A Study of Pressure Drop in a Capillary Tube-Viscometer For a Two- Phase Flow.

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Abstract

The analysis of pipeline transportation of highly concentrated suspensions such as coal-water slurries, can exhibit several flow characteristics depending on the concentration and the physical parameters of the dispersed phase.

Experiments were conducted for coal-water slurries flows in a series of horizontal capillary tubes of diameters 0.8, 1.5 and 3.0 mm and 100 mm in length, in order to investigate the effect of concentration, pressure drop, and the transitional Reynolds number from laminar to turbulent flow in a homogeneous slurry.

The solid concentration was varied from 15% to 63% in 0.1% xanthum gum solution. Pressure drop and the volume flow measurement were made using HVA-6 Capillary viscometer. The Reynolds numbers obtained were found to be dependent on the slurry concentration and the viscosity of the slurry mixture, but independent of the capillary diameter.

Introduction

The analysis of flow characteristics of coal-water slurries can go through different grades of complexity depending on the concentration profile of the dispersed phase, the rheological properties of the system and on the intensity of the flow [1,2].

The flow of a slurry can be influenced by several factors including drag, turbulence, the particles free fall velocity, particle-particle interaction, and the rheological properties of the carrier fluid [3]. Although a large number of experimental investigations have been conducted for the determination of one more of these effects, the complexity of the two-phase flow, limit the ability to describe the exact flow behavior for such systems [4].

Although many numerical models have been developed for multiphase flow, their application is still very limited, The dependence of empirically-determined stress expressions are not very clear due to lack of complete elucidation of the mechanism of the complex flow through numerical modelling [6].

There is therefore, a continuous need for further experimental data on such multiphase flows, in order to increase the database needed for the development of successful numerical simulation, for predicting realistic multiphase flows.

This paper describes the flow of varying concentrations of coal-water slurry through a horizontal capillary tube, and measuring the pressure drop at both low and high flow rates. The experimental parameters were chosen in order to emphasize the effect of turbulence, so as to allow the determination of possible transitional Reynolds number from laminar to turbulent flow.

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Experimental

The HVA-6 Capillary Viscometer was used to determine the flow rates of the slurries. The HVA-6 automated high shear viscometer permits measurements from low to high flow rates. Capillary tubes of diameters 0.8mm, 1.5mm and 3.0mm and 100 mm in length were used in these measurements. In this device, the sample to be measured is forced through a capillary tube at definite pre-adjusted pressure and pressed into a burette where the flow rate is measured. The exit samples were collected and the coal content determined at each applied pressure.

Results

The pressure drop in slurry flows is a key design parameter since it governs the pumping power required to move the slurry through the system. The change from laminar to turbulent flow results in a change in the flow resistance or friction loss. The prediction of the transition from laminar to turbulent flow can be inferred from the variation in the friction factor, which is dependent on the pipe diameter, the rate of flow, the length of the pipe, and the acceleration due to gravity.

In a horizontal flow, the actual deposition of the suspended particles is determined by the competing effects of gravity, particle-particle interaction and the rheological properties of the carrier fluid. As a result, either concentric or eccentric plug flow may result.

The CWS utilized in this work followed either the Power law or the Heschelley- Buckley model (Figure 1). The power law and the Herschel- Buckley models can be represented by:

$$\tau = k\gamma^n \text{ (Power Law Model)} \quad (1)$$

$$\tau = \tau_o + k\gamma^n \text{ (H. Buckley Model)} \quad (2)$$

where k and n are rheological constants, and τ and γ are the shear stress and shear rate respectively.

For slurries whose properties are time independent, the dependence of the shear stress (τ) on the shear rate (γ) can be expressed as $\gamma = f(\tau)$. The distribution of velocity in the radiant direction and the relation between volumetric flow rate, Q and loss of pressure ΔP , can be easily obtained through Rabinowitsch's Equation [7].

$$\frac{Q}{\pi R^3} = \frac{1}{3} \int_0^{\tau_o} \tau^2 f(\tau) d\tau \quad (3)$$

Where τ_o is the wall stress.

