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Full Length Research Paper

Improving the flow in pipelines by *Cocos nucifera* fiber waste

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In this study, fiber performance as drag reducing agent in aqueous media flow in pipeline was investigated. Use of fiber from the *Cocos nucifera* (coconut) to reduce friction in pipe flow is a new invention in the fluid transport technology. The use of coconut fiber in liquid pipelines can reduce operating costs which can have a significant impact on the revenue and profit of the pipeline company. An experiment facility with three different pipe diameters (0.0127, 0.0254 and 0.0381 m, respectively) was built in order to investigate the performance of these fiber suspensions as drag reducing agent (DRA). The dependence of drag reduction on various factors including fiber concentration, pipe length, pipe diameter and solution flow rate is investigated. Rheological test were investigated and conducted using programmable rheometer. It was observed that a small amount of fiber in suspension causes drag reduction in pipeline. The percent drag reduction (%DR) is calculated using the obtained experimental data in presence of the DRA. The results showed that percentage drag reduction increases by increasing the coconut fiber concentration and increasing flow rate. Adding the coconut fiber to the water, percentage drag reduction in pipeline can reach up to 56%.

Key words: Coconut fiber, drag reduction, turbulent, concentration, friction.

INTRODUCTION

The phenomenon of the use of additives for drag reduction in turbulent flow has been the subject of intensive research since decades ago. The study attracted the attention of researchers because of the use of additives in small quantities as only part per million can reduce drag by almost 50% (Bark et al., 1975). Although this effect has been known for almost half a century, the physical mechanism that causes this drag reduction has still not been clearly identified. The term drag usually refers to the mechanical strength of the movement to change the turbulent flow of liquid in the transport system.

The drag reduction is a possible measure to reduce the friction pressure drop in pipelines. The addition of small amount of additives such as surfactants, polymers and fibers can result in important drag reduction effects in many types of flows. Figure 1 shows a typical turbulent flow in a pipeline that has three parts to the flow. In the very center of the pipe is a turbulent core. Turbulence is an irregular motion which in general makes its appearance in fluids, gases or liquids when they flow past solid surface or even when neighboring streams of the same liquid flow past over one another (Garde, 2000). It is the largest region and includes most of the fluid in the pipeline. This is the zone of the eddy currents and random motions of turbulent flow. Nearest to the pipeline wall is the laminar sub layer. In this zone, the fluid moves laterally in sheets. Between the laminar layer and the turbulent core lies the buffer zone.

Once the Reynolds number exceeds some critical value, a substantial part of the energy needed for moving a liquid in a tube is used to create turbulence. An additive that is capable of damping this turbulence would then be valuable for reducing the necessary pump work or alternatively increasing the flow rate (Martin, 2002). The addition of drag reducing agent causes the height of the liquid film to decrease; hence more liquid is needed to

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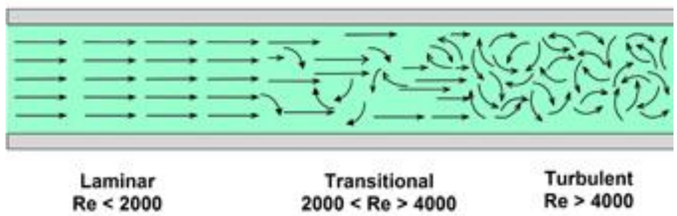

Figure 1. Typical turbulent flow.

bridge the pipe cross section which can be reached at higher liquid velocities (Mutaz, 2000). Most of the existing literature dealing with drag reduction by additives has focused on wall-bounded flows due to importance in many technological processes (Azaiez, 2000). It is very economical and practical to use drag reducing agents to reduce pressure loss along pipeline and maintain throughput without mechanical modifications.

