An Investigation in Using UVP for assisting in Rheological characterisation of Mineral Suspensions

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The rheological characterisation of mineral suspensions for the prediction of flow in pipes and open channels is of considerable practical importance. Most predictive models depend on accurate rheological parameters. Mineral suspensions including mining tailings are mostly non-Newtonian suspensions with many exhibiting an apparent yield stress. These models are empirical in nature and require extensive laboratory testing to determine their characteristics. The Flow Process Research Centre at the Cape Peninsula University of Technology has for a number of years been investigating the behaviour of such suspensions. Rheological parameters have been mainly obtained from tube viscometry. This means measuring pressure drop and flow rate in two or more tubes of different diameter to produce flow curves. For comparison, rotary viscometry has also been used. Mineral suspensions are opaque and laser technology cannot be used. To progress to a more fundamental understanding of the flow behaviour of these fluids in pipes, fittings and flumes it is essential to measure velocity profiles. The principal problem here is that the acoustic behaviour and measurement techniques for these fluids using UVP techniques is as yet unproven.. This objective of this paper is to show that these techniques are viable, and show some promising initial results in both the tube and flume geometries with two different mineral suspensions.

Keywords: Mineral suspensions, rheology, velocity profiles, tube viscometry, ultrasound.

1 INTRODUCTION

As chemical, mechanical and mining engineers all over the world have had to deal with stricter environmental restrictions and use less water, the concentrations of the mining tailings have had to increase, in order to comply with superior disposal techniques. With this increase in concentration the tailings have become progressively non-Newtonian in character, and therefore more and more difficult to transport in pipelines and flumes. A proper understanding of the rheological behaviour and in-line control of rheology has become critical. These tailings are complex suspensions and are opaque. With the development and adaptation of the UVP system for measuring velocity profiles and using this for in-line rheological characterisation [1-6] this has given engineers and scientists in the mining engineering field a new tool to investigate the industrial flow process behaviour of these fluids.

2 LITERATURE

The objective of this paper is not to give a detailed overview of the literature available in this field but only to provide the relevant material related to the test work.

2.1 Rheological characterisation

The two fluids tested can be classified as follows: The Bentonite is a typical Bingham fluid and the kaolin suspension a Herschel-Bulkley or yield-pseudoplastic fluid. The general rheological equation for a Herschel-Bulkley fluid is:

$$\tau_0 = \tau_y + K(\dot{\gamma}_0)^n , \qquad (1)$$

where τ_0 is the wall shear stress, $\dot{\gamma}_0$ true shear rate at the wall, K the consistency index and n the power law index [7].

2.2 Tube viscometry

A tube viscometer is in essence a small diameter pipeline and therefore geometrically similar to a pipe. The test fluid flows at a measured flow rate through the tube and the pressure drop Δp is measured between two fixed points L m apart in the pipe. The relationship between the wall shear stress τ_0 and the volumetric flow rate Q and the shear stress τ is as follows [8]:

$$\frac{Q}{\pi R^3} = \frac{8V}{D}\frac{1}{\tau_0^3}\int_0^{\tau_0} \tau^2 f(\tau) d\tau \qquad (2)$$

Where $\tau_0 = \frac{R}{2}\left(-\frac{\Delta p}{L}\right)$ and $\left(-\frac{\Delta p}{L}\right)$ is equal to the pressure drop per unit length of tube. The shear stress at any radius r is:

$$\tau = \frac{r}{2}\left(-\frac{\Delta p}{L}\right). \qquad (3)$$

A plot of 8V/D vs τ_0 will give a unique line for a given material for all values of R and $\left(-\frac{\Delta p}{L}\right)$ in laminar flow, [9]. This also provides confirmation of the assumption that the time dependent properties of the fluids tested are not significant (ibid).

The problem with tube viscometry is that 8V/D is not true shear rate but the wall shear rate for a Newtonian fluid, therefore this “pseudo” shear rate has to be transformed to the true shear rate at the wall, ($\dot{\gamma}_0$).

For a flow curve where the form is unknown Equation 1, after some manipulation, will yield the following according to (ibid).

$$\left(-\frac{du}{dr}\right)_0 = \frac{8V}{D}\left(\frac{3}{4}+\frac{1}{4}\frac{d\log(8V/D)}{d\log\tau_0}\right). \qquad (5)$$

Various forms of this equation exist, one being the Rabinowitsch-Mooney Equation:

$$\dot{\gamma}_0 = \left(-\frac{du}{dr}\right)_0 = \frac{8V}{D}\left(\frac{3n'+1}{4n'}\right) \qquad (6)$$

where

$$n' = \frac{d(\log\tau_0)}{d\left(\log\left(8V/D\right)\right)}. \qquad (7)$$

If one plots a log-log pseudo shear diagram with τ_0 versus 8V/D for the laminar flow region, then n′ is the slope of the tangent of the graph. The slope will only be approximately constant if the fluid is a power-law fluid (ibid).

