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# A METHOD OF SKIN FRICTIONAL RESISTANT REDUCTION BY CREATING SMALL BUBBLES AT BOTTOM OF SHIPS

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**Abstract.** Most of ship energy consumption spends for its propulsive device to create a propulsive force that helps the ship to win its resistant force to move forward or backward. The ship resistant is including skin frictional resistant force, wave-making resistant force and wind resistant force. This paper mentions to a method of skin frictional resistant reduction by creating small bubbles at bottom of ships. When a ship moves on/under water surface, for skin resistant force to be generated, the ship must be in contact with the water. Skin frictional resistant force is generated by the difference in velocity between the ship and the water. Frictional resistant force will act in the direction opposite to the direction of motion of the ship. The method of skin frictional resistant reduction is injecting air flows to creating small bubbles into the turbulent boundary layer developing on the ship skin. Research found that this method may reduce ship energy consumption. This method could be applied to large ships with not high speed movement. A model ship that is scaled 1/33 of a 20000 ton cargo ship had been created for carrying out experiment in calm water and in regular wave conditions. Authors found that the highest effect from creating small bubble method on reduction ship energy consumption in calm water is 15.3% and in regular wave is 10.3%.

*Keywords:* Energy consumption, skin frictional resistant, small bubbles, turbulent boundary layer, ship model.

## 1. INTRODUCTION

Comparison with other transporters, ship is the most energy-saving transporter. For example, a very large cargo carrier (VLCC) of 280,000 DW (dead weight) can run at 15 knots driven by a diesel engine of 30,000 kW. A tanker whose own weight is 0.4 ton can transports 2.8 tons oil at 15 knots, using an engine of 0.3 kW.

Reduction ship fuel consumption is very important because it save cost for shipping. Nowadays, most of import and export goods on the world are transported by ships. The more reduction on ship fuel consumption, the more reduction on $CO_2$ discharge to the air we obtain. McCormick and Bhattacharyya [1] first discovered the drag reduction by microbubbles in 1973. They measured the drag force of a fully submerged body of revolution covered with hydrogen bubbles, which were created by electrolysis. The length of the tested body is 3 feet and it was towed up to a speed of 8.5 feet per second in a towing tank. They found that the hydrogen bubbles are very effective and the high effect is obtained at low Reynold number area. Fig. 1 shows the sketch of the setup for experiments in McCormick research.

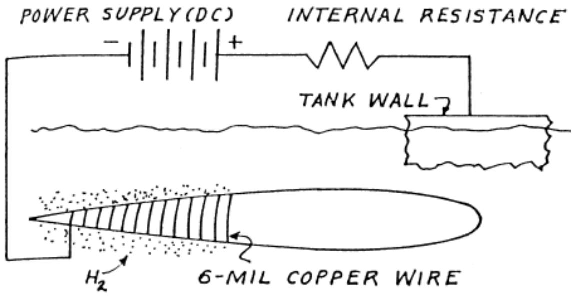


*Fig. 1.* Sketch of the setup for experiments in McCormick research

After McCormick and Bhattacharyya pioneer experiments, many other researchers had conducted air microbubble experiments, Bogdevich [2], Madavan [3], Merkle [4], Kato [5], Yoshida [6], Komada [7], Robert [8]. Not only carrying researches on theories and model experiments but also full scale ships had been tested by some Japanese authors.

This paper will mention about reduction ship energy consumption by injection small bubbles to the bottom of the ship. Experiment is carried out in a Vinashin towing tank.

## 2. THEORETICAL FOUNDATION

If the propulsive work of the ship in cases using and not using small bubble injection method are $W_b$ and $W_0$. Then, the net work ratio $r_w$ could be determined as in Eq. (1).

$$r_w = \frac{W_b}{W_0} = \frac{D_b U_\infty + W_p}{D_0 U_\infty}, \tag{1}$$

where,

$W_0$: propulsive work of the ship in no bubble condition.

$W_b$: propulsive work of the ship in bubble condition.

$D_0$: total ship resistance in no bubble condition.

$D_b$: total ship resistance in bubble condition

$U_\infty$: ship speed, assumed to be unchanged by bubble injection.

$W_p$: work of bubble injection pump.