Drag reducing agents are easy to transport, handle and inject. For this class of flows, there was a special interest in the use of surfactants to reduce pressure drops and friction effects and there is a large number of experimental and numerical studies that document the effects of surfactants on such flows. On the other hand, the use of fiber additives as drag reducing agents remains limited. One of the most attractive applications of drag reducing flow by additives is to reduce the pumping power required for circulating water in district heating and cooling systems (Li et al., 2009). Due to the economics of construction and operation costs, polymer and surfactant additives are currently the only commercially utilizable additives. Great practical success of polymer solution additives was achieved in increasing the throughput in the Alaska crude oil pipeline by up to 25% as early as 1979 (Zakin et al., 1998) and polymer drag reduction additives are now used extensively in oil pipelines of Conoco Inc., Shell Oil Co., Dow Chemical Co., etc (Manfield et al., 1999). Several papers that mainly review the practical applications of the drag reduction additive mostly in single phase liquid flows were published. A limited amount of research on polymer additive in multiphase flow, Manfield concluded that an essential understanding of the drag reduction phenomena needs more study and investigations. Al-Sarkhi (2010) have published a paper which focused on research work, methodology and the aspects of the mechanism in this area based on the current situation and future needs. In this paper the focus will be on the specific possible applications in multiphase flow.

Drag reducing surfactants are mainly intended for district heating and cooling circuits which may be wholly or partly underground. In case of leakage, it is highly desirable that the surfactants are both aerobically and anaerobically biodegradable. Rapid aerobic biodegradation is also important when part of or all of the circuit has to be emptied for maintenance purposes so that the surfactant solution can be discharged into the sewage system of the community without any harmful effects on the biological treatment in the sewage works. If the surfactants solution reaches a river or lake directly without passing a soil bed or an organized biological treatment, it is desirable that its toxicity against marine organisms be as low as possible. The requirement is less serious when biodegradability is rapid and completed (Martin, 2002). Fibers are chemically and mechanically stable in an aqueous environment. Since they are insensitive to water chemistry, piping materials, and temperature, they can be effective over a wide temperature range (Yi Wang et al., 2011). Use of this fiber to reduce the drag will not cause any problems related to environmental pollution because it does not react with any material and does not produce toxic substances when process flow of fluid in the pipe occurs. Neighboring fibers in suspension interact and entangle even at low populations and can form bundles or entities that behave differently from the individual fibers. Fibers interlock at moderate concentrations to form three-dimensional structures or networks which in liquid suspension alter the transport properties of the suspension (Md Salim et al., 1999).

Chemicals used as additives to reduce friction in the pipe may have an impact on the environment. Therefore this study was done to resolve the issue. Coconut fiber is a waste product extracted from the coconut to get coconut milk. It is a natural material which has diversified interests in manufacturing today. Research conducted showed that coconut fiber also plays a role in reducing friction in the pipes. This material is safe and easily accessible in the coconut milk industry. Capacity may be increased by installing more pumping power on the pipeline system, by installing parallel pipe sections or by increasing the diameter of the mainline pipe. The installation of new pumping facilities or additional pipe is a big investment and is a time consuming process. A coconut fiber additive in its simplest form. This typically requires a much smaller investment and can be quickly installed at almost any existing facility. Coconut fiber can reduce a drag shows lots of advantages compared with the commercial product. This new technology involving the new additive into the pipe to reduce friction and change the fluid flow is a new discovery that have not been introduced in this decade.

EXPERIMENTAL DESIGN

Materials used

Coconut fiber or coir used in this study was obtained from algro mart at Jaya Gading, Kuantan. In this study, investigating the possibility of using coconut fiber can be used as a drag reducer for engineering application. The husk from the coconut palm comprises 30% weight of fiber and 70% weight of pith material. The fiber is abundant, non-toxic in nature, biodegradable and low density. The density of the coconut fiber is between 0.67 to 10.0 g/cm^3 as

Figure 2. Coconut fiber powder.

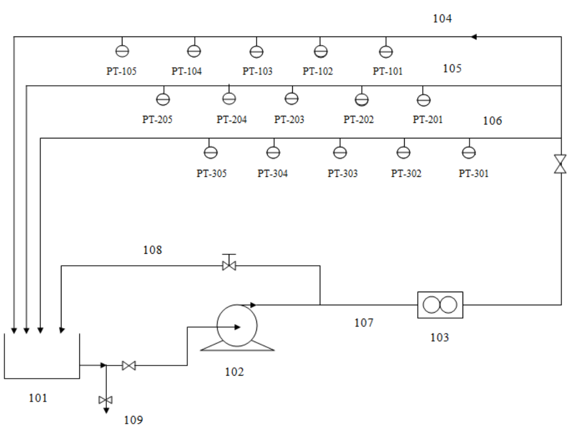

Figure 3. The experimental diagram.

described by Toledo et al. (2005). Different density values are based on the fiber size. Figure 2 shows the coconut fibers in powder form. Coconut fiber has high lignin content and thus low cellulose content, as a result of which it is resilient, strong and highly durable. The remarkable lightness of the fibers is due to the cavities arising from the dried out sieve cells. Coconut fiber is a product which is extracted from the outer shell of the coconut fruit. It is used in a variety of ways worldwide, being especially popular for rope and matting and there are a number of sources for coir and coir products (Ana Austin, 2008).

