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CHARACTERISTICS OF SILICA SLURRY FLOW IN A SPIRAL PIPE

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ABSTRACT

Silica sand slurry is a multiphase flow that consists of liquid and particle solids. Slurry flow characteristics are affected by particle size, particle distribution, particle concentrate, pipe geometry, flow regime, and viscosity factors. Spiral pipe is one of the solutions to increase drag reduction at a certain velocity and Reynolds number (Re). The aim of this experiment is to figure out the influence of using spiral pipe in increasing drag reduction of silica sand slurry flow. The pipeline used is spiral pipe with a helicial tape with two ratios of pitch per diameter (p/D), i.e. = 4 and 7. The test loop is set up as 3,500 mm (3.5 meters) in length. The size of the particle is 1 mm in diameter. The mean density of the silica sand particles is 2,300 kg/m^3. The velocities are set between 1m/second and 5m/second. The percentage of volumetric concentration of solids in slurry (Cw) varies between 20%, 30%, and 50% in weight. Particle concentration, the Reynolds number and ratio of pitch and diameter give significant impact to the drag reduction. At a ratio of pitch/diameter (p/Di) = 7, at a Reynolds number (Re) of 30,000 and at Cw 50% can increase drag reduction to about 33%.

Keywords: Drag reduction; Particle concentration; Pitch ratio; Silica slurry flow; Spiral pipe

1. INTRODUCTION

Studies of drag reduction from the viewpoint of energy conservation have been conducted in practical fluid engineering. Passive control is a simple method that enables us to obtain a large drag reduction ratio compared with active control. In general, the target for obtaining drag reduction in passive control is the turbulence modification of flow in turbulent flow range. Thus it is necessary to change the fluid properties or the physical characteristics of the surface to reduce the turbulence. Many studies about drag reduction for turbulent flow have been performed for drag-reducing polymers or surfactant additives and for ribblet surfaces (Dean & Bhushan, 2010).

Recently, research on drag reduction has attracted considerable attention concerning the problem with energy conservation, which is closely related to the prevention of global warming. As is well known, the methods for obtaining drag reduction are divided into two categories: passive control and active control. The practical application of drag reduction solutions has been limited, because it has an adverse effect on the environment or it causes mechanical degradation. In terms of mechanical degradation solutions, the use of surfactant additives is effective for closed-loop pipeline systems. The additives are increasingly used in city thermal energy supply pipeline systems or air-conditioning pipelines in large-scale buildings for energy conservation related to pumping power at present. Piping systems not only consist of circular

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pipe, but also special geometries like spiral pipe. In twisted spiral pipe with a constant pitch in relation to the axis, a swirling flow occurs when fluids flow through the pipe. According to Yanuar et al. (2012), spiral pipe has a higher level of major and minor losses than circular pipe. By adding drag reduction agents, like bamboo fiber in the base fluid, the flow characteristics in spiral pipe can be changed. Therefore, drag reduction may occur accordingly.

Basically, transportation of slurry material using a pipeline system will produce sedimentation, especially in low velocity flows. Figure 1 shows slurry flow in a circular pipe. Circle 1 is the condition where the sedimentation occurs at a low velocity. In this condition, the pressure drop is quite low, but there is loss in transporting materials. In Circle 3, the solid particle and liquid mix is almost homogeneous, yet pressure drop is still quite high. In Circle 4, solid particles and liquids mix homogeneously. This condition gives advantages of transporting material; however, it produces a high pressure drop, and it indicates high energy consumption.

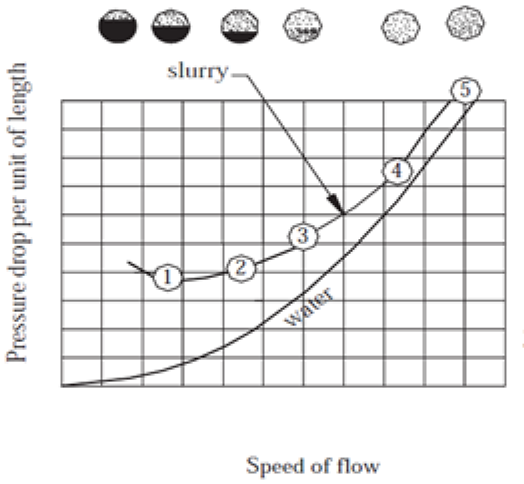

Figure 1 Relation of flow velocity and pressure drop in circular pipe (Abulnaga, 2002)

