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DRAG REDUCTION BY BIOPOLYMER OF MONEPTERUS ALBUS SLIME ON SHIP MODEL WALL

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ABSTRACT

The surface viscous liquid is one of fish's resistance reduction elements. The fish surface is covered with viscous liquid, which is considered to reduce the resistance. As compared with a solvent, a certain polymer solution of several ppm to several hundred ppm offers substantially reduced turbulent frictional resistance. The relationship between the Tom's effect and reduction of viscosity resistance is described. The purpose of this research is to study the drag reduction in resistance of ship model wall by monepterus albus slime. The ship model with L = 2.3 m, B = 0.4 and T = 0.15 m pulled by electric motor which speed can be varied. The ship model resistance is measured by load cell dynamometer. The results show the drag reduction is about 8%.

Keyword: *Monepterus albus slime, drag reduction, ship model wall.*

1.0 INTRODUCTION

There is a strong demand for a reduction in fluid frictional drag, especially in the operation of marine transportation. This is because fluid frictional drag accounts for as much as 60%–70% of the total drag of a cargo ship, and about 80% of that of a tanker. It has also been reported that NO_x and SO_x emissions from ship engines in maritime transport account for 7% and 4% of total NO_x and SO_x contaminants, respectively, in the entire world, and they are posing an increasingly serious problem [1]. For many years, scientists and technologists have considered methods to minimize this effect. In 1946, B.A. Toms [2] found that diluted polymeric solution required a lower pressure gradient, in pipe flow, than the pure solvent to produce the same flow rate in turbulent flow. The possible levels of drag reduction under laboratory conditions range up to 80% [3]. Vogel and Patterson [4] concluded that the drag reduction effect can be generated on the hull by spraying a solution of condensed polymer from a location near the ship's stem. Vogel and Patterson[4] spraying a solution of poly (ethylene oxide) in various molecular weight and concentration of a slot near the ship's stem with a diameter of 5.08 cm and 41.3 cm in length. They found the drag reduction measured in the water channel. The biggest obstacle reduction occurs by spraying a solution of 500 ppm concentration Polyox WSR-301. Tests in full scale vessel with a length of 140 feet, HMS Highburton, where the trial

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was reported by Canham [5]. By adding poly (ethylene oxide) at 10 ppm, obtained a significant drag reduction that is equal to 12.7%. Most authors agree that fish mucus reduces drag. Hoyt and W. White in 1965 [6] tested the slime of a sea fish and of a hagfish and found small drag reductions of 14.5% and 12.8%, respectively. Also Ripken and Pilch in 1964 [7] reported that dogfish slime showed a drag-reduction. Rosen and Neri [8] investigated slime for some aquatic animals. They investigate influence of slime for drag reduction with rheometer. They found out that the influence of slime was decreasing in accordance with the number of testing runs. After 17 runs the friction reduction was lowered from about 69% to 51%. The purpose of this research is to study the drag reduction in resistance of ship model wall by slime solution of monepterus albus. The dimensions of ship model are: L = 2.3 m, B = 0.4 and T = 0.15 m, the ship model was pulled by an electric motor which speed can be varied. The ship model resistance was measured using load cell dynamometer.