The coconut fibers were first dried in hot air oven at 60 to 80°C until constant weight to remove the moisture content. The dried coconut fibers were grind using grinder and sieved in order to obtain powder (200 μm).

Preparation of sample solution

Coconut powder sample was placed in a tank filled with water according to the concentrations specified. Fiber and water are mixed and stirred to ensure that the solution mixed thoroughly. The fibers were soaked for a minimum 24 h before the experiment is run. For each investigation the flow rate was measured in the range from 1 m^3/h until 10 m^3/h where temperature is at room temperature. To realize this method in a real industry, the method of separation by sedimentation and filtration is recommended.

Experimental rig and procedure

Drag reduction was measured in a closed flow loop. The experiment is performed in a re-circulatory flow facility which is shown in Figure 3. This system consists of reservoir tanks, pipes, valves, pumps, flow meters and pressure sensors. Reservoir tank is supported by an exit pipe connected to a centrifugal pump. The flow of liquid from the tank is directly into the test pipe before flowing back into the reservoir tank. Three PVC pipes connected to the galvanized iron pipes have an internal diameter of 0.0127, 0.0254 and 0.0381 m, respectively. The pressure drop is taken at four different points of 0.5, 1.0, 1.5 and 2.0 m long, respectively. The testing section was located about 50 times of pipe diameter to ensure the turbulent flows are fully developed before the testing point. Five sets of building were used, especially in the design of pressure sensors for industrial use to detect the pressure in the pipeline. To measure the liquid flow in pipes, Ultraflux Minisonic Portable Flow Meter has been used. This measurement of ultrasonic flow meters is very sensitive to small changes in flow rate and can detect as low as 0.001 ms^{-1}.

The operation begins when the pump starts delivering the solution through the test section. The solution flow rate is fixed at certain value by controlling it from inlet valve. Pressure readings are recorded every two seconds to this flow rate. By changing the solution flow rate to another fixed point, pressure readings are recorded again until finishing the desired values of flow rates. This procedure was repeated for transported water before and after the addition of coconut fiber additive with different concentrations to test its effect on the drag reduction operation. Pressure reading through measuring section before and after addition were needed to calculate the percentage drag reduction DR% and fanning friction factor (f) is defined as (Virk, 1975).

$$DR(\%) = \frac{\Delta P_b - \Delta P_a}{\Delta P_b} x100 = 1 - \frac{\Delta P_a}{\Delta P_b} \quad (1)$$

Where ΔP_b is the pressure drop with no additives and ΔP_a is the pressure drop with additives present. Drag reduction ratio is defined as the ratio of the pressure drop of the fiber suspension to the pressure drop for water alone at the same flow rate and applies to the transition flow regime between plug and fully developed turbulent flow (Md Salim et al., 1999). The friction factor of liquids flowing in a circular tube given is by the equation below

$$f = \frac{\frac{\Delta P.D}{4L}}{\frac{\rho . V^2}{2}} \quad (2)$$

Where f is the friction factor, D is the pipe diameter, ρ is the fluid density, L is the pipe length, V is the fluid velocity and ΔP is the hydraulic gradient. The relationship between friction factor and Reynolds number (Re) for fluids in turbulent flow can be approximated by the Blasius equation.

$$f = \frac{0.079}{\mathrm{Re}^{0.25}} \quad (3)$$

Rheological test

The determination of the rheological parameters is important in

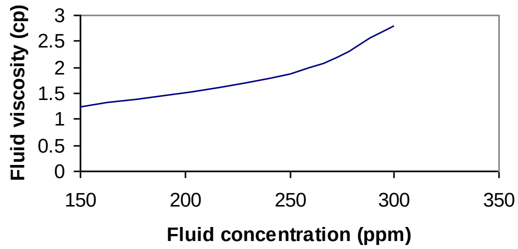

Figure 4a. Fluid Viscosity vs. fluid concentration for coconut fiber solution.

