Springer

Journal of Mechanical Science and Technology

Journal of Mechanical Science and Technology 23 (2009) 1835~1839

www.springerlink.com/content/1738-494x
DOI 10.1007/s12206-009-0611-1

Hydraulics conveyances of mud slurry by a spiral pipe †

Yanuar[1], Ridwan[2], Budiarso[1] and Raldi A Koestoer[1,*]

[1]*Department of Mechanical Engineering, University of Indonesia, Jakarta 16424, Indonesia*
[2]*Doctor Candidate of Mechanical Engineering Department, University of Indonesia, Jakarta 16424, Indonesia*

(Manuscript Received Arpil 8, 2009; Revised April 14, 2009; Accepted April 27, 2009)

Abstract

Indonesia particularly East Java has been suffering from eruption of gas and mud slurry, caused by oil and gas exploration. Everyone calls this disaster as Sidoarjo mud or Lapindo mud. Mud slurry is essentially a mixture of a carrying fluid and solid particles held in suspension. When the mud slurry flow speed is not sufficiently high the particles will not be maintained in suspension. In spiral pipe twisted with a constant pitch in relation to the axis a swirling flow occurs when fluids flow in the pipe. The aim of this study is to examine characteristics of the hydraulic transport of mud slurry flowing in the spiral pipe with three-shape groove pipe walls. The shear stress and the shear strain are calculated by measuring the pressure drop and the volumetric flow rate in circular pipe, respectively. The power law exponent were about 0.93-1.0 for mud slurry solution of 45%, 30% and 20% of weight concentrations. The diameter of particles was 0.95 mm and the density was 2.19×10^3 (kg/m^3). The apparent viscosity of mud slurry solution is not constant to the shear strain but the relationship is approximated by model of power law. The friction factor of mud slurries in a spiral pipe with ratio pitch per diameter 6.7 is lower than circular pipe and spiral pipe with P/Di= 3.9 and 4.3. It was shown that the spiral pipe caused drag reduction in flowing of mud slurries. The drag reduction ratio of spiral pipe was about 28% for Cw=30% at Re'=32×10^3.

Keywords: Drag reduction; Friction factor; Mud slurry; Pressure drop; Sprial pipe

1. Introduction

Indonesia particularly East Java has been suffering from eruption of gas and mud, caused by oil and gas exploration. Everyone calls this disaster as Sidoarjo mud or Lapindo mud. It is a major environmental and economical issue, concerning not only the Indonesia government, but also local and some global communities. Even until this day, it is still impossible to stop or to control the mud flow from eruption. So the only way to prevent further damages is to flow the mud to river or directly to sea. Now we are facing the problem of how to flow the mud effectively, efficiently and also safely.

The problem of flowing of the mud in pipe is when the slurry flow speed is not sufficiently high the particles will not be maintained in suspension. It is well know that the friction or the drag of turbulent flow is reduced by adding some additives to liquids or gas. This phenomenon is called drag reduction. The hydraulic transport of solids in pipes is economically attractive in comparison to transport by truck, railway or ship. The goods transported over long distances are mainly coal and iron ore and the carrier fluid is water. Since the longest pipelines for the hydraulic transport are about 400 km in length, by using drag reducing additives considerable energy saving should be possible in the hydraulic transport of solids. Mud slurry is essentially a mixture of solids and liquids. Its physical characteristics are dependent on many factors such as size of particles, concentration of solids in the liquids phase, size of the conduit, temperature and viscosity of the carrier [1]. The flow of slurry in a pipeline is much different from the flow of a single-phase liquid. Theo-