2.0 EXPERIMENTAL SETUP

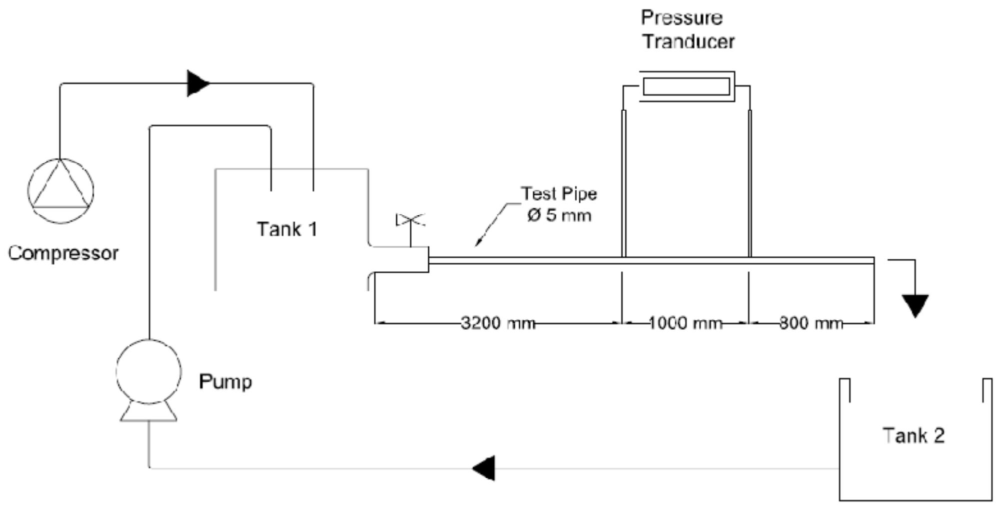

Figure 1: Experimental set-up for rheological behavior

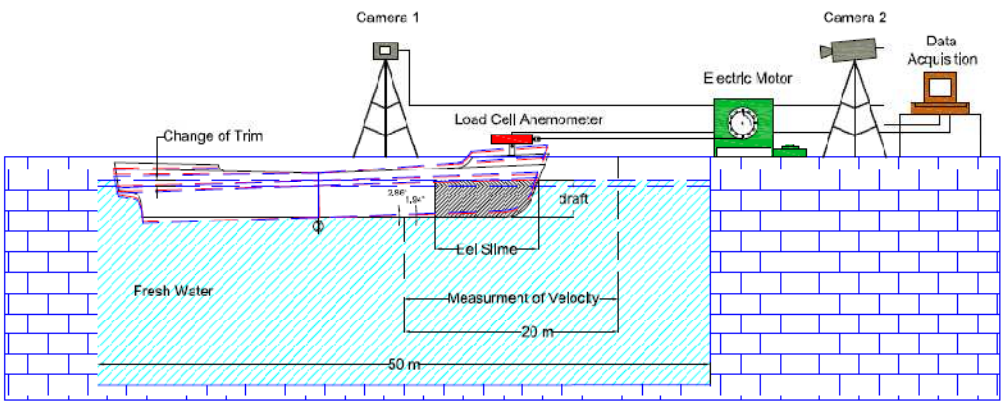

Figure 2: Experimental set-up for pull test

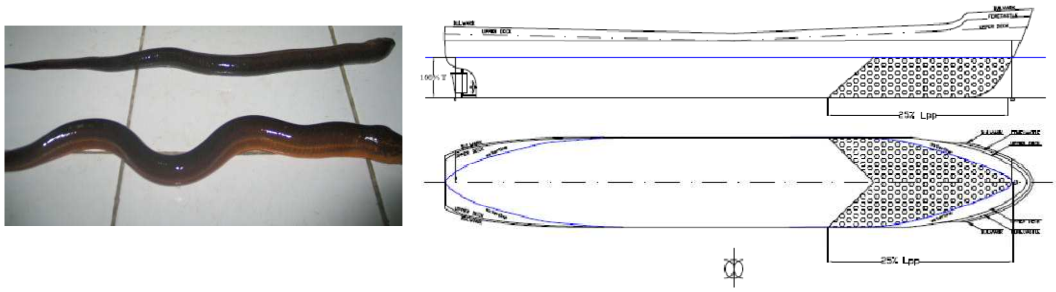

Figure 3: Eel and placing eel slime in ship model

The experimental set up is shown in Figure 1 and 2. Figure 1 shows the test of rheological properties. The polymer solution was circulated by piston pump from tank 2 to tank 1. Flowing of polymer solution was compressed by compressor to test pipe. The pressure drop gradient was measured at 1000 mm length between each pressure tap by pressure transducer. The diameter of pressure tap was 2 mm. The inner diameter of test circular pipe d was 5 mm. The shear stress and the shear rate can be obtained by measuring the pressure drop gradient and the gradient of velocity, respectively. The concentrations of polymer solution in the form of aqueous suspension were 250 ppm and 500 ppm. The temperature was kept at 25^{o}C. The polymer that was used in this research was eel slime (monepterus albus). Slime is a viscous liquid on the skin of an eel. The slime was taken not from dead eels, but from the life ones. The life eel body was gently wiped across the surface of a special smooth metal table. The slime adhering to the table was collected by a soft rubber blade and allowed to drip into a receptacle.