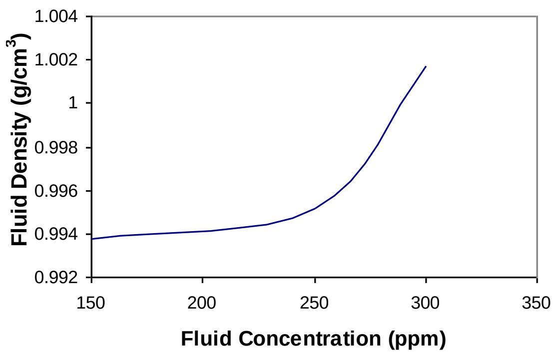

Figure 4b. Fluid density vs. fluid concentration for coconut fiber solution.

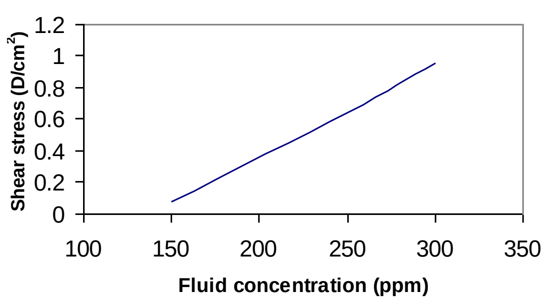

Figure 4c. Shear stress vs. fluid concentration for coconut fiber solution.

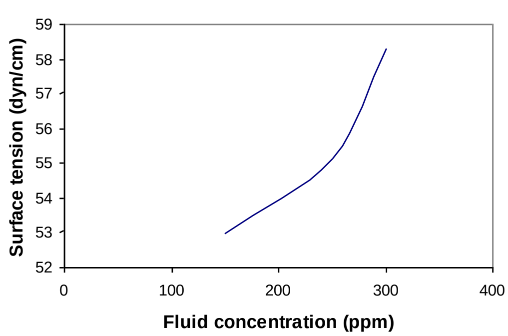

Figure 4d. Surface tension vs. fluid concentration for coconut fiber solution.

order to predict the drag reduction behaviour of coconut fiber during its transportation in pipelines. Rheological measurements were made with rotational rheometers. Parameters involved in the rheological tests are surface tension, shear stress, density and viscosity. Surfactants are also known as tensides, which are wetting agents and can lower the surface tension of a liquid, allowing easier spreading leading to lowering of the interfacial tension between solid particles and the liquid. Surfactants possess the property of reducing the surface tension of water by absorbing at the solid-liquid interface (Naik et al., 2009). Surface tension of the three samples in this investigation was measured by surface tensiometer.

RESULTS AND DISCUSSION

Rheological test results are shown in the Figures 4a to d. All experiments were performed at room temperature.

Addition of coconut fiber into water shows the solution is higher in density, viscosity, shear stress and surface tension by increasing of fluid concentration. Highest density for solution is at 350 ppm which is 1.0017 g/cm^3 as shown in Figure 4b. Highest dynamic viscosity is 2.81 centipoises (cP) at 350 ppm and highest surface tension is 58.297 dyne/cm at same concentration. All evaluation shows slight fluctuation but overall it shows increment pattern. From the results it is confirmed that the fiber used for this study has increased the surface tension to about 9.2% which will lead to smooth flow of coconut fiber powder in the pipeline. From these figures it is observed that the shear stress decreases sharply from 0.96 to 0.08 D/cm^2 when fluid concentration was decreased.

Figure 5a to d show the effect of the Reynolds number on the percentage drag reduction (%DR) for 0.0127 m pipe diameter. The testing section involved is an indication of the ability of coconut fiber in drag reduction. In the present work, four testing section lengths (0.5, 1.0, 1.5 and 2.0 m) were used to examine the drag reduction performance.

From Figure 5a to d, it can be noticed that the %DR increases by increasing the testing section length. Figure 5 shows that the maximum %DR of almost 55.58% was achieved within the 2.0 m testing.

Furthermore, it has been observed that the DR strongly depends upon the flow rate as well as concentration of fiber. Many parameters influence drag reduction. In this case of fiber, the main parameters are concentration, pipe length and fluid flow rate. Normally, Drag reduction increases rapidly with concentration to a saturation value, and then slowly decreases with further increases in concentration.

