number

In triangle stern configuration the overall graph is under the ship without injection and tends to be lower than triangle bow configuration graph. Whereas, in the position of triangle bow, on the first three Froude (Fr) numbers, the graph tends to be higher than ship without injection. This phenomenon can be explained through image visualization. In figure 10 and figure 11, can be seen the image comparison at Alpha-2 and Fr-3 on each configuration. In the triangle bow, there are micro-bubble built up from the front to the left, resulted in the formation of larger air bubbles. This larger bubbles can be detrimental if the bubble bursts and creates wake rake. This phenomenon is called pilling up effect (Sayyaadi and Nematollahi, 2013). From this phenomenon it can be concluded that at lower speeds micro-bubble injection in triangle bow configuration is not effective. While at higher speeds, micro-bubble is effective in reducing drag in both configurations. It can be shown on the graph that the total injection coefficient (C_T) is lower than without injection. Based on the five graphs can also be concluded that the triangle stern configuration is more effective than triangle bow configuration.

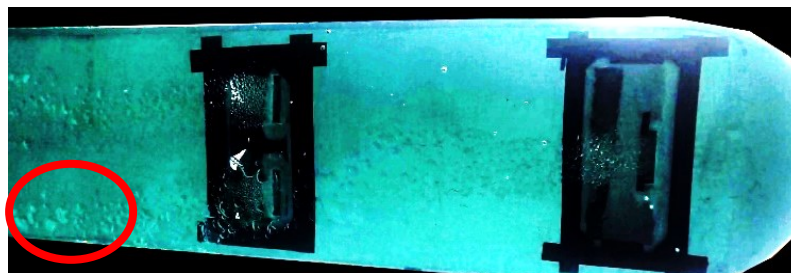


Figure 10. Triangle Bow at Alpha-2 (0,3) and Fr-3 (0,15)



Figure 11. Triangle Stern at Alpha-2 (0,3) and Fr-3 (0,15)

4.3. Drag Reduction (DR)

Based on analysis of the total resistance coefficient (C_T) vs Froude number (Fr) and also on the total resistance (R_T) vs Speed (V), the most effective drag reduction (DR) occurs in triangle stern configuration. Therefore, the drag reduction graph shown in figure 12 is the triangle stern configuration, to find the most effective air injection (α) ratio.

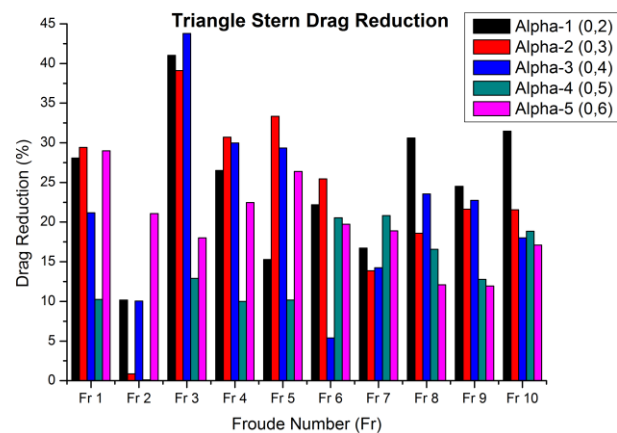


Figure 12. Drag Reduction on Triangle Stern Configuration

Based on the drag reduction graph in figure 12 it can be inferred that at low velocities from Fr-1 to Fr-5 the dominant air injection ratio in reducing drag is at 0.2-0.4, with a 10-43% reduction range. At low speed, the higher injection coefficient in some conditions were less effective in reducing the resistance. This is due to the pilling up effect (Sayyaadi and Nematollahi, 2013), where in higher injection coefficient at low speeds there is an accumulation of air on the bottom of the ship due to the low velocity of the vessel. The air moved slowly toward the stern of the vessel causes the formation of larger air bubbles. If this bubble is not broken, then it can be beneficial, because the wetted surface area is much reduced. However, in the event of a split on the bubble, it will cause a wake rake that created drags to the ship. This phenomenon showed in figure 13 and 14. In figure 13, micro-bubble did not coalesce and flows well behind the ship.



Figure 13. Triangle Stern at Alpha-2 (0,3) and Fr-3 (0,15)

However, in figure 14 and 15 there is a pilling up effect phenomenon which the micro-bubble joined into larger bubble in the midship but became small bubble in the stern, indicates that bubble burst has occurred. But, this phenomenon did not occur at a ratio of 0.2; 0.3; And 0.4. At this ratio, the micro-bubble did not creating larger bubbles, flows smoothly to the stern of the ship. Therefore, it can be concluded that the effective injection ratio at low speed is at 0.2; 0.3; and 0.4.