From Eq. (1), it is realized that $r_w = 1$ when the ship does not use the small bubble injection and the resistance reduction is zero. When the ship uses the small bubble injection, the resistance reduction is effected, then $r_w < 1$.

Work of bubble injection pump, $W_p$, is expressed by taking into account the energy loss due to head pressure at injection point and the local pressure.

$$W_p = Q_a \left( \rho g d + C_p \frac{1}{2} \rho U_\infty^2 \right), \tag{2}$$

where,

$Q_a$: air flow rate for bubble injection.

$\rho$: water density.

$g$: gravity acceleration.

$d$: water depth at injection point.

$C_p$: local pressure coefficient at injection point.

Ship resistance, $D$, is expressed in conventional non-dimensional form.

$$D = \frac{1}{2}\rho U_\infty^2 S C_T = \frac{1}{2}\rho U_\infty^2 S \left(C_F + C_W\right) = \frac{1}{2}\rho U_\infty^2 S \left\{(1+K)\, C_{F_0} + C_W\right\}, \tag{3}$$

where,

$S$: wetted surface area of the ship.

$C_T$: total resistant coefficient.

$C_F$: frictional resistant coefficient.

$C_W$: wave making resistant coefficient.

$C_{F_0}$: frictional resistant coefficient of equivalent flat plate (having the same area and the length as the ship).

$K$: ship form effect coefficient.

Frictional resistance of the equivalent flat plate could be estimated as Schoenherr's empirical formula as follow

$$\log\left(R_e C_{F_0}\right) = \frac{0.242 \log 10}{\sqrt{C_{F_0}}} \tag{4}$$

where, $R_e$ is Reynolds number.

In case the ship using small bubble injection method.

$$D^* = \frac{1}{2}\rho U_\infty^2 S C_T^* = \frac{1}{2}\rho U_\infty^2 S \left(C_F^* + C_W\right) = \frac{1}{2}\rho U_\infty^2 S \left\{(1+K)\, C_{F_0}^* + C_W\right\} \tag{5}$$

It is assumed that $C_W$ and $K$ do not change between using and not using small bubble injection method. Thus, the net work ratio $r_w$ could be rewritten as

$$r_w = \frac{W_b}{W_0} = \frac{D^*}{D} + \frac{W_p}{DU_\infty} = \frac{\dfrac{C_{F_0}^*}{C_{F_0}} + r_D}{1 + r_D} + \frac{Q_a}{U_\infty S}\,\frac{\dfrac{2}{F_d^2} + C_P}{(1+K)C_{F_0}(1+r_D)} \tag{6}$$

where,

$r_D = \dfrac{C_W}{(1+k)C_{F_0}}$ is ratio of wave drag to viscous drag.

$F_d = \dfrac{U_\infty}{\sqrt{gd}}$ is Froude number based on water depth.

## 3. SIMULATION AND EXPERIMENTS

Research group has chosen a cargo ship for CFD simulation and experiments. A model ship that is scaled 1/33 from a real 20000 ton cargo ship was made for carrying out experiments in the research. It is a wooden model ship with 5.06 m in length, 0.76 m in breadth and 0.23 in draft. Real ship and model block coefficients are 0.848. Tab. 1 below shows the parameters of the real ship and model ship.

*Table 1.* Parameters of real ship and model ship

| | Real ship | Model ship |
|---|---|---|
| Length (m) L | 165.5 | 5.06 |
| Breadth (m) B | 25 | 0.76 |
| Draft (m) | 7.6 | 0.23 |
| DWT (ton) DW | 20000 | 0.57 |
| Block coefficient $\delta$ | 0.848 | |

An air flow injection system for creating small bubbles is setup at the bow and bottom of the model ship. At the position of 0.5 meter from the bow to the stern, a small container with three separate air injection tanks is located. The pressure and volume rate of air flows is adjustable by a pressure setup equipment and volume rate setup equipment. At the position of 0.8 meter from the stern to the bow, a glass window is installed at the bottom of the model ship.

For simulation, a ship with the model dimension is drew in Solid work 3D software and simulated by Fluent software. Mesh for simulation is conducted follow ICEM CFD model type. Fig. 2 shows the geometry of the model ship. Figs. 3–4 show the mesh in simulation with Prism and Tetra net types. Net density of the mesh is lower in the bow and higher in the bottom, after air injection tank position.