Graph found that the drag reduction initially increases with increasing additives concentration. However, beyond a certain threshold concentration in experiments no additional drag reduction is observed. The DR characteristics of the three tested pipe diameter at different concentration and different flow rates are therefore investigated. The increase in concentration also means an increase in the value of the critical mean

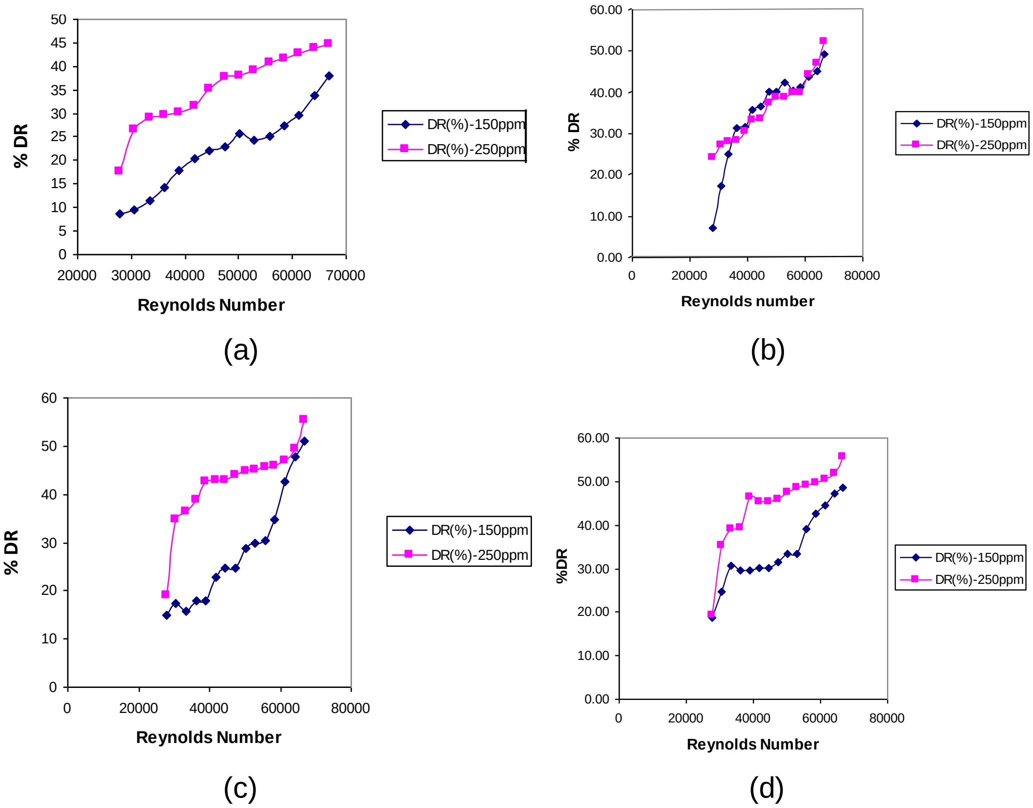

Figure 5. Percentage drag reduction for diameter pipe 0.0127 m with different concentration in (a) 0.5 (b) 1.0 (c) 1.5 and (d) 2.0 m pipe length.

velocity at which the drag reduction region extends with concentration. The addition of coconut fiber to the flow is to examine its effect on improving the flow (increasing DR%). It is clear that addition of the coconut fiber improves the DR% of the following suspensions. DR% was shown to increase by increasing the additive concentration reaching maximum values at 55.58% with concentration up to 250 parts per million of fiber in water. The optimum flow rate in coconut fiber solution is 2.4 m^3/h at 2.0m pipe length.

Figure 6a to 6d show the effect of the Reynolds number on the percentage drag reduction (%DR) for 0.0254 m pipe diameter.

Based on Figure 6a to d, the graph represents three zones. The first zone represents the small values of the Reynolds number as the DR ratio evolves slowly. In the second zone, the DR ratio decreases and then increases again in a third zone. The experiment was repeated thrice to obtain accurate and precise results and results are represented by lines of pink and black. The graph shows the drag reduction increases as the flow rate is increased.