Figure 2 shows the experimental setup for pull test. This set-up consists of ship models, electric motor, data interface, camera and load cell dynamometer. The total drag between clean ship model and ship model with diluted eel slime were compared. The ship models were pulled with a rope. Pull test simulation was carried out in order to know the total resistance value of the ship model (R_t) at various conditions of velocity (V). During the pull test experiments, the ship model was pulled by an electric motor that has been so designed that the motor rotation can be used to pull the ship model and the pull force was measured by using a load cell dynamometer. The load cell dynamometer is affixed to the vessel and connected to the rope model pullers. Load cell anemometer was mounted on the bow tip of the ship model. Towing rope was connected to an electric motor that the speed can be set so that its velocity can be varied. Load cell gauge was connected to data interface to obtain pull force that occurred when the ship was pulled. Figure 3 shows eel and eel slime stuck on the ship model. The dilute eel slime was stuck at 25% from the bow of the ship. The arrangement was carried out by referring to the maximum of drag reduction mechanism stated by Virks, which mentioned that the effect of polymer will not proceed the limit of Virks' equation. The degradation of the eel slime effect was also investigated to take account of its content being washed off due to the pulling test.

3.0 EQUATION MODELS

The shear stress is proportional to the velocity gradient (shear rate), which can be described by power law model:

$$\tau = K\left(\frac{du}{dy}\right)^n \tag{1}$$

k and n are constant for particular fluid. The higher value of k, the more viscous the fluid. For n=1 that is for Newtonian fluid the behavior of $k=\mu$ corresponds to the Newtonian viscosity. N<1 for pseudoplastics model and n>1 for dilatant model. The Newtonian viscosity depends on the temperature and the pressure and is independent of the shear rate. The viscosity is defined as the ratio of shear stress to shear rate. Several rheological models or rheological equations of state have been proposed in order to describe the nonlinear flow curves of non-Newtonian fluids. Non-Newtonian fluids such as Bingham, pseudoplastics, and dilatants are those for which the flow curve is not linear. The viscosity of a non-Newtonian fluid is not constant at a given temperature and pressure but depends on other factors such as the rate of shear in the fluids. Thus, the relationship of shear stress and shear rate may be described by measuring the pressure drop gradient and the volumetric flow rate in circular pipe flow is given by

$$\frac{D\Delta P}{4L} = K\left(\frac{8u}{D}\right)^{n} \tag{2}$$

Where: D is the inner pipe diameter, ΔP is pressure drop, L is the length of pipe (test section), K is consistency of the fluid, n is power Law index, u is the avarage velocity.

Power Law Index (n), can be obtained from equation:

$$n = \frac{d1n(D\Delta P / 4L}{d1n(8u / D)} \tag{3}$$

The coefficient of n is the determinable from the slope of a log-log plot of DΔP/4L versus 8u/D where ΔP/L is the pressure gradient at a flow velocity, u in a pipe of diameter D.

Coefficient of friction, f, can be obtained by Darcy Equation:

$$f = \left(\frac{D}{L}\right)\left(\frac{2g}{u^2}\right)\Delta h \tag{4}$$

Where: f is the coefficient of friction, Δh is the head gradient over the considered pipe length, and g is the gravity acceleration.

Drag reduction, DR in pipe can be obtained by equation:

$$DR = \left|\frac{f - f_{s\lim e}}{f}\right| x100\% \tag{5}$$

Total resistance of ship is:

$$R_t = R_f + R_r \tag{6}$$

Where R_t is total resistance, R_f is frictional resistance and R_r is residual resistance.

Total resistance can be obtained by:

$$R_t = \frac{1}{2} C_t \rho V^2 S \tag{7}$$

Where C_t is total coefficient resistance, ρ is specific mass of water and *S* is wet area.R_t is obtained by load cell gauge

Coefficient of total resistance is:

$$C_t = C_r + (1 + k)C_f \tag{8}$$

Where C_t is the coefficient of total resistance, C_r is coefficient of residual resistance, C_f is coefficient of friction resistance and (1+k) is form factor

Reynolds number is:

$$\mathrm{Re} = \frac{VL}{\nu} \tag{9}$$

Where V is the speed of the ship, L is the length of the ship, ν is the kinematic viscosity of water.

Frouds Number is:

$$Fn = \frac{V}{\sqrt{gL}} \tag{10}$$

Where g is acceleration of gravity.

$$DR(\%) = \left| \frac{C_t - C_{to}}{C_{to}} \right| x100\% \tag{11}$$

C_{to} is total coefficient resistance without eel slime.