† This paper was presented at the 7th JSME-KSME Thermal and Fluids Engineering Conference, Sapporo, Japan, October 2008.
*Corresponding author. Tel.: +6221 727 0032, Fax.: +6221 727 0033
E-mail address: yanuar@eng.ui.ac.id

retically, a single-phase liquid of flow absolute (or dynamic) viscosity can be allowed to flow at slow speeds from a laminar flow to turbulent flow. If the slurry's speed of flow is not sufficiently high, the particles will not be maintained in suspension. On the other hand, in the case of highly viscous mixture will be too viscous and will resist flow. The flow regimes were classified into six categories: homogeneous flow, heterogonous flow, fully moving bed, part stationary bed and stationary bed, and the empirical formulations to estimate the pressure drop in two phase flow was obtained [2]. In spiral pipe twisted with a constant pitch in relation to the axis a swirling flow occurs when fluids flow in the pipe. According to Watanabe K at al. [3] in spiral pipe twisted with a constant pitch in relation to the axis a swirling flow occurs when fluids flow in the pipe. The drag reduction for slurry flowing in spiral pipe maybe will be occurred from the ratio of pitch and diameter suitable with properties of slurry [4]. The aim of this study is to examine the characteristics of the hydraulic transport of mud slurry flowing in the spiral pipe with three-shape groove pipe walls by measuring the pressure drop. The flow curve of mud slurry and the friction factor are calculated by measuring the pressure drop and the gradient of velocity in circular pipe and spiral pipe, respectively. For practical application the spiral pipe presents a very useful method for preventing the holdup phenomenon in a transport pipeline for the hydraulic transport of mud slurry.

2. Rheological models

The shear stress is proportional to the velocity gradient (shear rate), can be described by Power Law model:

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

where K and n are constant for the particular fluid. The higher value of K, the more viscous the fluid. For n=1 that is for Newtonian behavior K=μ 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 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 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:

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

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.

The relationship between volume percent solids, solids specific gravity of the suspending medium, and the weight concentration of solids is given as follows [2]:

$$Cw = \frac{Cv\rho_s}{Cv\rho_s(100 - Cv)} = \frac{Cv\,\rho_s}{\rho_m} \tag{4}$$

where C_w, C_v are concentrations of solids in percent by weight and volume, respectively. ρ_s is density of the solid phase and ρ_m is density of the mixture phase.

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

$$f = \left(\frac{D}{L}\right)\left(\frac{2g}{u^2}\right)\Delta h \tag{5}$$

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

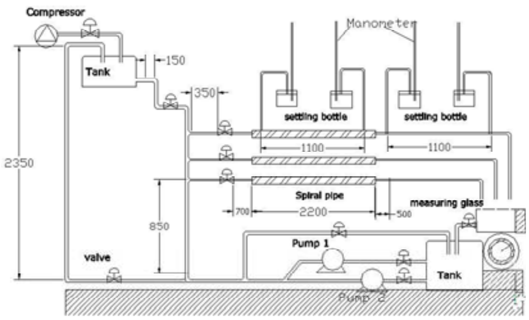

Fig. 1. Experimental set up.

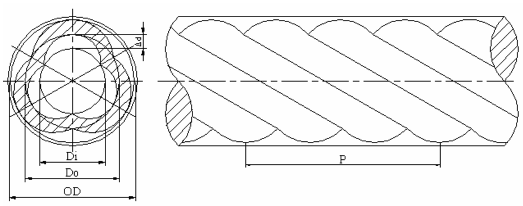

Fig. 2. Shape of tested spiral pipe.

The drag reduction, DR, is given by the coefficient of friction ratio or by the ratio of the wall shear stress, τ, for the coefficient of friction of circular pipe with the suffix *PB* and the coefficient of friction of spiral pipe with the suffix *PS*:

$$DR\,(\%) = \left|\frac{f_{PB} - f_{PS}}{f_{PB}}\right| x100 \qquad (6)$$

3. Experimental set up

The experimental set up was shown in Fig. 1. The mud slurry were circulated by pump and collected in tank. The pressure drop gradient was measured at 1100 mm length between each pressure tap by manometer through a settling bottle. The diameter of pressure hole was 2 mm and the flow rate was measured by a weighing machine. The inner diameter of test circular pipe was 12.7 mm. The shear stress and the shear rate can be obtained by measuring the pressure drop gradient and the gradient of velocity, respectively. Weight concentration (Cw) of mud slurry was 20 %, 30 % and 45 %. The temperature was keep at 27 ^{o}C. The particle size distribution of mud slurry for the hydraulic transport in this study was 0.95 mm in the mean diameter and the density was 2.19×10^3 (kg/m^3).