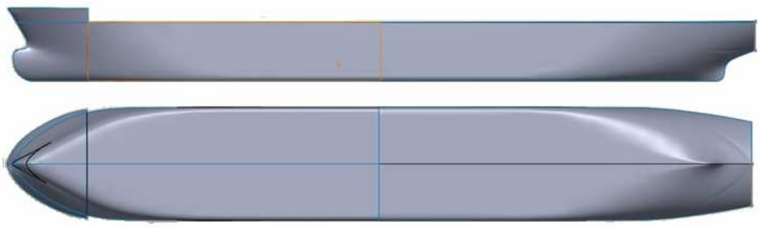

*Fig. 2.* Geometry of model ship

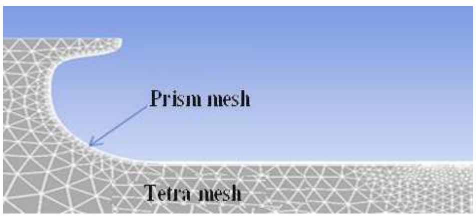


*Fig. 3.* Meshing for simulation

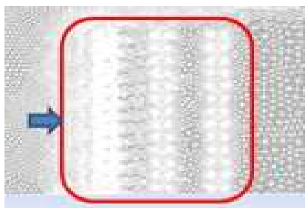

*Fig. 4.* Meshing in air bubble creating area

Fig. 5 displays the contour of air volume fraction at the bottom of the model ship in the simulation. Fig. 6 displays the contour of air volume fraction at air injection tank area.

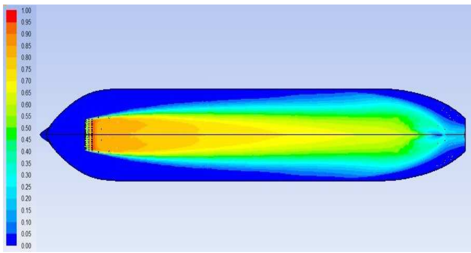

*Fig. 5.* Contour of air volume fraction

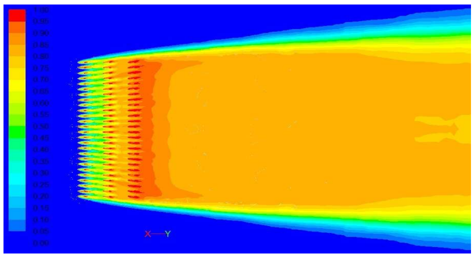

*Fig. 6.* Contour of air volume fraction at air injection tank

For experiments, when the air is injected from the air injection tanks and the model ship is towed, the created small bubbles at the bottom of the model ship could be observed through the glass window that located at the position of 0.8 meter from the stern to the bow. A sketch of experimental conduction method is shown in Fig. 7.

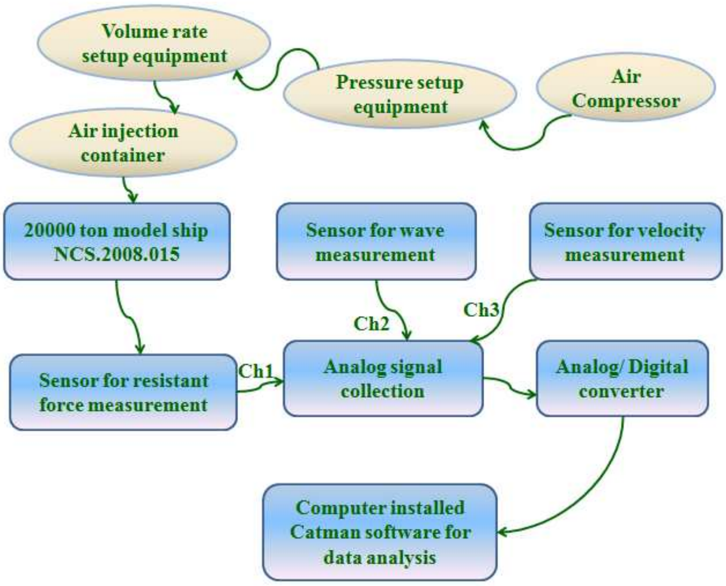


*Fig. 7.* Experimental conduction method

Figs. 8–11 show the setups for experiments. Fig. 8 shows the small bubble injection container, front and back sides. Fig. 9 shows the equipment for setting up the pressure of injected air flow. Fig. 10 shows the equipment for setting up the volume rate of injected air flow. Fig. 11 shows the model ship for experiments.