4.0 RESULTS AND DISCUSSION

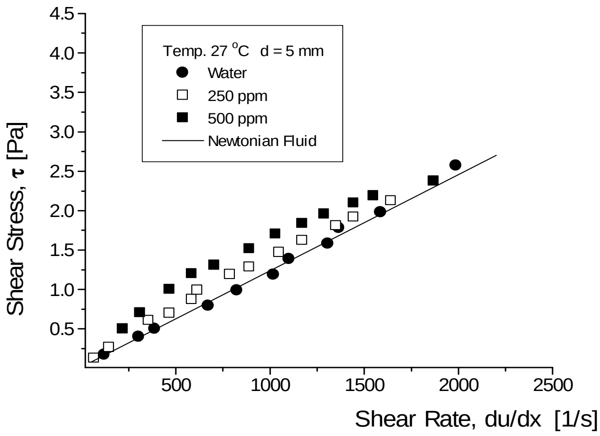

Figure 4: Rheological behaviour of slime solution

Figure 4 shows the flow curve of the slime solution measured using a horizontal circular pipe. The temperature is maintained at T = 25^o C throughout the experiments because the rheology is temperature dependent. Using standard tangent-drawing procedures, tangents are drawn to the curve at various 8V/D, to obtain corresponding value of n from the tangent slop and K from the tangent intercept at 8V/D equal to unity. The flow curve shear Stress τ is plotted against shear rate, du/dy for slime solution at 250 ppm and 500 ppm. The plot data for slime solution is not parallel, indicating that the material is a Power Law fluid over this range of shear stress. Since the value from all the particle volume of solution on the same single curve, the value of power law index for slime solution are n = 0.78-0.85

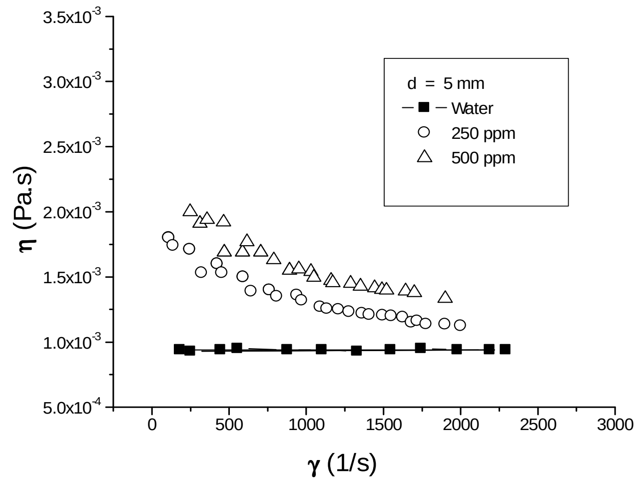

Figure 5: Apparent Viscosity of slime solution

Figure 5 shows the relationship apparent viscosity with shear rate. Measurements of the viscosity of slime solution are carried out by horizontal pipe viscometer and the data of slime solution at 250 ppm and 500 ppm. It is shown that the viscosity decreases with an increase in gradient velocity. Because the viscosity of slime solution is complicatedly depend on many parameters and the generalized Reynolds numbers, Re', is calculated using the apparent viscosity of slime solution.