Attempts have been conducted to reduce pressure drop in pipeline systems. A spiral pipe with a certain ratio of pitch per diameter (p/Di) can increase drag reduction significantly (Yanuar et al., 2009; Watanabe et al., 1988). Slurry flow is affected by velocity, particle size and particle concentration (Pinto et al., 2014; Kaushal et al., 2005). Higher velocity produces higher pressure drops. The higher the concentration is, the higher the pressure drop will be. For larger particle sizes, a larger friction coefficient occurs in horizontal pipe, when compared to vertical pipe (Ravelet et al., 2013). Previous experiments explained that the main problem of flowing slurry is how to overcome the sedimentation in the bottom of the pipe at lower energy consumption. The objective of this research is to figure out the influence of using spiral pipe in increasing drag reduction of the slurry flow.

2. EXPERIMENTAL SETTINGS

The conduit used is a spiral pipe with a helical tape placed at two ratios of pitch per diameter, i.e. 4 and 7. The tube was made from acrylic. Figure 2 is the sketch of the experimental apparatus that consists of a centrifugal pump, the spiral pipe installation, valves, a compressor, a tank, and measurement instruments to get the data. Table 1 shows the spiral pipe data used in this experiment. Figure 3 shows a sketch of a spiral pipe, where p is pitch, Do is the outer diameter, Di is the inner diameter, and Δd is half the difference of the outer and inner diameter.

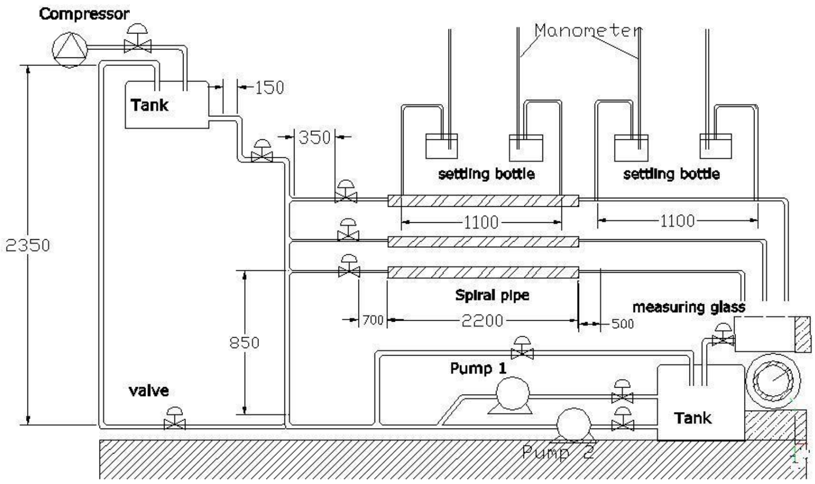

Figure 2 Schematic of experimental apparatus

Table 1 Dimension of spiral pipe

Pipe	Di	Do	Δd	P (pitch)	p/Di
Circular pipe	25.4	25.4	0	-	-
Spiral pipe 1	35.0	45.0	5	245	7
Spiral pipe 2	35.0	45.0	5	140	4

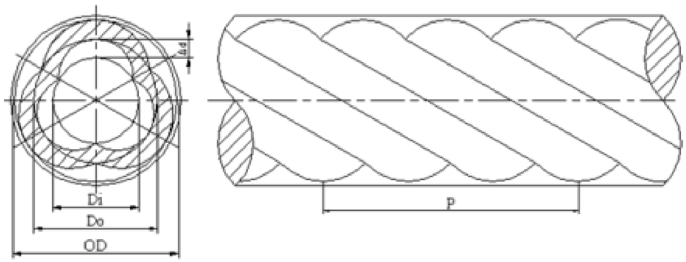

Figure 3 Sketch of a spiral pipe

Silica sand with different concentration ratios is the experiment fluid. Fluid flows to the tank by pump and then to the pipe test loop. To avoid flow fluctuation, a compressor is used. The distance between the pipe inlet and the first transducer is set at more than 135 times the hydraulic diameter. This condition is intended to have fully developed flow. Two manometers are mounted on a test pipe connected to the pressure transducer to determine the value of the pressure drop. A transducer is connected to the Data Acquisition (DAQ) logger and installed with a computer in order to have data recording. The flow rate was varied by adjusting the valve. To get the flow capacity, a measuring glass is placed at the outer discharge. To understand the relative velocity distribution, a pitot tube is used. The relationship between shear stress and shear rate is obtained to make the flow curve. The particle size used is varied from 1 mm in diameter. The Cw concentration percentage is varied 20 %, 30%, and 50%, and the ratio of pitch/diameter is equal to 4 and 7.