*Fig. 8.* Small bubble injection container

*Fig. 9.* Pressure setup equipment

*Fig. 10.* Volume rate setup equipment

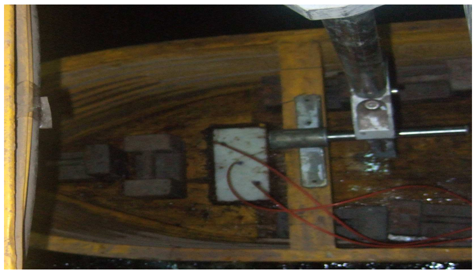

*Fig. 11.* Model ship for experiments

## 4. DISCUSSION

Experiments have been done for several times in both calm water and regular wave effect conditions, in a towing tank. For calm water experiments, the experiments had not calculated the effect of wave and wind. Experiments were done by towing the model ship on fresh water. The results of experiments in calm water are shown on Figs. 12–14 and Fig. 16.

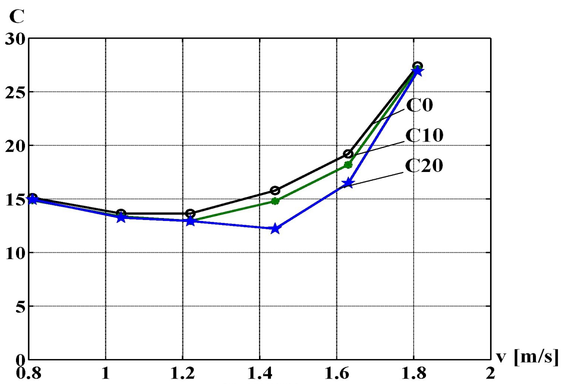


*Fig. 12.* Total resistant coefficient comparison

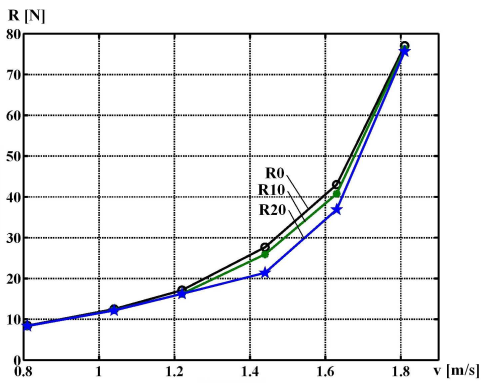


*Fig. 13.* Total resistance comparison

In Figs. 12–16, the note of 0, 10 and 20 on the curves means the simulation and experiments are conducted without using small bubble injection method and with using small bubble injection method with the volume rate of injected air flows of 10 liter per minute and 20 liter per minute, correlatively.

Figs. 12–14 show the comparison of total resistant coefficient (C) and total resistance (R) between using and not using small bubble injection method. In cases of using small bubble injection method, the experiments were carried out with 2 volume rates of injected air flow. They are volume rates of 10 liter per minute and 20 liter per minute. Fig. 14 shows the total resistant coefficient and the total resistance in simulation and in experiments. The results are obtained when using small bubble injected method and the volume rate of the air is set at 20 liter per minute. In this figure, the continuous curves are the results in simulation and the interrupted curves are the results in experiments. It shows that the result in simulation and in experiment have the same trend. However, there is a little difference in value between simulation and experiment results. This difference is not hight and acceptable. Causes of the difference may came from the experimental instrument, such as sensor tolerance, data recorder...