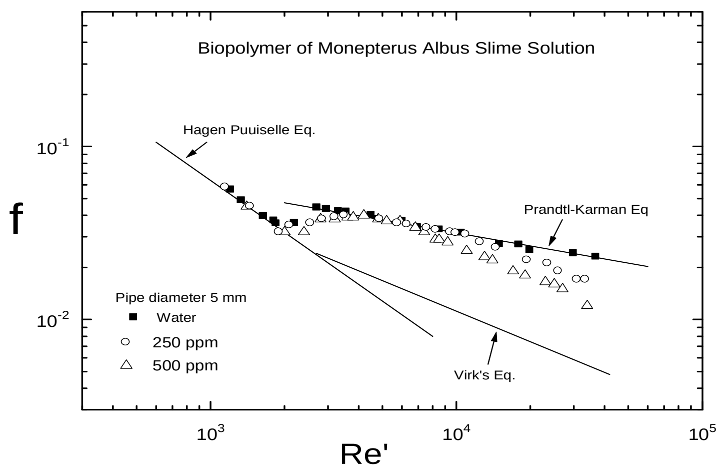

Figure 6: Coefficient of friction of slime solution for circular pipe d = 5 mm

The experimental coefficient of friction results of slime solution is shown in Figure 6. The data will be compared with Hagen Pouiselle equation in laminar flow and the Prandtal-Karman equation in turbulent flow. The coefficient of friction of slime solution fit with the coefficient of friction of water for circular pipe in laminar flow, but in turbulent flow, the coefficient of friction is lower than coefficient friction of water. It is indicating that in turbulent flow drag reduction occurs from slime solution. With equation 5, drag reduction that occurred about 30% and 17% for 500 ppm slime solution and 250 ppm at Reynolds number $2x10^4$.

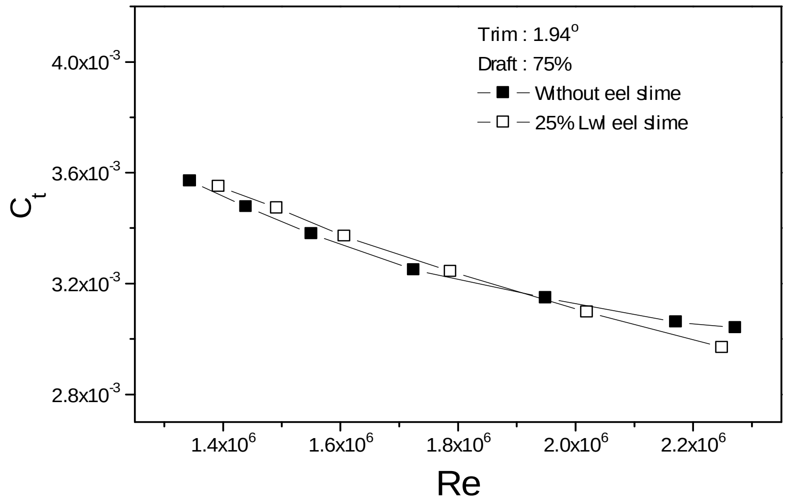

Figure 7: Relationship between coefficient of total resistance and Reynolds number at 75% draft

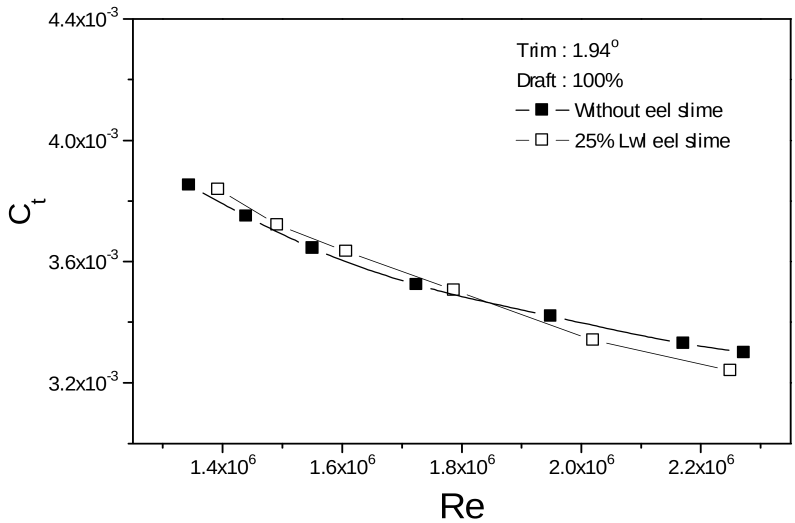

Figure 8: Relationship between coefficient of total resistance and Reynolds number at 100% draft

Figure 7 and 8 shows the relationship between coefficient of total resistance and Reynolds number by variation of draft. The pull test data were collected from ship model which was coated with slime and without slime. It appears that for the ship model with coating, the value of C_t is relatively higher at low speeds. When the Reynolds number further increased, C_t of ship model with coating of eel slime is smaller than the ship model without coating at a certain range of Reynolds number values. It can be said of the effects seen in the biopolymer solution or high Reynolds numbers where the turbulent flow drag coefficient of resistance is smaller.

