Effect of coconut fiber suspensions on drag reduction in circular pipe

W Wulandari¹, K T Waskito², S Mau¹, Yanuar² and Marcus A Talahatu²

¹Graduate Student Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI Depok, Depok, 16424, Indonesia
²Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI Depok, Depok, 16424, Indonesia

E-mail: yanuar@eng.ui.ac.id

Abstract. Pipeline system as fluid transport is very commonly used. Thus, the drag reduction becomes very interesting to be studied because it is related to energy efficiency. One method of drag reduction is the active method by adding drag reduction additive agents such as surfactants, polymers, nanofluids, and fibers. The purpose of this study is to analyze the effect of coconut fiber on drag reduction by adding coconut fiber with varied concentration. The experimental was experimented by using circular pipe ID 38 mm with 1200 mm length. The test fluid was coconut fiber suspension with concentration 300, 500, and 1000 ppm. This study was conducted from low Reynolds Number until Reynolds Number about 25,000. In this research condition, the results showed that the drag reduction on circular pipe ID 38 was about 7.6% in the Reynolds Number about 25,000. The maximum drag reduction was for coconut fiber suspension with concentration 1000 ppm. The drag reduction increases with the increase of coconut fiber suspension concentration. Based on this research, it can be concluded that coconut fiber can be used as a drag reducing agent which save natural resources and environmentally friendly.

1. Introduction

Drag reduction in pipes becomes very attractive to investigate because pipeline is very commonly used for fluid transport. By reducing drag in pipes, it can reduce energy usage and it means energy efficiency. There are two methods used in the drag reduction, namely the passive method and the active method. The passive method is by utilizing geometry in a solid object flowed by fluid, such as utilizing the geometry of the spiral pipe [1], coating the pipe with the anti-wet agent [2], injecting the micro bubble as in the marine application [3], and using the riblets such as shark skin [4]. The active method is by adding drag reduction additive agents such as surfactants, polymers, nanofluids, and fibers. The effect of using surfactant, cetyltrimethyl ammonium chloride (CTAC), in fluid can reduce the drag up to 51% that occurs at concentration 75 ppm [5]. Polymethyl methacrylate suspension on monochlorobenzene have been added to the fluid can even reduce the reduction of resistance up to 80% [6].

In addition to surfactants and polymers, nanoparticles have also been experimented. The results showed that the drag reduction by adding Nano silica- particles (nano-SiO2) reaches 24% occurred at 1 Wt% nanofluids concentration [7]. Fibers have been studied such as asbestos, the result showed that
asbestos reduced the drag up to 40% that occurred at about concentration 100 wppm on Reynolds number around 20,000 [8]. Of the three common types of drag reduction additive agents above, it can be concluded that the active method by using additives is effective in reducing the drag of fluids. However, the lack of these additives is that those additive agents can pollute the environment and are unsafe for the environment, due to those additives are chemical. Therefore, it is necessary to find some kind of additive reducing agent which is certainly effective in reducing the drag, yet safe for the environment.

The active method using natural fibers has already been done by adding a wood pulp fiber which showed a drag reduction up to 40% [9]. The bamboo fiber also used to reduce the drag up to 20% [10]. In addition, paddy husk fiber which also reduced the drag in pipes up to 32% [11]. Hence in this study, coconut fiber is chosen for the experiment to determine the effect in reducing the drag in circular pipe. Coconut fiber is a natural fiber that is widely available in nature, especially in Indonesia, thus it is very easy to get and relatively inexpensive. The important thing is the coconut fiber is environment friendly, due to its characteristics are easy to decompose. Hence, the purpose of this study is to analyze the effect of coconut fiber solutions on drag reduction with concentration of 300, 500, and 1000 ppm in circular pipe ID 38 mm with length 1200 mm. This study was conducted from low to high Reynolds number about 25,000. The results explain that there is an effect of drag reduction in the circular pipe by using coconut fiber solution with varied concentrations.

2. Methodology

Figure 1 is coconut fiber that has been processed into a very fine fiber. The process for obtaining coconut fiber for the experimental is done by several processes. The outer shell of coconut husk that is old and brown is separated from the inner coconut husk manually. The coconut husk is then cut into smaller pieces to make it easier for the next process. After that, the cut coconut husk is fed into a crusher to get a finer fiber about 1 mm length. In this experimental, the coconut fiber is mixed with tap water to get concentration 300, 500, and 1000 ppm. The temperature of coconut fiber suspension is constantly maintained at 27 °C.