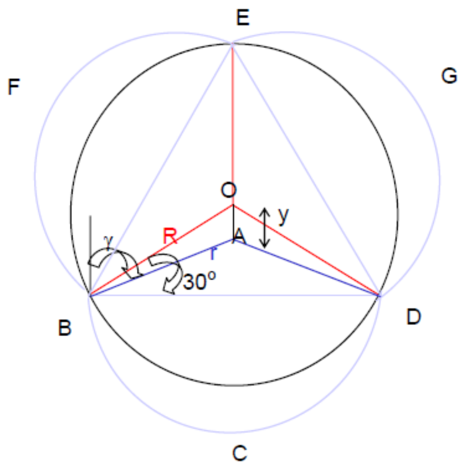

Figure 4 Initial design of a swirl pipe of spiral pipe

3. RESULTS

The relation between shear stress (τ) and velocity gradient (ϒ) is proportional, and follows the non-Newtonian fluid model shown in Equation 1:

$$\tau_w = K\left[\left(\frac{d_\gamma}{d_t}\right)\right]^n \quad (1)$$

where τ_w is the shear stress, *K* is the concentration index, *n* is the power law index and $\frac{d_y}{d_t}$ is the velocity gradient.

The relation between shear stress and velocity gradient can also be obtained by measuring the pressure drop and flow rate as follows in Equation 2:

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

where *D* is the pipe diameter, *ΔP* is the pressure drop, *L* is the length of pipe, *μ* is the viscosity and u is the velocity.

The friction coefficient (*f*) can be calculated by using the Darcy equation as follows in Equation 3:

$$f = \left(\frac{D}{L}\right)\left(\frac{2g}{u^2}\right)\Delta h \quad (3)$$

where *f* is the friction coefficient, *Δh* is the delta of the head gradient between two points of the manometer, and *g* is the gravity acceleration.

The drag reduction ratio (DR) is calculated using the formula shown in Equation 4:

$$DR = \left[\frac{f_c - f(s_p)}{f_c}\right] x\ 100\% \quad (4)$$

where DR is Drag Reduction, f_c is the friction coefficien at the circular pipe and $f_{(sp)}$ is the friction coefficient at the spiral pipe.

4. DISCUSSION

Figure 5 shows the typical flow curve affected by particle concentration at a temperature of 27^{o}C. It is important to set temperature because rheological behavior is time dependent. Slurry fluid with a 20% concentration seems to be a straight line and close to the Newtonian flow rate.

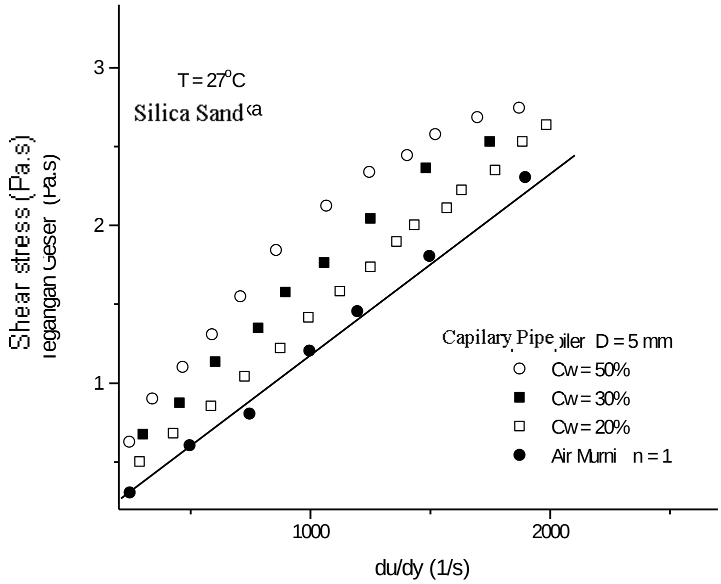

Figure 5 Flow curve of silica sand slurry

Meanwhile slurry with a 50% concentration is pseudoplastic. Cw is the the concentration of solids in the slurry, by weight. The Power Law Index for each concentration is Cw 20% n = 0.96, Cw 30% n = 0.92 and Cw 50% n = 0.90, respectively, which is related to Equation 1. It seems that a certain particle concentration has a significant effect on the typical curve, although is not linear.

