DRAG REDUCTION OF A SPIRAL PIPE FLOW BY NATA DE COCO SUSPENSIONS

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ABSTRACT

The addition of drag-reducing agents to reduce spiral pipe friction loss has attracted attention as a method to conserve energy. In addition to reducing drag, these agents are required to have a low environmental load and conserve natural resources. Therefore, naturally occurring natural cellulose additives, which are considered to have a low environmental load, have recently received much attention. In spiral pipe twisted with a constant pitch in relation to the axis a swirling flow occurs when fluids flow in the pipe. The practical application the spiral pipe presents a very useful method for preventing the sedimentation phenomenon in a transport pipeline for the hydraulic transport. Here we focused on Nata de coco, a type of biopolymer that exhibits low mechanical degradation, and found that it reduced drag by up to 22% at a concentration of 100 ppm with error ± 2 %. With respect to the drag reduction (DR) mechanism, we investigated the relation between DR phenomena and the degradation of Nata de coco by measuring the pressure drop. From the pressure drop and volumetric measurement, shear stress and shear strain were calculated, and characteristic of Nata de coco flow was examined. Spiral pipe with was larger ratio of pitch and diameter (p/D) gives significant effect to reduce friction, and increase drag reduction. The effect of Nata de coco was delayed the transition regime. DR increased as the size of the network of Nata de coco increased.

INTRODUCTION

Energy efficiency issues are a major topic of interest studied mainly in fluid transport systems. Toms [1] initiated the research and have result that the addition of a small amount of additives suspension such as polymers, surfactans and fibers to a turbulent Newtonian fluid flow can result in a drag reduction, which appears in a number of flow fields, and has received considerable attention. The application of drag reduction of polymers or surfactant additives is limited to closed-loop pipeline systems, since the disposal of these solutions has an adverse effect on the environment. From the viewpoint of environmental impact, the practical application of biopolymers is convenient because drag-reducing additives biodegrade with time. Thus, if the effect of environmental loading is considered, the application to open pipeline systems can be expected in the future. Using surfactans [2,3] to obtain drag reduction in turbulent flow is very effective and low mehanical degradation. However, surfactans are contain as syntetic chemical so very dangerous in environment. Although polymers are safe in environment, they are not practical due to their significant mechanical degradation. Yanuar et al [4] also investigated the influence of biopolymer solutions for drag reduction in internal and external flow. His research show that biopolymer can reduce frictional drag up to 30% but the mechanical degradaton occured fastly.

The drag-reduction effect of the some fibers additive bacterial cellulose was verified [5].The maximum drag reduction ratio of 11% and found that it increased with the concentration of the fibre suspensions from bacterial cellulose. Cellulose is the most abundant of all the natural fiber. Cellulose is water insoluble due to its strong intermolecular hydrogen bonding, but its glucose backbone can be derivatized to obtain water solubility. Three cellulose derivatives are used in oil-field applications, carboxymethyl cellulose (CMC), hydroxyethyl cellulose (HEC) and carboxymethyl hydroxyethyl cellulose (CMHEC). The primary advantage of all cellulose derivatives is that they are residue free upon degradation.

Spiral pipe has special geometry and widely used in the engineering system. In spiral pipe twisted with a constant pitch in relation to the axis, a swirling flow occurs when fluids flow through the pipe. Spiral pipe has higher major losses than circular pipe. By adding drag reduction agent in base fluid can exchange flow characteristic in spiral pipe. Therefore, drag reduction may be occurred. Drag reduction of mud slurry in spiral pipes also have been investigated [6].

Here we focused on Nata de coco, a type of natural cellulose that exhibits low mechanical degradation, and found that it reduced drag by up to 22% at a concentration of 100 ppm. With respect to the drag reduction (DR) mechanism, we investigated the relation between DR phenomena and the degradation of Nata de coco by measuring the pressure drop. From the pressure drop and volumetric measurement, shear stress and shear strain were calculated, and characteristic of Nata de coco flow was examined. Spiral pipe with was larger ratio of pitch and diameter (p/D) gives significant effect to reduce friction, and increase drag reduction. The effect of Nata de coco was delayed the transition regime. DR increased as the size of the network of Nata de coco increased.