![Figure 1. Coconut fiber.](image)

Figure 2 is a schematic diagram of an experimental set-up with a closed circulation system consisting of storage tank, pump, voltage regulator, horizontal pipe ID 38 mm with 1200 mm length, valve, pressure transducer, Data Acquisition (DAQ), computer, and measuring glass. The coconut fiber suspension in the storage tank is pumped by centrifugal pump to the test pipe. Two pressure transducers are mounted on the inlet and outlet of the test pipe to measure the pressure. Pressure transducer is connected to DAQ which is then recorded by the computer. The fluid through the outlet of the test pipe was measured using a measuring glass. The time required to fill the measuring glass with a certain volume can be determined by using a stopwatch. The fluid weighed using a digital scale to determine the mass of the fluid. The test is carried out from Reynolds numbers about 6,000 to Reynolds about 25,000 by using adjustable flow rate variations using a voltage regulator arranged from 100 volts to 200 volts.
3. Rheological model

Experimental data is plotted in the moody chart. The laminar region refers to Hagen-poiseuille line and the turbulent region refers to Blasius line. Drag reduction is defined by decreasing of the coefficient of friction on the flow. The friction factor is caused by shear stress that occurs between each layer of the velocity. The relationship between shear stress ($\tau$) in fluid is proportional to the velocity gradient or shear rate ($\gamma$) and can be described by Newtonian model (equation 1) as stated bellow:

$$\tau = \mu \frac{du}{dx}$$  \hspace{1cm} (1)

where the constant of proportionality $\mu$ is known as the viscosity. The Newtonian viscosity only depends on temperature and pressure. It is not affected by the shear rate. Viscosity is described as the ratio between the shear stress and the shear rate. Other than that, some fluids show a non-linear relationship between shear stress and shear rate. It shall follow Power Law model or non-Newtonian fluid. Non-Newtonian fluid is divided into Bingham, Pseudoplastics, and Dilatant. It does not depend on temperature and pressure, but affected by shear rate. The relationship between shear stress and shear rate can be described by measuring the pressure drop and the flow rate by using equation 2 stated below:

$$\frac{\Delta P}{4L} = \mu \frac{8u}{D}$$  \hspace{1cm} (2)

where $D$ is inner diameter, $\Delta P$ is pressure drop, $L$ is length of the experimental pipe, $u$ is average velocity. Whereas, coefficient of friction ($f$) can be expressed by Darcy equation (equation 3) as stated below:

$$f = \frac{2Dg\Delta h}{Lu^2}$$  \hspace{1cm} (3)

where $f$ is friction factor, $g$ is gravity, and $\Delta h$ is different height of head between two measuring point.

Drag reduction can be obtained by using equation 4 as stated below:

$$DR = \frac{f_{water} - f_{fiber}}{f_{water}} \times 100\%$$  \hspace{1cm} (4)
4. Result and discussion

4.1. Characteristic of coconut fiber suspensions

In order to know the type of fluid suspension of coconut fiber, it can be done by comparing with water. From figure 3 it can be seen that the relationship between shear stress and shear rate shows a linear relationship for the coconut fiber suspension with concentrations 300, 500, and 1000 ppm. The diagram is formed to resemble a straight line and close to the water data. The straight line is a shear stress and shear rate line for Newtonian fluid, where water data indicates conformity with the straight line. Thus it can be seen that the coconut fiber suspension is a type of Newtonian fluid.

4.2. Pressure drop

The pressure drop in the flowing fluid is influenced by several factors such as the pipe length, the medium that the fluid flows and the flow velocity. Pressure drop in the fluid flow is kept as small as possible to reduce losses in fluid flow. The value of the pressure loss is an important parameter in the fluid flow because it corresponds to the energy required in the fluid distribution. The relationship between velocity and pressure drop of coconut fiber suspension can be seen in figure 4. Figure 4 shows that at low velocities starting at about 0.13 m/s to 0.35 m/s, the pressure drop of the coconut fiber suspension remains relatively similar as the water. However, at the flow rate above 0.35 m/s to 0.6 m/s, the pressure drop of coconut fiber suspensions decrease and lower than the pure water.

Other than that, the higher the concentration value of coconut fiber suspension, the pressure drop is lower than water. This may occur because coconut fiber suspension has a lower viscosity than water, especially at higher concentrations 1000 ppm. Thus causing the shear stress to occur is also lower than the water at similar velocity. Another influencing factor is the flow velocity. The higher the flow rate, the pressure drop of coconut fiber suspension also becomes lower than the water.