For a fluid described by the Herschel-Buckely model,

The Constitutive Equation is [8]

$$\gamma = \begin{cases} 0 & \text{when } \tau < \tau_o \\ \left[\frac{\tau - \tau_o}{k} \right]^c & \text{when } \tau > \tau_o \text{ and } c = \frac{1}{n} \end{cases} \quad (4)$$

From the equation of force equilibrium on a cylindrical element given the radius, r and length, L , the shear stress, is:

$$\tau = r \frac{\Delta P}{2L} \quad (5)$$

By substituting equation (5) in equation (4), we obtain

$$\tau = \begin{cases} 0 & \text{when } r < r_p \\ \Gamma \left(\frac{\Delta P}{2L} - \tau_o \right)^c & \text{when } r > r_p \text{ where } \Gamma = (1/k)^c \text{ and } r_p = \frac{2L}{\Delta P} \tau_o \end{cases} \quad (6)$$

By integration of equation (6), with the boundary conditions $U(R)=0$, gives the velocity profile.

$$\int_0^U du = -\Gamma \int_R^r (r \frac{\Delta P}{2L} - \tau_o)^c dr \quad (7)$$

The velocity profile is:

$$U(r) = \frac{\Gamma}{c+1} \frac{2L}{\Delta P} \{ (R \frac{\Delta P}{2L} - \tau_o)^{c+1} - (r \frac{\Delta P}{2L} - \tau_o)^{c+1} \} \quad (8)$$

Near the pipe axis, where $\tau < \tau_o$ the slurry displacement can be treated as a solid plug with radius r_p . By substituting the value of r_p in the above equation, we obtain the plug velocity as:

$$U_p = \frac{\Gamma}{c+1} \frac{2L}{\Delta P} (R \frac{\Delta P}{2L} - \tau_o)^{c+1}; \quad \tau_o = R \frac{\Delta P}{2L} \quad (9)$$

Figure 2 compares the flow curves of the slurries studied, and Tables 1-5 list the experimental data obtained. The data show a transitional Reynolds number of 1500. The results indicate that the turbulence intensity is damped as the solids concentration increase.

The coal content in the exit slurry at each applied pressure did not differ significantly from the initial slurry concentration. This suggests a concentric flow through the capillary tubes.

Increasing the applied pressure increases the flow rate and thus, the kinetic energy. For slurry concentration greater than 25% solids, the effect of increasing the initial applied pressure had no significant effect on the Reynolds number. This effect is however, pronounced in slurries having solids concentration less than 20% solids.

The effect of increasing the capillary size, for the high solids concentration slurries, had no significant effect on the Reynolds Number.

Conclusion

This study indicates that the HVA-6 capillary viscometer offers a unique approach for investigating the flow characteristics of homogeneous slurries. In this study, the solids concentration was found to play a significant role in establishing conditions from laminar to turbulence flow for a homogeneous slurry. Turbulence effect is completely damped for slurries containing solids concentration greater than 25% in 0.1% xanthan gum solution. Increasing the capillary diameter, however, had no significant effect on the Reynolds Numbers.

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Table 1.

Flow Rate of 61% CWS Through 0.8mm Capillary Tube

P(bar)	Flow Rate(ml/s)	Reynolds Number	Coal Content in Exit Sample(%)
10.2	.56	6	62
12.2	.66	7	60
14.9	.81	8	60
18.1	1.0	10	59
20.6	1.1	12	59

Table 2.

Flow Rate of 61% CWS Through 1.5mm Capillary Tube

P(bar)	Flow Rate(ml/s)	Reynolds Number	Coal Content in Exit Sample(%)
4.0	.41	0	59
6.1	1.9	5	61
8.0	2.5	6	59
10.4	3.3	8	59
12.7	4.2	11	60
14.4	4.8	13	60

Table 3

Flow Rate of 61% CWS Through 3.0mm Capillary Tube

P(bar)	Flow Rate(ml/s)	Reynolds Number	Coal Content in Exit Sample(%)
1.2	0.47	0	55
1.7	1.7	0	60
3.2	3.5	1	59
5.1	5.6	2	60
6.4	8.7	3	59

Table 4.

Flow Rate of 35% CWS Through 0.8mm Capillary Tube

P(bar)	Flow Rate(ml/s)	Reynolds Number	Coal Content in Exit Sample(%)
2.6	2.4	344	37
4.6	3.9	557	36
6.8	6.1	995	34
8.3	6.5	906	35
10.2	5.3	439	36

Table 5.

Flow Rate of 15% CWS Through 0.8mm Capillary Tube

P(bar)	Flow Rate(ml/s)	Reynolds Number	Coal Content in Exit Sample(%)
1.2	2.6	1047	14
3.1	5.2	1858	13
4.6	7.2	3851	14
6.3	9.6	4947	14

Figure 1. Shear Stress As A Function of Shear Rate for 62% CWS.
A Rotational Viscometer Generated Data.

Figure 2. Log Flow Rate (mL/s) As A Function of Log Pressure (bar).