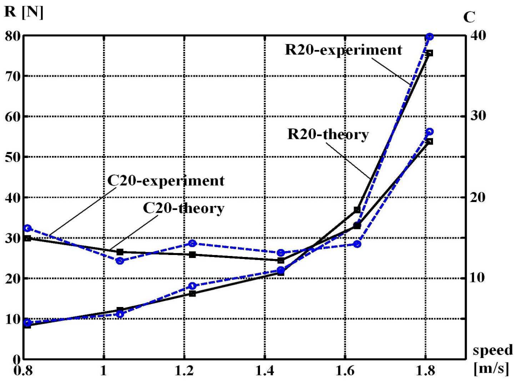


*Fig. 14.* Total resistant coefficient and total resistance, $Q = 20$ l/min

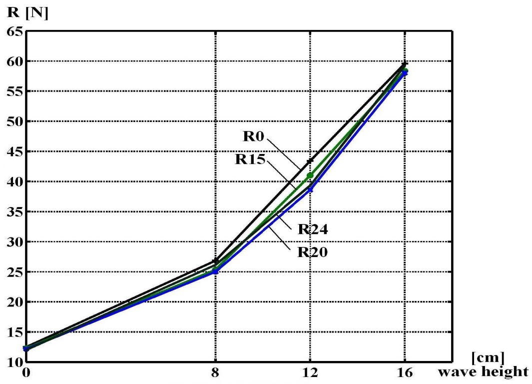


*Fig. 15.* Result of experiments in regular wave

The results of study in calm water in Figs. 12–14 show that the small bubble injection method has a good effect on a ship at an interval identified operating speed. In the 20000 ton model ship, the interval identified operating speed for obtaining good effect from the small bubble injection method is between the speed of 1.2 meter per second and the speed of 1.6 meter per second.

In calm water, the highest reduction on resistance of the model ship is obtained when the model ship is towed at the speed of 1.4 meter per second and the small bubble injection is set at the injected air volume rate of 20 liter per minute. In this case, the correlative total resistant reduction is 22.5%.

Fig. 15 displays the result of experiments in regular wave effect condition. The model ship is towed at speed of 1.0 m/s. Experiments were tested with the wave height magnitudes of 8 cm, 12 cm, 16 cm and injected air volume rates of 15 liter per minute (R15), 20 liter per minute (R20), 24 liter per minute (R24). This figure shows that the highest effect from small bubbles method on reduction ship resistance is obtained when the model ship is experimented with injected air volume rate of 20 liter per minute and wave height magnitude of 12 cm.

Figs. 16–17 show the power supply for towing the 2000 ton model ship in calm water and in regular wave experiments. In Fig. 16, the horizontal axis is model ship speed (m/s) and the vertical axis is power supply (PS, W) for towing the model ship. In Fig. 17, the horizontal axis is wave height magnitudes (cm) of regular wave experiments and the vertical axis is power supply for towing the model ship.

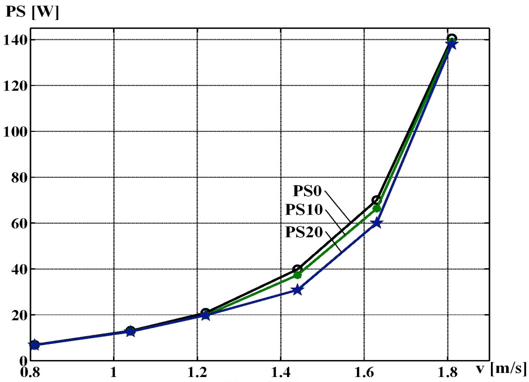


*Fig. 16.* Power supply for towing model ship in calm water

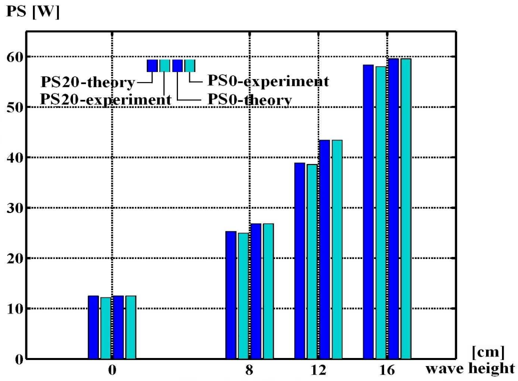


*Fig. 17.* Power supply for towing model ship in regular wave, $Q = 20$ l/min

Fig. 16 clearly shows that in the interval speed, between 1.2 m/s and 1.6 m/s, when the model ship using small bubble injection method, its power supply is reduction. The highest power supply reduction is 15.3%. This reduction is obtained when the model ship is towed at a speed of 1.4 meter per second and the injected air volume rate of 20 liter per minute.