4.3. Friction factor and drag reduction

From figure 5, it can be seen that the water fluid is in the turbulent Blasius equation. The relation between Reynolds number to friction coefficient of coconut fiber shows that friction coefficient of coconut fiber is smaller than water starting from Reynolds number about 15,000 to Reynolds number higher which is about 25,000 in this research. The higher the Reynolds number, the lower the friction coefficient. Low friction coefficient leads to lower energy use, thus saving energy.

4.4. Drag reduction

Based on figure 6, the drag reduction ratio of coconut fiber suspension began to occur in the Reynolds number about 15,000 to the highest Reynolds number about 25,000 in this study. Drag reduction occurs for all concentrations of coconut fiber suspension. The drag reduction ratio increases with
increasing Reynolds numbers. There are two factors that influence the drag reduction ratio, which is the Reynolds number and the concentration of coconut fiber suspension. The higher the concentration of coconut fiber suspensions get, hence the drag reduction ratio also gets higher. Then it can be concluded that the highest drag reduction ratio in circular pipe ID 38 mm occurs in coconut fiber suspension with concentration 1000 ppm. The drag reduction ratio is about 7.6% and occurs in the Reynolds number about 25,000.

4.5. Characteristics of drag reduction of coconut fiber suspensions

The drag reduction is divided into two types: type A and type B [12]. In the drag reduction type A, the additive suspension produces a friction factor segment expanding outward from the "common" point on the Prandlt-Karman line, the curve rising with increasing concentration. In addition, the drag reduction also increases with the increase of $Re.f^{1/2}$. This happens due to the characteristic of random macromolecules. While in the drag reduction type B, the additive suspension produces a segment relatively parallel to the Prandtl-Karman (P-K) line where the drag reduction does not depend on $Re.f^{1/2}$, but increases with increasing of concentration. This behavior is indicated by various types of additives including extended polyelectrolytes, fibers, soaps, and clays. This reduction of resistance occurs without a clear onset effect in which the macromolecules causing the effect are already in an extended state and need not be stretched by a strong flow.

**Figure 5.** Friction coefficient of coconut fiber suspensions.

**Figure 6.** Ratio of drag reduction of coconut fiber suspensions.

**Figure 7.** Friction factor of Prandlt-Karman coordinate $f^{1/2}$ vs $Re.f^{1/2}$. 
Figure 7 is the experimental results for coconut fiber suspension in circular pipe using the semi-logarithmic coefficient of Prandtl-Karman $f^{1/2}$ vs $Re^{f^{1/2}}$. Three straight lines characterized by L, N, and M. L are Newtonian laminar flow, N is Newtonian turbulent flow, and M is maximum possible drag reduction asymptote (MDRA) [13]. From figure 7, it can be seen that the coconut fiber suspension results on turbulent flow parallel to the N line where higher concentration is at higher curve. This indicates that coconut fiber suspension is the drag reduction type B that can be seen in fiber suspensions. In general, the drag reduction type B mechanism is associated with suppression of vortices [14]. In the fiber suspension, it is thought that the floc produced in the flow field affects fluid resistance and the fiber suppresses the vortices as they are distributed evenly toward the destination, resulting in drag reduction.

4.6. Drag reduction mechanism of fiber suspensions

The drag reduction mechanism of fiber suspensions is affected by fiber tissue and the influence of tidal flow, both for synthetic fibers and natural fibers [15].

![Drag reduction mechanism of fiber suspensions](image)

(a) No drag reduction. (b) Drag reduction occurs. (c) Maximum drag reduction.

**Figure 8.** Drag reduction mechanism of fiber suspensions.

At low velocity, plug flow occurs where the fiber suspension friction on the pipe wall and form fiber network on the wall. The friction of the fibers on the pipe wall causes an increase in the friction coefficient as shown in figure 8(a) However in figure 8(b), when the flow velocity is increased, the annulus of water fluid is formed between the fibers and walls. Shear is concentrated in the annulus. As the velocity increases, the size of the annulus also increases with a larger size than the velocity increase, causing shear on the pipe wall to decrease and resulting in a decrease in friction loss. In this phase, drag reduction starts to occur but the ratio is still very low. Furthermore, when the velocity is increased higher, the annulus will become turbulence. This annulus will attract and stir the fibers. At this stage, the mixed flow regime begins. By increasing the velocity even higher, the size of the turbulent annulus increases and the plug core decreases. In this mixed flow regime, the friction loss at the suspension becomes lower than the water at the same rate. This phenomenon is called the drag reduction. Fiber tends to spread and flows relatively parallel to the axis of the test pipe as shown in figure 8(c) and the water layer develops on the wall. This causes a decrease in friction on the wall and leads to maximum drag reduction. If the velocity increases even higher, there will be a fully turbulent flow regime reaching the overall diameter of the pipe.