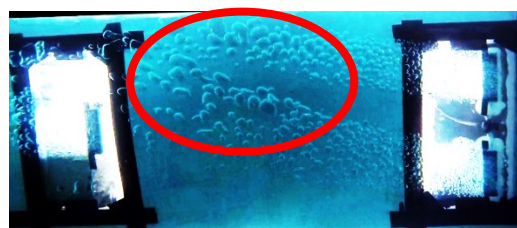


Figure 14. Triangle Stern at Alpha-4 (0,5) and Fr-3 (0,15)



Figure 15. Triangle Stern at Alpha-5 (0,6) and Fr-3 (0,15)

At higher speeds from Fr-6 to Fr-10 there is no graphic trend occurred. The increase in speed is not influential on the reduction of drags. The reduction percentage ranged from 15-30% with the highest reduction at Fr-8 and Fr-10 velocities in Alpha-1 injection coefficient (0.2). Meanwhile, at Fr-8 in the highest coefficient, drag reduction drops dramatically. This can be explained through image visualization. In figure 16 it appears that micro-bubbles were moving well toward the stern of the vessel, thus reducing the drags which occurred better than Alpha-5 (0.6) in figure 17.

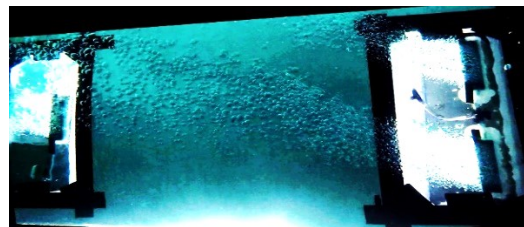


Figure 16. Triangle Stern at Alpha-1 (0,2) and Fr-8 (0,29)



Figure 17. Triangle Stern at Alpha-5 (0,6) and Fr-8 (0,29)

It appears the micro-bubble did not flow towards the stern of the ship properly, but goes straight to the side of the ship (leaking), thus drag reduction is lowered. Therefore, it can be concluded that at higher speeds the given injection ratio tends to provide drag reduction not much different at each step, thus the five ratios are effective to be used.

5. Conclusion

The experiment has been performed with and without injection of micro-bubble. Porous media was used to produce micro-bubble along the hull of model, with two configurations; triangle stern and triangle bow. By using 10 steps increment of speed 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; 1.38 m/s. and 5 steps of air injection ratio, 0,2; 0,3; 0,4; 0,5; 0,6, this research yield the following conclusion:

1. The use of micro-bubble using porous media with triangle stern and bow configuration can reduce drag on ship model at 5 - 40%.
2. Triangle stern configuration is more effective than triangle bow, hence total resistance graphic shown in Figure 8 shows resistance in triangle stern lower than triangle bow.
3. The most effective air injection ratio at lower speeds were 0,2; 0,3; dan 0,4 while at higher

speeds all coefficients gave not so much different results. Therefore, the most effective air injection ratio for all conditions were 0,2; 0,3; dan 0,4.

6. References

- [1] Harvald S A 1983 *Resistance and propulsion of ships* (New York: Wiley)
- [2] Kodama Y, Kakugawa A and Takahashi T 2002 A full-scale experiment on micro-bubbles for skin friction reduction using Seiun-Marui, pt. 1: the preparatory study *J. Soc. Navy Architects japan* **192** pp. 1-13
- [3] Kurniawan 2008 *Influence of Micro-bubble to Drag Reduction at Ship Model* Mechanical Engineering Department Universitas Indonesia
- [4] ITTC 2002 *Testing and extrapolation methods in resistance towing tank test. Recommended procedures and guidelines*
- [5] Lattore R, Miller A and Philips R 2003 Ship hull drag reduction using bottom air injection *Ocean Eng.* **30** pp 161-176
- [6] Madavan N K, Deutsch S and Merkle C L 1983 Reduction of turbulent skin friction by micro bubbles *Phys Fluids* **27** pp 356-363
- [7] Kawabuchi, Mizokami and Kodan 2011 CFD Predictions of Bubbly Flow around an Energy-saving Ship with Mitsubishi Air Lubrication System *Mitsubishi Heavy Industries Technical Review* **48** (1)
- [8] Munson B R, Young D F and Okiishi T 2003 *Fluid Mechanics 4th Ed* Erlangga publishing
- [9] NASA 2016 Global Climate Change *Fact Sheet: Global Warming USA*
- [10] Sayyaadi H and Nematollahi M 2013 Determination of optimum injection flow rate to achieve maximum micro bubble drag reduction in ships; an experimental approach *Scientia Iranica. Transaction B, Mechanical Engineering* **20** (3) pp. 535-541
- [11] Yanuar, Gunawan, Sunaryo and Jamaluddin A 2012 Micro-bubble Drag Reduction on a High Speed Vessel *JMSA* pp. 301-304