NOMENCLATURE

T	[Pa]	Shear stress
γ	[1/s]	Shear rate
M	[N/m^2]	Viscosity
D	[m]	Diameter pipe
L	[m]	Pipe length
U	[m/s]	Mean Velocity
P	[kg/m^3]	Mass specific
f	[-]	Friction factor
f_{fiber}	[-]	Friction factor with Nata de coco fiber cellulose addition
Cw	[ppm]	Weight concentration
$\triangle P$	[Pa]	Pressure drop

EXPERIMENTAL SETUP

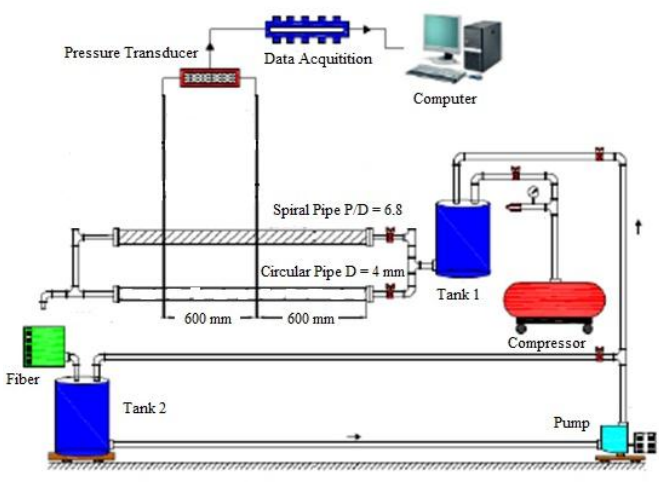

Figure 1 Experimental Setup

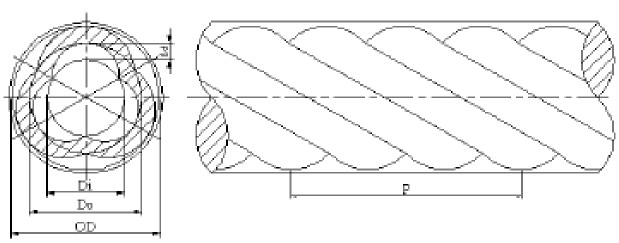

Figure 2 Shape of tested spiral pipe

The experimental set up is shown in figure 1. Figure 1 shows the test of rheological properties. The Nata de coco suspensions are circulated by piston pump. The pressure drop gradient is measured at 600 mm length between each pressure tap by pressure transducer. The diameter of pressure tap is 2 mm. The inner diameter of test circular pipe d is 4 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 fibers solution in form of aqueous suspensions are 50 ppm and 100 ppm. The temperature is kept at 27^{o}C. The ratio of pitch per diameter (p/D) of spiral pipe is 6.8.

The tested Nata de coco suspensions were made from commercial sources. First, the Nata de coco was washed with pure water and then immersed in pure water for 24 hours to remove sugar. Second, Nata de coco was pressed and then dried in a refrigerator. The mass of dried Nata de coco was 0.26% compared to that of commercial Nata de coco before it was dried. This suggested that cellulose, which is a major component of Nata de coco, was extracted from the commercial product because Nata de coco contains over 99% water and less than 1% cellulose. Finally, Nata de coco suspensions were prepared by mixing the dried Nata de coco with pure water in a blender. The blender was operated at a rate of 12,000 rpm with a mixing time, T_{blender} is 3 minutes.

RHEOLOGICAL MODEL

The shear stress, τ is proportional to the velocity gradient, γ (shear rate), can be described by Newtonian model:

$$\tau = \mu \frac{du}{dy} \tag{1}$$

Where μ is constant for the particular fluid that is viscosity. 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.

Thus, the relationship 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:

$$\frac{D\Delta P}{4L} = \mu \frac{8u}{D} \tag{2}$$

Where: D is the inner pipe diameter, ΔP is pressure drop, L is the length of pipe (test section), and u is the avarage velocity.

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

$$\Delta H = f \frac{L}{D} \frac{U^2}{2g} \tag{3}$$

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 in pipe can obtain by equation:

$$DR = \left| \frac{f - f_{fiber}}{f} \right| x100\% \tag{4}$$

f_{fiber} is friction factor with Nata de coco fiber cellulose addition. The solution concentration, Cw was determined based on the mass ratio of dried fiber or cellulose to pure water, which is defined by:

$$C_w[ppm] = \frac{M_n}{M_n + M_w} x10^6 \tag{5}$$

Where Mn and Mw denote the masses of Nata de coco and pure water, respectively.