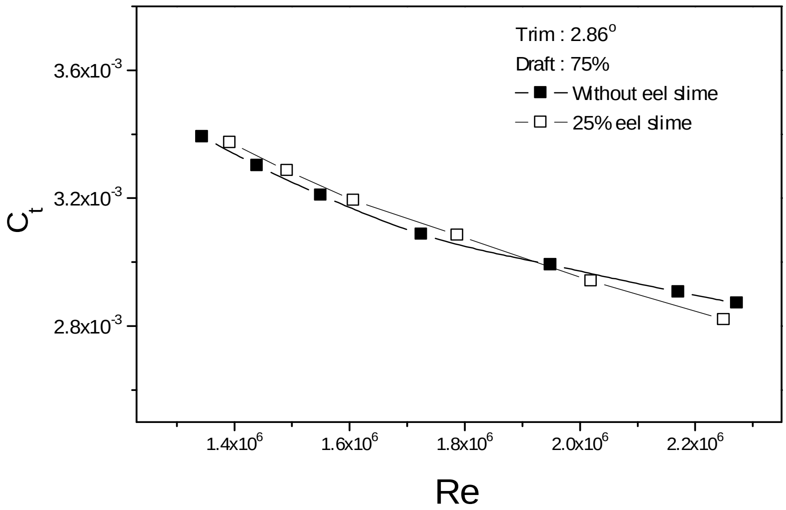

Figure 9: Relationship between coefficient of total resistance and Reynolds number at 75% draft and 2,86° trim

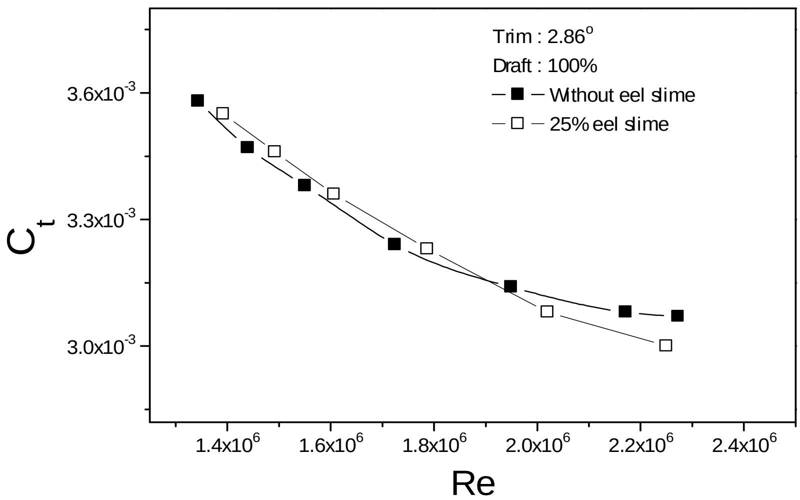

Figure 10: Relationship between coefficient of total resistance and Reynolds number at 100% draft and 2,86° trim

Figure 7 and 9 or 8 and 10 shows the relationship between coefficient of total resistance and Reynolds number by variation of trim. It shows that the value of C_t depends on the attitude of trim. It appears that for the ship model with higher trim, has a smaller value of C_t. Thus, it can be say that trim is affected by the value of resistance coefficient.

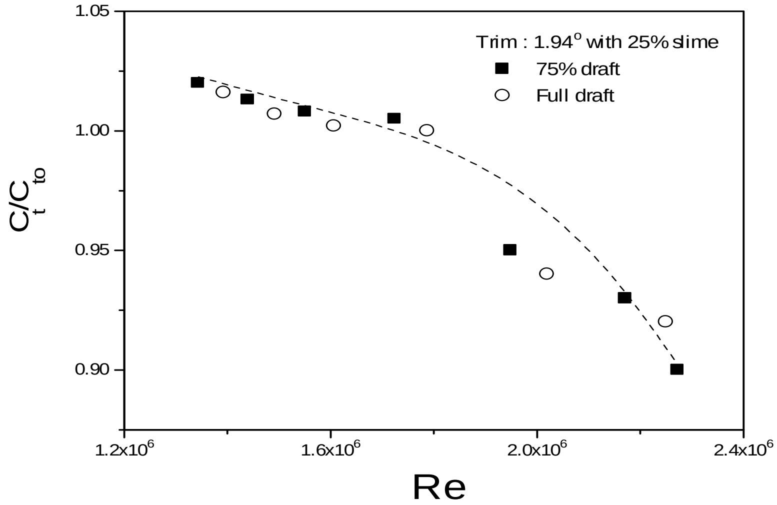

Figure 11: Relationship between total resistance ratio and Reynolds number at 75% draft and 1,94° trim