High percentage of drag reduction up to 52.34% was established using coconut fiber for 2.0 m length with Reynolds number of 90509. These results give a great indication on how effective this coconut fiber is on improving the flow in pipelines and saving the pumping power up to 60 to 70%. This saving in the pumping power means reducing the number of supporting pumping stations along the pipeline to between 60 and 70% which will reduce the cost of constructing and maintaining these pumping stations and that will lead to great economical benefit.

Figure 7a to d show the value of drag reduction for the pipe diameter 0.0381 m. The size of solid particles plays an important role in reducing drag reduction. This maybe due to the large momentum needed to transport larger particles that make these particles not easily controlled by the turbulence but it play an opposite effect by decreasing the degree of turbulence and then the power of dissipation made by the turbulence. It is harder to have an eddy that will make larger particles part of its shape during turbulent flow which will make those particles to behave as turbulence streaks breaking agent and that will lead to the fact that these particle will break up the larger eddies to smaller ones which will eventually result in increasing the DR% (Hayder and Rosli, 2009). The entire Figure 7 shows a significant increase in drag reduction of the concentration of 250 ppm compared to the concentration of 150 ppm as shown in Figures 5, 6 and 7.

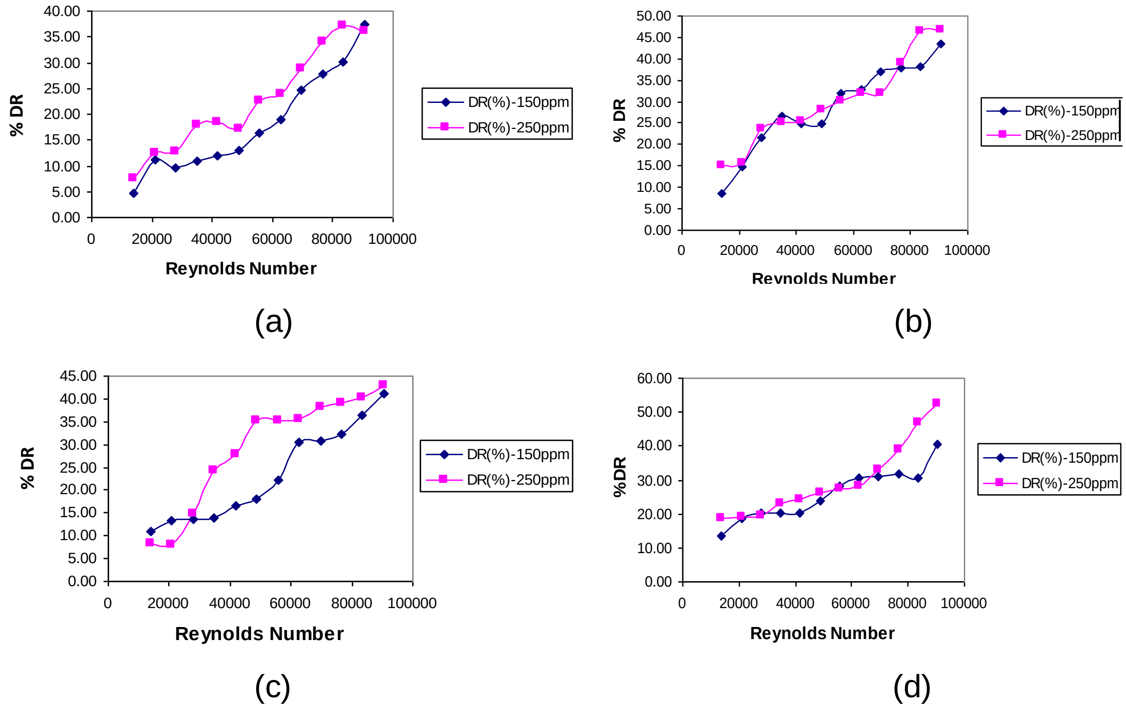

Figure 6. Percentage drag reduction for diameter pipe 0.0254 m with different concentration in (a) 0.5 m (b) 1.0 m (c) 1.5 m and (d) 2.0 m pipe length.