The average velocity of tested spiral pipe was calculated from the measured value of the cross-sectional area.

Table 1. Dimensions of spiral pipe.

Pipe	Di	Do	Δ d	P (pitch)	P/Di
Circular	25.4	25.4	0	∞	∞
Spiral 1	35	45.5	5	235	6.7
Spiral 2	23.5	32.5	4.5	100	4.3
Spiral 3	23	32.2	4.6	90	3.9

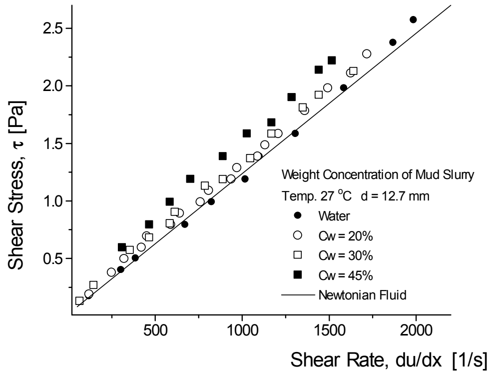

Fig. 3. Flow curve of mud slurry.

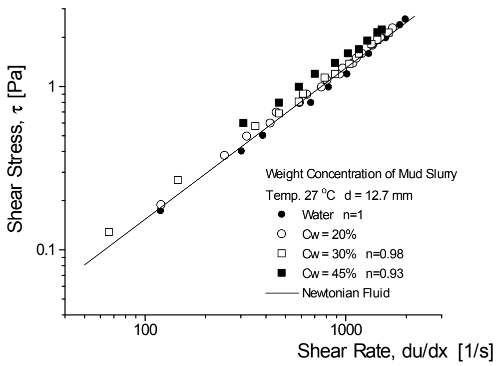

Fig. 4. Flow curve of mud slurry (log-log).

The dimension of the tested spiral pipes are given in Table 1. A Cross-sectional diagram and the side views are shown in Fig. 2.

4. Results and discussion

Fig. 3 shows the flow curve of the mud slurry solution measured using a horizontal circular pipe. The temperature of mud slurry was maintained at T = 27 ^{o}C throughout the experiments because the mud slurry rheology is temperature dependent. The effect of mud slurry degradation on the result was examined by pipe friction loss measurement at the start and end of the experiment. The plot data for Cw = 45 % is not linear, indicating that the material is a Power Law fluid over

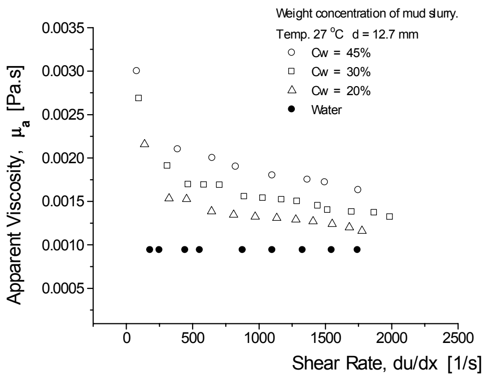

Fig. 5. Apparent Viscosity of mud slurry.