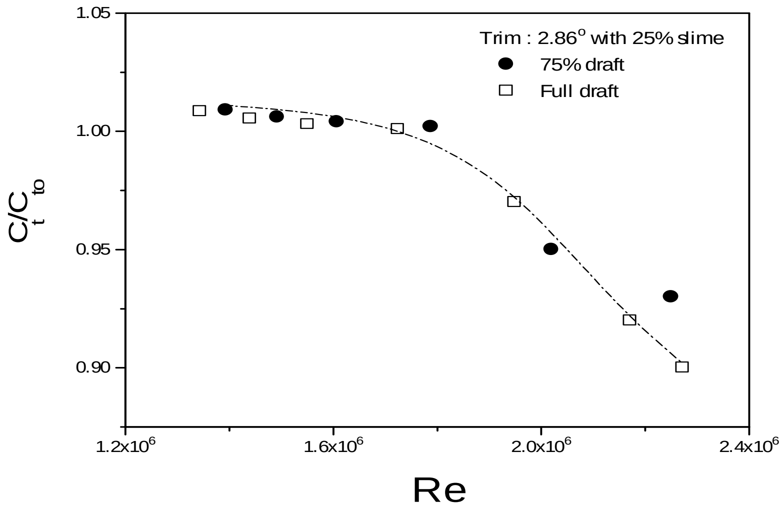

Figure 12: Relationship between total resistance ratio and Reynolds number at 75% draft and 2,86° trim

Figure 11 and 12 shows the relationship between total resistance ratio and Reynolds number. The horizontal axis is Reynolds number, and the vertical axis shows the ratio of the total resistance with or without eel slime. Increasing the Reynolds number can cause decrease to the coefficient ratio. If the value of coefficient ratio is lower than 1, we can conclude that drag reduction occurs. Base on the figures above, the drag reduction occurs only in the area with Reynolds number higher than about 1.8 x 10^6.

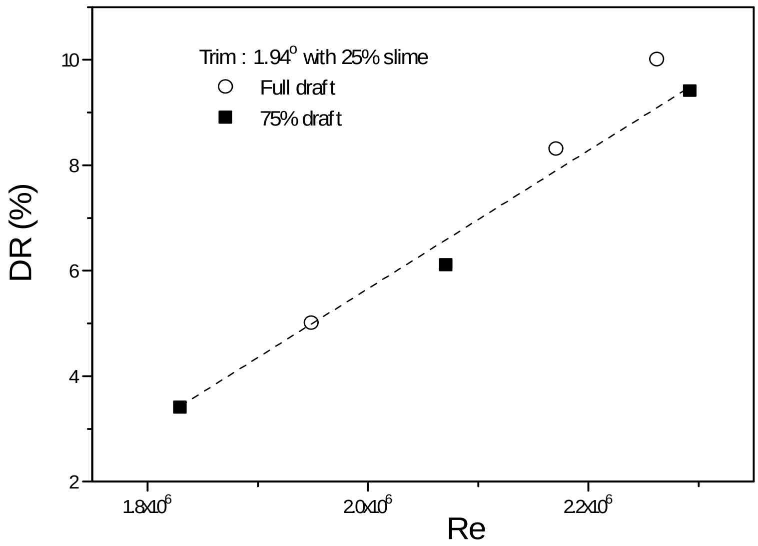

Figure 13: Relationship between drag reduction and Reynolds number at 75%, 100% draft and 1,94° trim

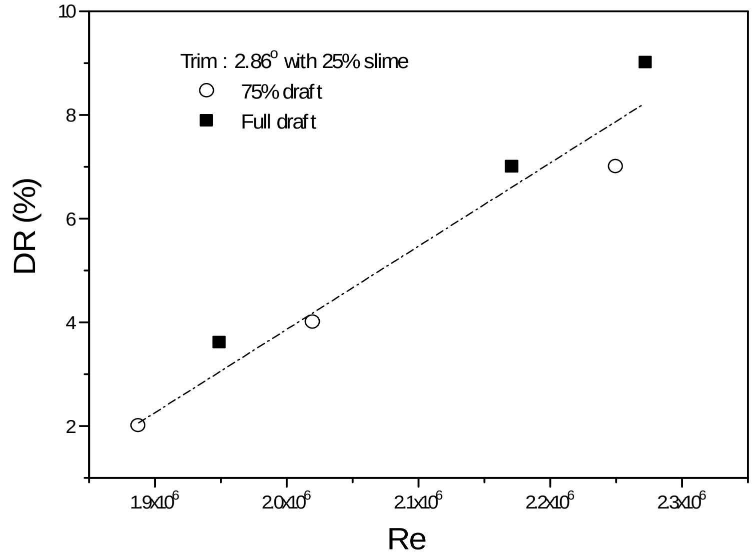

Figure 14: Relationship between drag reduction and Reynolds number at 75%, 100% draft and 2,86° trim