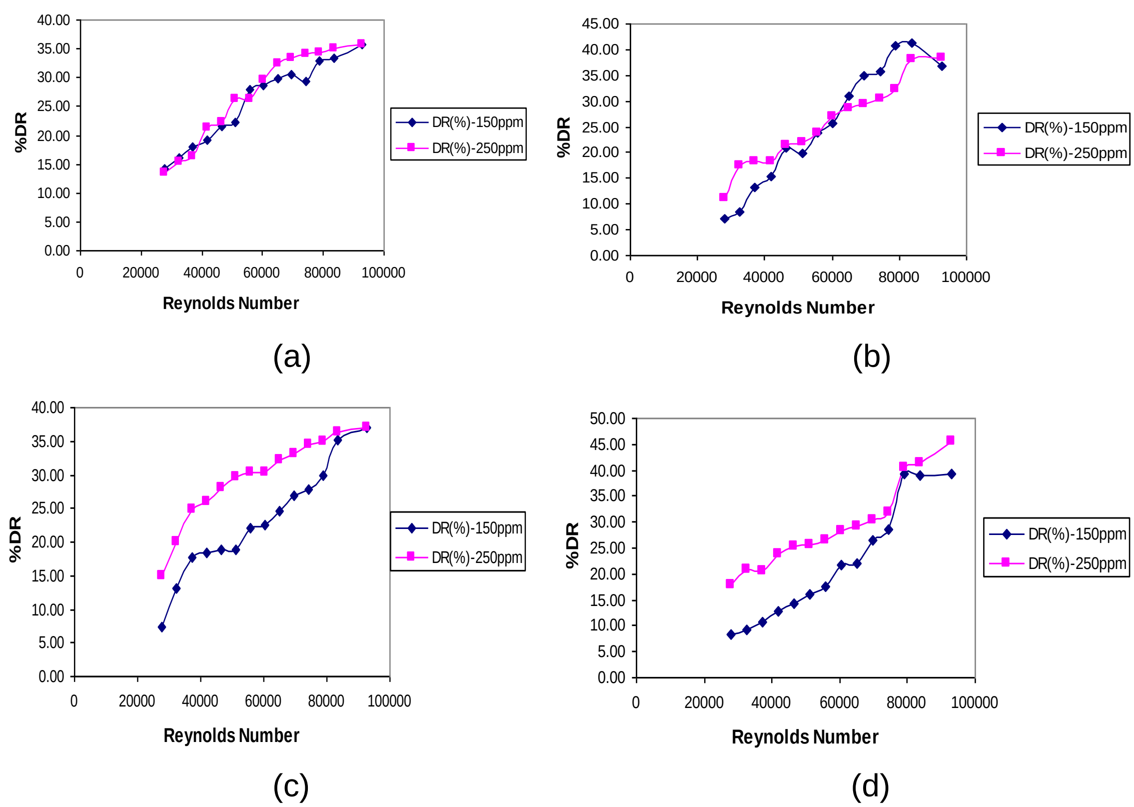

Figure 7. Percentage drag reduction for diameter pipe 0.0381 m with different concentration in (a) 0.5 (b) 1.0 (c) 1.5 and (d) 2.0 m pipe length.