Figure 6 presents the effect of shear strain on the apparent viscosity where in the case of Newtonian flow, the water flow is expected to be constant. For slurry with a Cw 20% concentration, it is also almost constant. Viscosity change is seen at Cw 30% and 50%. It means that viscosity (µ) is influenced by the shear rate. Accordingly, it is observed that a low shear rate tends to be related to non-Newtonian fluids.

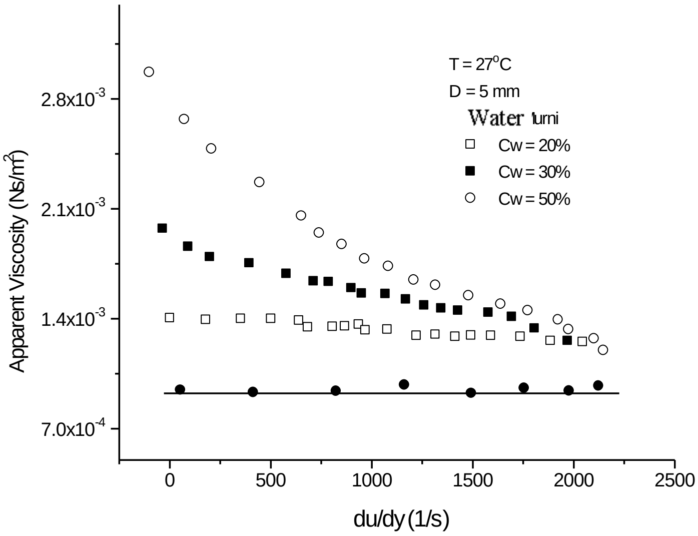

Figure 6 Relation of shear rate and apparent viscosity

The friction parameter determines the performance of the slurry flowing in pipe. Figure 7 presents the effect of pitch per diameter (p/Di) = 4. There is a difference in the friction coefficient between slurry and water. Based on the Blasius equation and the Hagen Poiselle equation, the friction coefficient of slurry is higher than water. This result indicates that there is no drag reduction occurrance at p/Di = 4.

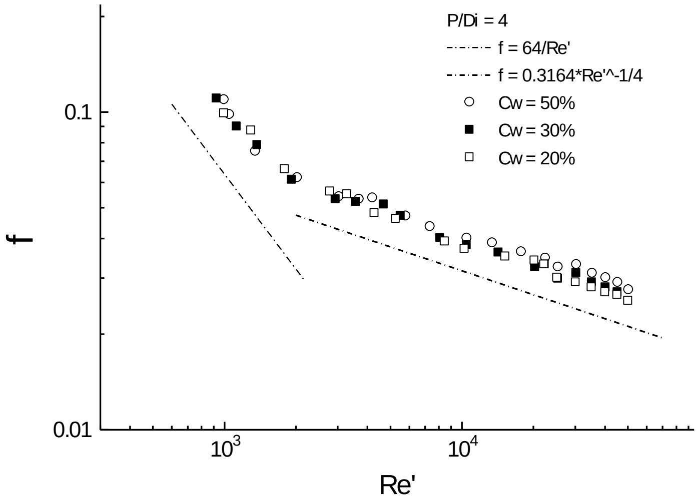

Figure 7 Friction coefficient for spiral pipe at p/Di = 4

Figure 8 presents the result of the experiment with spiral pipe having pitch per diameter (p/Di) = 7 at below the Reynolds number (Re) of 10,000. The Reynolds number (Re) is the ratio of momentum forces to viscous forces, quantifiying the relative importance for flow conditions. The friction coefficient is still above that of water (above formula line) and it begins to decrease for a Reynolds number (Re) higher than 1.5×10^4.