5. Conclusion

From the results of analysis of coconut fiber suspension characteristics in the horizontal circular pipe ID 38 mm, it can be concluded that the coconut fiber suspensions has an effect on the drag reduction about 7.6% in the Reynolds number around 25,000. Drag reduction is influenced by fiber suspension
concentrations. The higher the concentration of coconut fiber suspensions, the greater the drag reduction ratio occurs. In this study, the concentration of fiber with the highest drag reduction is coconut fiber with concentrations 1000 ppm.

6. References

[1] Yanuar, Ridwan, Budiarso and Koestoro R A 2009 Hydraulics conveyances of mud slurry by a spiral pipe J. Mech. Sci. Technol. (South Korea: Korean Society of Mechanical Engineers) vol 23(7) pp 1835-1839

[2] Yanuar, Gunawan, Waskito, K T 2017 Effect of Agar Jelly Coating in Rectangular Pipe to Flow Drag Reduction J. Appl. Fluid Mechanics Vol 10(4) pp 1161-1166

[3] Yanuar, Gunawan, Sunaroyo and Jamaluddin A 2012 Micro-bubble drag reduction on a high speed vessel model J. Marine Sci. Appl. (China: Haerbin Gongcheng Daxue/Harbin Engineering University) vol II(3) pp 301-304

[4] Fu Y F, Yuan C Q and Bai X Q 2017 Marine drag reduction of shark skin inspired riblet surfaces Biosurface and Biotribology (Amsterdam: Elsevier) vol 3(1) pp 11-24

[5] Li F, Kawaguchi Y, Yu B, Wei J and Hishida K 2008 Experimental study of drag-reduction mechanism for a dilute surfactant solution flow Int. J. Heat and Mass Transfer (United Kingdom: Elsevier) vol 51(3) pp 835-843

[6] Toms B A 1949 Some observations on the flow of linear polymer solutions through straight tubes at large Reynolds numbers Proc. of the 1st Int. Congress on Rheology vol 2 pp 135-141

[7] Pouranfard A R, Mowla D and Esmaeilzadeh F 2014 An experimental study of drag reduction by nanofluids through horizontal pipe turbulent flow of a Newtonian liquid J. Industrial and Engineering Chemistry (South Korea: Korean Society of Industrial Engineering Chemistry) vol 20(2) pp 633-637

[8] Sharma R S, Seshadri V and Malhotra R C 1979 Drag reduction in dilute fibre suspensions: Some mechanistic aspects Chemical Engineering Science (United Kingdom: Elsevier) vol 34(5) pp 703-713

[9] Kazi M S N, Duffy G G, Chen X D 1999 Heat transfer in the drag reducing regime of wood pulp fibre suspensions Chemical Engineering Journal (Netherland: Elsevier) vol 73(3) pp 247-253

[10] Kubo T and Ogata S 2012 Flow properties of bamboo fiber suspensions in ASME 2012 Int. Mechanical Engineering Congress and Exposition, IMECE (Houston)

[11] Hayder A A B, Mohd A A and Rosli B M Y 2010 Experimental Study On The Reduction Of Pressure Drop Of Flowing Water In Horizontal Pipes Using Paddy Husk Fibers Canadian Journal of pure & applied sciences (British Columbia: SENRA Academic Publishers) vol 4(2) pp 1221-1225

[12] Virk P S 1975 Drag reduction fundamentals AIChE Journal (United States: Wiley-Blackwell) vol 21(4) pp 625-656

[13] Virk P S, Mickley H S and Smith K A 1970 Ultimate Asymptote and Mean Flow Structure In Toms' Phenomenon J. Applied Mechanics, Transactions ASME (United States: ASME) vol 37(2) pp 488-493

[14] Ogata S, Tetsuya N and Takuya K 2011 Drag reduction of bacterial cellulose suspensions Advances in Mechanical Engineering (United States: SAGE Publications) vol 2011

[15] Kazi S N, Duffy N N and Chen X D 2015 The Effect of Varying Fiber Characteristics on the Simultaneous Measurement of Heat and Momentum Transfer to Flowing Fiber Suspensions J. of Heat Transfer (United States: ASME) vol 137(1)