RESULTS AND DISCUSSIONS

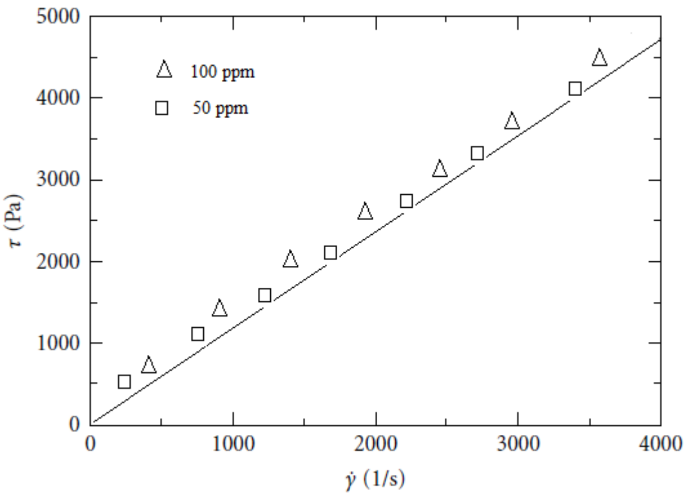

Figure 3 Flow curve for test fluids

Figure 3 shows the flow curves for the tested Nata de coco suspensions. The wall shear stress τ and shear rate γ were calculated from the experimental data in the laminar and turbulent flow region. The solid line in Figure 3 indicates the value obtained by the viscosity of water. The Nata de coco suspensions are considered to be Newtonian. The values in Figure 3 were used to calculate the Reynolds number. Figure 3 shows that the relation between shear stress and shear rate is linear. The trend is same with solid line.

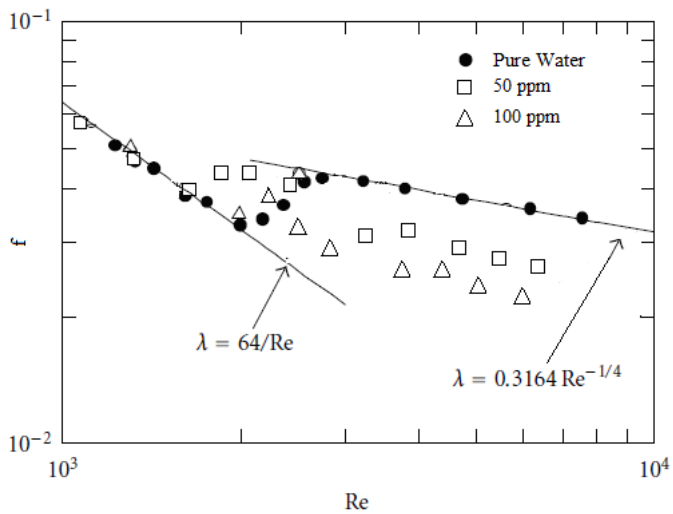

Figure 4 Friction Coefficient versus Reynolds number in circular pipe

Figure 4 shows the relationship between Reynolds number and friction factor coefficient based on the measured pressure drop for Nata de coco suspension with two different of concentration. The data will be compared with Hagen Pouiseuille equation in laminar flow and the Blasius equation in turbulent flow. The data of water also shown in this figure. The coefficient of friction of Nata de coco suspensions fit with the coefficient of friction of water for circular pipe in laminar flow. Based on this figure, there is no drag reduction in laminar regime for circular pipe.

In transition with Reynolds number about 2,000 the coefficient of friction still had higher friction coefficients than pure water for each concentration. In turbulent flow, up to Reynolds number about 7,000, the coefficient of friction had lower friction coefficients than pure water for each concentration. The DR increased with the increasing concentration of the suspensions, and the slope of this increase was not parallel to the line of the Blasius equation. The graph shows that not occurred delay on transition regime with Nata de coco suspension.

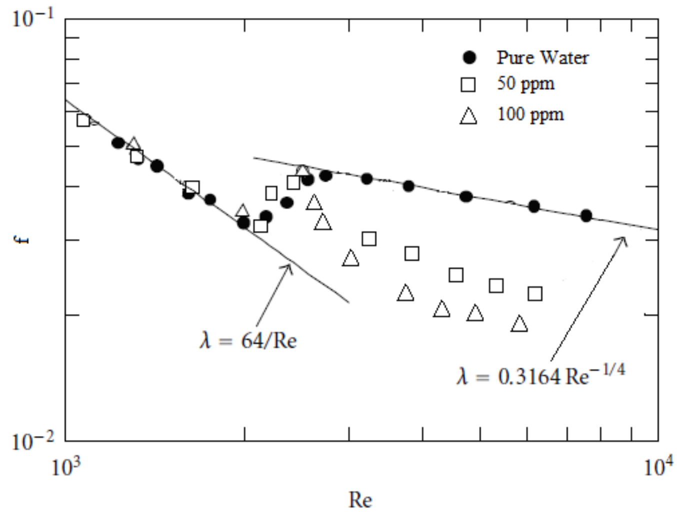

Figure 5 Friction Coefficient versus Reynolds number in spiral pipe

Figure 5 shows the relationship between Reynolds number and friction factor coefficient for Nata de coco suspension in spiral pipe. The data will be compared with Hagen Pouiseuille equation in laminar flow and the Blasius equation in turbulent flow. The coefficient of friction of fibers suspensions fit with the coefficient of friction of water in laminar flow. In transition with Reynolds number about 2,000 the coefficient of friction still had higher friction coefficients than pure water for each concentration. In transition and turbulent flow, up to Reynolds number about 7,000, the coefficient of friction had lower friction coefficients than pure water for each concentration. The DR increased with the increasing concentration of the suspensions, and the slope of this increase was not parallel to the line of the Blasius equation. The graph shows that occurred delay on transition regime with Nata de coco in spiral pipe. Drag reduction increase with increasing of Reynolds number.