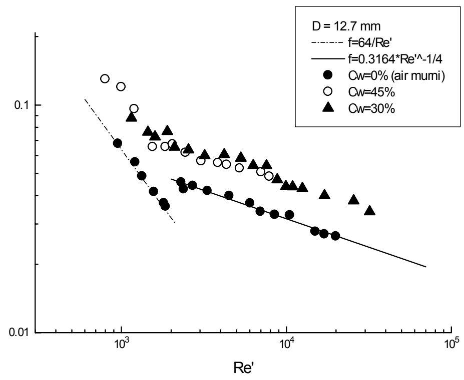

Fig. 6. Coefficient of friction for circular pipe d=12.7 mm.

this range of shear stress.

In Fig 4. 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 mud slurry. The plot is linear, indicating that the material of mud slurry is a power law fluid over this range of shear stress. Since the value from all there weight concentration of solution on the same single curve, the value of power law index for mud slurry were n = 0.93-1.0.

Measurement of the viscosity of mud slurry was carried out by horizontal pipe viscometer and the data of 20 %, 30 %, and 45 % weight concentration of mud slurry, Cw solution are presented apparent viscosity versus shear rate in Fig.5. It can be seen that the viscosity increased with decreasing shear rate although tended to a constant value in the high shear rate region. Measurements of viscosity depend on the type of viscometer and the hysteresis of the shear stress or shear rate may be occurred. Because the viscosity of mud

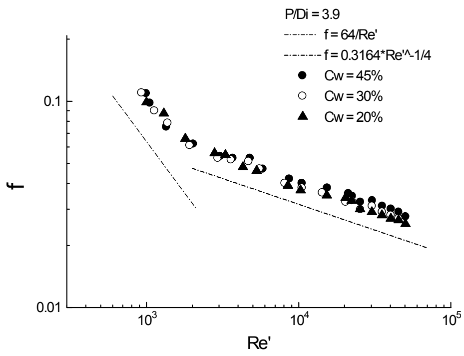

Fig. 7. Coefficient of friction for spiral pipe P/Di=3.9.

slurry was complicatedly depend on many parameters and the generalized Reynolds numbers, Re’, was calculated using the apparent viscosity of mud slurry. In this study, the rheogram for this mud slurry was based on the measured pressure drop data of tested circular pipes. This suggested that the viscometric properties of mud slurries vary in the low shear rate region. Accordingly, it can be considered that the rheological behavior in the low shear rate is that of non-Newtonian fluids.

Fig. 6 presents the data for coefficient of friction of mud slurry. Where the coefficient of friction of mud slurry was higher than the coefficient of friction of water for circular pipe. Correlation for the coefficient of friction and Reynolds number can also be used by designers to more accurately predict the pressure drop characteristics for mud slurry in circular pipe. Because the viscosity of mud slurry was complicatedly dependent on many parameters, the Reynolds number regenerative was calculated using the apparent viscosity of mud slurry.

The experimentally determined coefficients of friction of mud slurry are shown in Fig. 7, Fig. 8 and Fig. 9. The experimental coefficient of friction results of mud slurries for turbulent flow regions for P/Di=3.9 are shown in fig. 7, dash line indicate the analytical result of Hagen Pouiselle equation for laminar flow and the solid lines indicate the Blasius equation for turbulent flow, f=0.3164 $Re^{-1/4}$. All mud slurry data was located above the lines formula.

Fig. 8 shows there is only a slight difference between the spiral pipe with P/Di=3.9 and P/Di=4.3. Where coefficient of friction of P/Di=4.3 is lower than coefficient of friction of P/Di=3.9

Fig. 9 is shown that the coefficient of friction of mud slurry decreases compared to that of water. The coefficient of friction of mud slurries in a spiral pipe

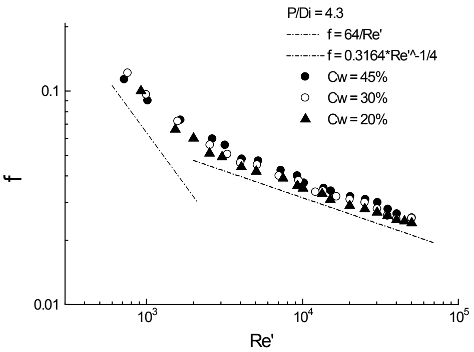

Fig. 8. Coefficient of friction for spiral pipe P/Di=4.3.