Figure 13 and 14 show drag reduction that occurred. It is clear that drag reduction for full draft condition is greater than 75% draft condition. The drag reduction started at Reynolds number about 1.8 x 10^6. As the amount of Reynolds number increases, drag reduction also increases. The effective drag reduction for this study is 8% at Re = 2.1 x 10^6. At this Reynolds number the velocity of ship is 14 knots.

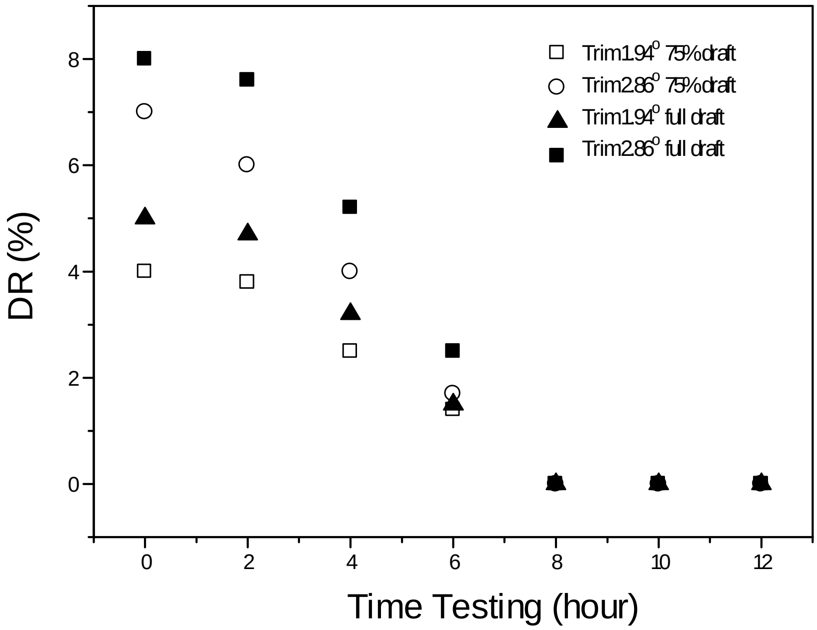

Figure 15: Degradation of eel slime biopolymer vs function of time

Figure 15 shows relationship between drag reduction and the time of test. The degradation of drag reduction occurs after about 2 hours. After 8 hours, the eel slime has no effect to drag reduction any more.

Results of the drag reduction occurred on the wall of ship model have not been applied to the full scale model or the real ship, because they cannot directly to be extrapolated, some adjustment and investigation need to be further carried out to see the eel slime drag reduction effect on the real ship. Some considerations that need to be taken are: the viscosity of the eel slime stuck on the ship model wall is different compare to the viscosity of the sea water, even though the temperature can be kept constant; the eel slime is considered as non-Newtonian fluid, which will be affected by the velocity of the model, eel slime is also a pseudo-plastic material which has a shear thinning effect. While on the other hand the effect of n (Power law index) can be neglected on the full scale ship.

5.0 CONCLUSION

Flow characteristics of slime were measured by using horizontal pipe and the shear stress and shear rate at the wall were calculated by the measurement of flow rate and the pressure drop. The results are summarized as follows: The slime solution behaves as the shear thinning fluid. The power law model describes approximately the behavior of slime solution. The range of the power law fluid index is n =0.78-0.85. For example with addition of 500 ppm of biopolymer reduced the drag in pipe by 30 percent at Reynolds number, Re’ 2 x 10^4, whereas in 250 ppm addition tested drag was reduced about 17 percent. The eel slime can also reduce the resistance of vessel. This effect was investigated using pull test on bulk carrier ship model. The effective drag reduction for this ship model is about 8% at Re = 2.1 x 1

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