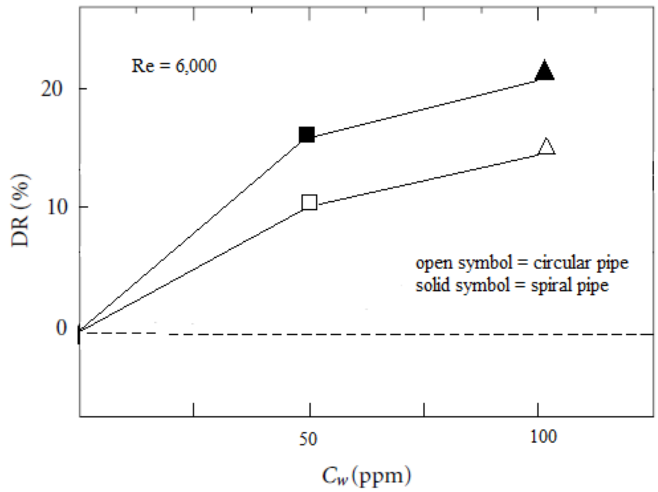

Figure 6 Maximum drag reduction

The relationship between Cw and DR for the Nata de coco suspensions is shown in figure 6. Spiral pipe is greater than circular pipe for the maximum drag reduction. The concentration also influence the amount of drag reduction. This data is collected for Re = 6,000.

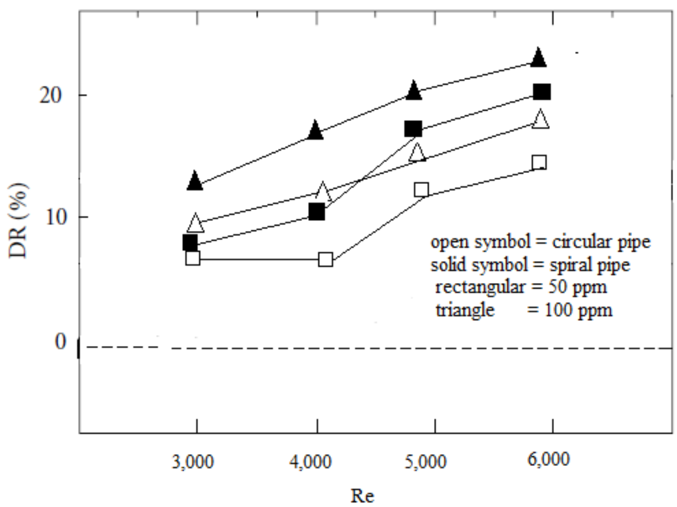

Figure 7 Drag reduction characteristic

Figure 7 shows the ratio of drag reduction for some conditions. Based on figure, it can be seen from these results that drag reduction for a given Nata de coco suspensions occurs in widely range of Reynolds number. But, in spiral pipe 50 ppm for Reynolds number less than 5,000 the drag reduction still closely lower than in circular pipe 100 ppm. This experiment is limited about low turbulent regime for about 3,000 to 7,000. The maximum drag reduction occurred at the Re about 6,000 for this limited range of test. The drag reduction tend to increases with increasing of Reynold number and concentration of Nata de coco. The reported value for Nata de coco suspensions for 100 ppm is 22% drag reduction in spiral pipe with error ± 2 %.

CONCLUSION

Pressure drop measurements for Nata de coco suspensions flowing in circular pipe and spiral pipe were performed and the following result is obtained. The drag reduction effect of Nata de coco suspensions both in circular and spiral pipe were verified. Nata de coco is considered a candidate drag-reducing agent in addition to existing polymer and surfactant solutions. Moreover, Nata de coco can be applied to full-scale experiment. Therefore, Nata de coco is highly suitable or application to actual equipment devices that must be enhanced with a long-lasting DR effect. The maximum drag reduction occurred at the Re about 6,000 for this limited range of test. The drag reduction tend to increases with increasing of Reynold number and concentration of Nata de coco. The reported value for Nata de coco suspensions for 100 ppm is 22% drag reduction in spiral pipe with error ± 2 %.

ACKNOWLEDGMENT

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