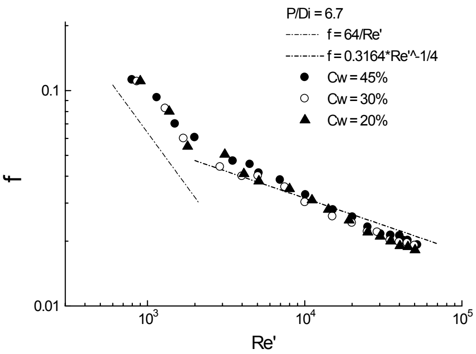

Fig. 9. Friction coefficient for spiral pipe P/Di=6.7.

with ratio pitch per diameter 6.7 lower than circular pipe and spiral pipe with P/Di= 3.9 and 4.3. It was shown that the spiral pipe caused drag reduction in flowing of mud slurries. Variation of weight concentration of mud slurry has not effect on coefficient friction in the pipe. An important outcome of this study is that the maximum drag reduction occurs at P/Di = 6.7 and the value of the drag reduction ratio is about 28%. By combining the results of this study, designers will be able to utilize the spiral pipe from the point of view of economizing energy in the transport process.

5. Conclusion

Curve flow characteristics of mud slurry were measured by horizontal pipe viscometer and calculated the shear stress and shear rate at the wall by the measurement of flow rate and the pressure drop. The results are summarized follows:

The mud slurry behaves as the Newtonian fluids for Cw 20 %, 30 % and the shear thinning fluid (pseudoplastics fluid) for Cw = 45 %. The power law model describes approximately the behavior of mud slurry and the range of the power law fluids index is n = 0.93~1.0. The coefficient of friction of mud slurries in a spiral pipe with ratio pitch per diameter P/Di=6.7 lower than circular pipe and spiral pipe with P/Di= 3.9, 4.3. The drag reduction on the hydraulic transport of mud slurry has been obtained by using the spiral pipe. The drag reduction ratio of spiral pipe was about 28% for Cw=30% at Re'=32×10^3 compared with that of a circular pipe that carrying water. Variation of weight concentration of mud slurry has not effect on coefficient of friction in the pipe.

Acknowledgment

This work supported by the Directorate for Research and Community Service, University of Indonesia (RUUI 2007), Jakarta. Indonesia.

References

[1] J. E. Wasp, P. J. Kenny R. L. Ghandy, *Solid – Liquid flow Slurry Pipeline Transportation*, Trans Tech Publication. Clausthal, Germany. 1977.

[2] B. E. Abulnaga, *Slurry Handbook*, McGraw-Hill, 2002.

[3] K. Watanabe, *Drag Reduction on Fly Ash Slurries in a Spiral Tube*. Elsevier science publishing company, Inc. 693-700, 1988.

[4] K. Watanabe, T Iwata and H. kato, *Flow in Spiral Tube*, 2nd *Report, Hydraulic Transport Of solid in a horizontal pipe,* Bull. JSME, 27 (230) 1692-1688, 1984.

[5] S. N. Shah and D. L. Lord, *Critical velocity correlation for slurry transport with non-Newtonian Fluids*, AIChE Journal, 37 (6) 1991.

[6] Yanuar and Damawidjaya. *Koefisien Gesek Aliran Dua fase pada Pipa Spiral*. SNTTM V. UI. Jakarta. Indonesia. 2006.

Yanuar received his B.S. degree in Mechanical Engineering from Indonesia University, Indonesia, in 1986. He then received his Master of Eng. and Doctor of Eng. in Mechanical Engineering from University of Tokyo Metropolitan, Japan, in 1995 and 1998, respectively. Professor at Mechanical Engineering at University of Indonesia in Jakarta, Indonesia.