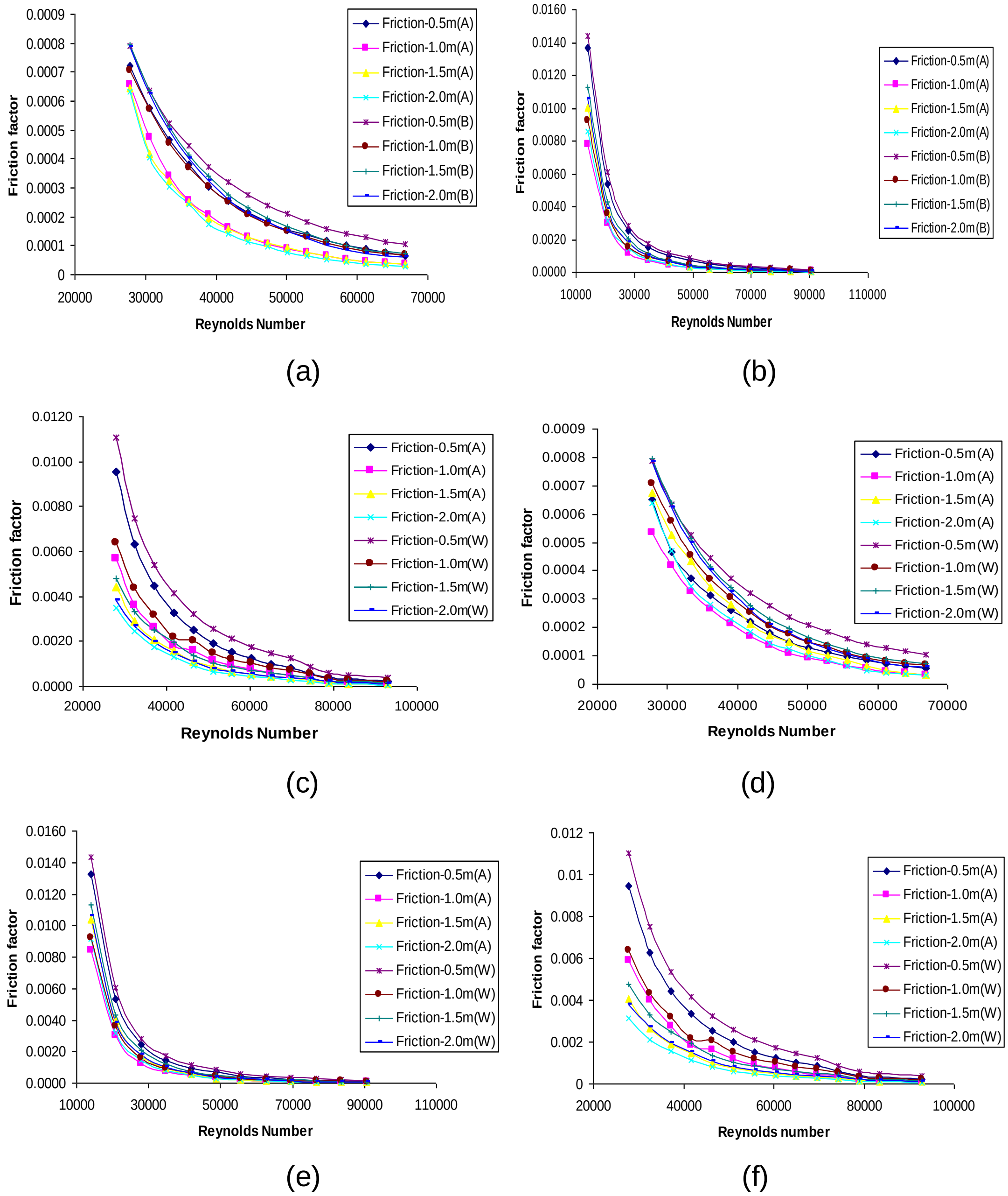

Figure 8. Friction factor of water without additives (W) and water with additives (A) in a 150 ppm concentration for diameter pipe (a) 0.0127 (b) 0.0254 and (c) 0.0381, respectively with different pipe length; and in a 250 ppm concentration for diameter pipe (d) 0.0127 m (e) 0.0254 and (f) 0.0381 m, respectively with different pipe length.

The relationship between the friction factor, f and Reynolds number Re at different concentration are depicted in Figure 8a to f respectively. The curves show a threshold point. From this point are observed a clear reduction in the friction factor and this corresponds to a shear threshold point which is called 'Onset'.

Figure shows the friction factor over the range 20000 < Re < 100000. Based on Figure 8, the friction factor decreased with the increase of Re and then reached a local minimum value. Increasing Re means increasing the degree of turbulence inside the pipe which will provide the suitable media for the suspended solid to work properly. The minimum friction factors at concentrations of 250 ppm were observed at Reynolds number 92836. The increase of DR before reaching the maximum value is thought to correspond to the process of forming called Shear Induced Structures (SIS). At a certain Re at which the DR reaches its maximum value, the SIS may be in the most effective state for reducing drag. Above that, the threadlike network begins to break up under the high shear stress and the drag reducing ability decreases (Lu et al., 1998). The maximum DR for these three cases occurs at Reynolds number of around 66×10^3 as plotted in Figure 5.

Conclusion

C. nucifera (coconut) fiber was found as a good drag reducing agents. It shows greater effectiveness in drag reduction. Effect of drag reduction depends on the fiber concentration, pipe length and pipe diameter. The friction factors can reach very low values. The coconut fiber is an excellent drag reducer with the ability to decrease friction losses by more than 50%.

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