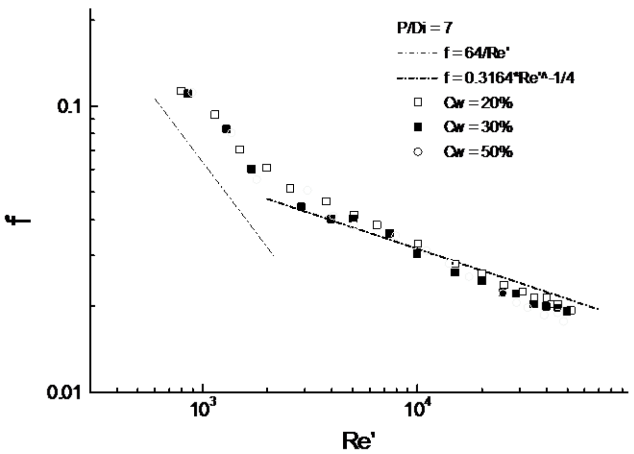

Figure 8 Friction coefficient for spiral pipe at p/Di = 7

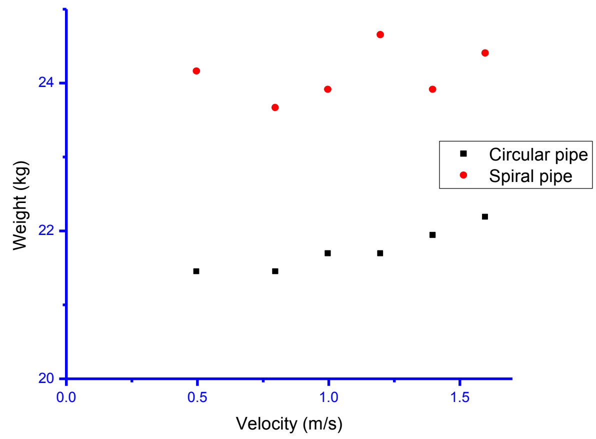

Figure 9 Slurry weight produced by circular pipe and spiral pipe at the same velocity

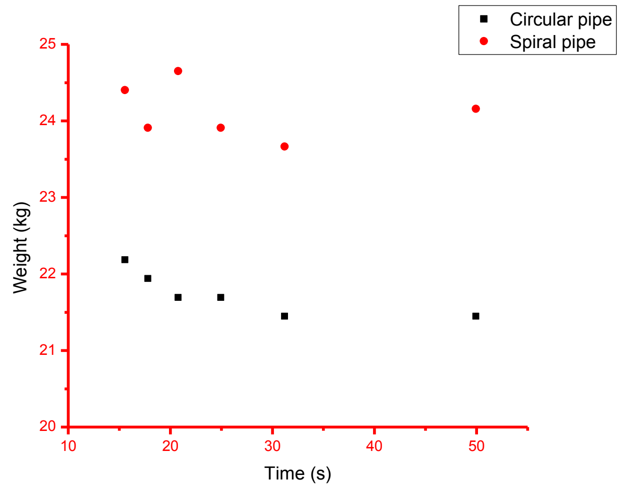

Figure 10 Slurry weight produced by circular pipe and spiral pipe at the same time duration

Figure 9 explains the correlation between velocity and weight at a volume of 20 liters of slurry flowing both in the circular pipe and the spiral pipe. The figure shows that the same velocity produces the same volume, but a different weight. Slurry flowing in a spiral pipe is a heavier weight, compared to the circular pipe. It is because of the swirl effect produced by spiral pipe that produces a uniform mix between solid particles and liquid. It means that the slurry transportation using the spiral pipe is more efficient compared to the circular pipe.

Figure 10 shows the correlation between time and weight conditions at the same volume. It can be seen that slurry flowing in the circular pipe tends to decrease over a longer time. Meanwhile, using a spiral pipe is more stable and it even tends to increase performance gradually. It means that flowing slurry in circular pipe can cause blockage, if the velocity cannot overcome sedimentation, especially at low velocity over a long time.

5. CONCLUSION

Silica sand slurry characteristics are affected by particle concentration, Reynolds number (Re), and viscosity. Data was taken from the experiment by measuring flow rate and pressure drop between two manometers placed at the test pipe. At Cw 20%, the slurry flow behaves as a

Newtonian fluid. Meanwhile, at Cw 30% and 50% the slurry flow behaves as a non-Newtonian fluid. The Power Law Index (n) for slurry is between 0.90–0.96. The ratio of p/Di gives influence to the drag reduction. At p/Di = 4, no drag reduction occurred. Meanwhile, at p/Di = 7 with particle concentration of Cw 50% and Reynolds number (Re) is about 30,000, the drag reduction can increase to about 33%.

6. ACKNOWLEDGEMENT

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