Fig. 17 displays the power supply for towing the 2000 ton model ship in regular wave experiments. The result is compared between theoretical calculation and experimental measurement. In this figure, power values are displayed in four groups by column bars. Each group, four column bars, displays for power values of a state of wave height magnitude (0, 8, 12 and 16 cm). In each group, from left to right, bars display for power value of theoretical calculation with injected air volume rate of 20 liter per minute (PS20-theory); experimental measurement with injected air volume rate of 20 liter per minute (PS20-experiment); theoretical calculation without air injection (PS0-theory) and experimental measurement without air injection (PS0-experiment).

Fig. 17 shows that the results of power supply for towing the model ship in theoretical calculation and in experimental measurement are approximately. It also shows that the effect of small bubble method on reduction power supply for towing the model ship in regular wave is around 10.3%. This reduction is obtained when the model ship is experimented with wave height of 12 cm and injected air volume rate of 20 liter per minute.

## 5. CONCLUSIONS

Small bubble injection method has an effect on reduction ship resistance, and therefore, the ship energy consumption is reduction, correlatively.

In calm water, the small bubble injection method has a good effect on a ship at an interval identified operating speed. In this research, experiments were carried out with a 20000 ton model ship, then, the interval identified operating speed for good effect from the small bubble injection method is between speeds of 1.2 meter per second and 1.6 meter per second. The highest reduction on resistance of the model ship is obtained when the model ship is towed at the speed of 1.4 meter per second and the small bubble injection is set at the volume rate of 20 liter per minute. In this case, the total ship resistance reduction is 22.5% and the correlative ship energy consumption reduction is 15.3%.

In regular wave experiments, the highest effect of small bubble method on reduction ship resistance in regular wave is around 10.3% and the correlative reduction of ship energy consumption is 8.6%. This reduction is obtained when the model ship is calculated and experimented with wave height magnitude of 12 cm and injected air volume rate of 20 liter per minute.

Research found that the effect of small bubble injection method on reduction of ship resistance and energy consumption in calm water conditions is higher than the ones in regular wave conditions.

## REFERENCES

[1] M., McCormick, R., Bhattacharyya, Drag reduction of a submersible hull by electrolysis, *Naval Engineering Journal*, 85, (1975), pp. 11–16.

[2] V. G., Bogdevich, A. R., Evees, A. G., Malyuga, Gas-saturated Effect on Near-wall Turbulence Characteristics, *Second International Conference on Drag Reduction*, Cambridge, England, BHRA, (1977), pp. 25 – 37.

[3] N. K., Madavan, S., Deutsch, C. L., Merkle, Reduction of Turbulent Skin Friction in Mircobubbles, *Physis Fluid*, 27, (1984), pp. 356–363.

[4] C. L., Merkle, S., Deutsch, S., Pal, Microbubble Drag Reduction, *16th Symposium on Naval Hydrodynamics*, Berkeley, USA, (1986), pp. 199–215.

[5] H., Kato, K., Miura, M., Yamaguchi, Experimental Study on Mircobubble Ejection Method for Friction Drag Reduction, *Journal of Marine Science and Technology*, 3, (1998), pp. 122–129.

[6] Y., Yoshida, Y., Takahashi, H., Kato, Study on the Mechanism of Resistance Reduction by Means of Micro-bubble Sheet and on Applicability of the Method to Full-scale Ship, *22nd ONR Symposium on Ship Hydrodynamics*, (1998), pp. 1–16.

[7] Y., Komada, A., Kakugawa, T., Takahashi, Preliminary Experiments on Microbubbles for Drag Reduction Using Flat Plate Ship, *ORN Workshop on Gas Based Surface Ship Drag Reduction*, Newport, USA, (1999), pp. 1–4.

[8] L., Robert, M., Aaron, P., Richard, Micro-bubble resistance reduction on a model SES catamaran, *Ocean Engineering*, 30, (2003), pp. 2297–2309.

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