2.2 Velocity Profiles

Equation (1) can be integrated to yield the velocity profile in a pipe [10]. In the case when $\tau = \frac{r\Delta p}{2L} \le \tau_y$, the fluid does not shear and adjacent laminae are stationary relative to one another. This occurs for values of $r \le r_{plug}$ where

$$r_{plug} = \frac{R\tau_y}{\tau_0}. \qquad (8)$$

For $R > r > r_{plug}$ the fluid shears and Eq. (1) can be integrated to yield

$$u = \frac{\left(\frac{1}{K}\right)^{\frac{1}{n}}}{\left(\frac{\Delta p}{2L}\right)}\frac{n}{n+1}\left(\left(\tau_0-\tau_y\right)^{\frac{n+1}{n}} - \left(\tau - \tau_y\right)^{\frac{n+1}{n}}\right). \qquad (9)$$

When $0 < r < r_{plug}$ the fluid moves as a plug at a uniform plug velocity u_{plug} .

3 EQUIPMENT USED

The tests were all conducted in the Flow Process Research Centre laboratory of the Cape Peninsula University of Technology.

3.1 Flow Profile Measurements

For measuring the velocity profiles the Metflow-SA UVP was used with a 4 MHz transducer mounted at an angle of 20 degrees with the vertical. The measurents in the pipe were made through the Perspex wall. A small adaptor was fitted onto the pipe and US gel was used to transmit the echo from the transducer to the pipe wall. In the flume the transducer was suspended into the fluid from a small unit housing the transducer.

3.2 Tube viscometer

The pipe used was a 50 mm diameter plexi-glass tube which forms part of a fittings rig. The flow in the tube is measured with a mass flow meter and the point pressure with Fuji pressure sensors. The pressure transducers are mounted 2 m apart. Flow is produced by a progressive cavity positive displacement pump fitted with a variable speed drive. The pressure drop and flow measurement signals are relayed via a data logger to a PC.

Figure 1: Layout of fittings rig.

The transducer position is displayed in Figure 2.

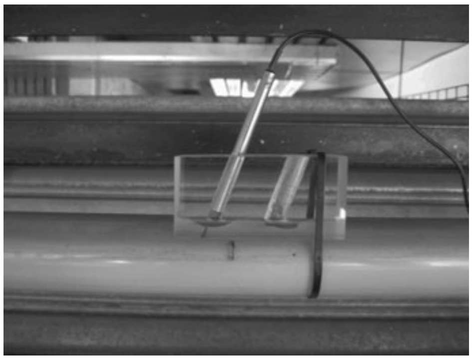

Figure 2: The 4 MHz probe fitted to the 40 mm pipe.

3.3 Tilting Flume

The flume used for the test work is a 75 mm wide by 5 m long tilting flume. The flume is linked to an in-line tube viscometer fitted with three diameter pipes from 13 mm to 80 mm in diameter. Each tube is fitted with a magnetic flow meter and pressure tappings connected to a differential pressure sensor. Flow depth in the flume is measured with electronic depth gauges. For purposes of these preliminary tests a simple device was built to lower the ultrasound transducer at a fixed angle into the fluid flowing in the flume. A picture of the flow setup depicting the position of the probe in the flume is shown in Figure 3.

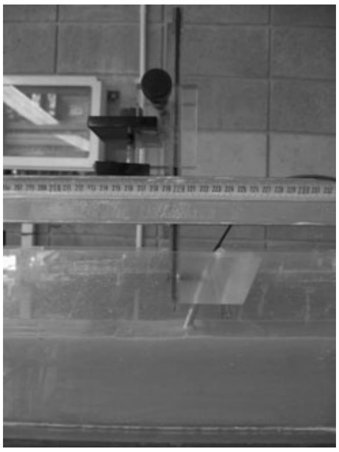

Figure 3: The 4 MHz probe fitted to the flume.

3.4 Rotary Viscometer

The rheological parameters were also obtained from flow curves measured with a Paar Physica MC-1 rheometer fitted with a cup and roughened bob.

3.5 Materials tested

Two mineral suspensions were tested namely kaolin and Bentonite.

Kaolin: Dry kaolin powder was used to prepare kaolin:water suspensions. The d85 was about 8 micron. The concentration tested was 8,25% c/v with an RD of 1,136.

Bentonite: The concentration tested was 5,66% c/w with an RD of 1,035.

4 RESULTS AND DISCUSSION

5.1 Rheology

From the rotary viscometer a flow curve for the kaolin and Bentonite was obtained and the rheological parameters determined. The results are summarised in Table 1.

Table 1: Rheological parameters of fluids tested

Material	τ_y (Pa)	K (Pa.s)	n
Kaolin 8.25%	5	0.92	0.59
Bentonite 5.66%	21.95	0.043	1

5.2 UVP settings

The setting used for the velocity measurements are summarised in Table 2.

Table 2: UVP settings

Kaolin 8.25%	2,8 l/s	1.9 l/s	1.3 l/s
Sound speed (m/s)	1601	1601	1601
PRF (kHz)	12.87	8.75	5.26
Angle probe	20^0	20^0	20^0
Frequency (MHz)	4	4	4
Cycles	4	4	4
US Voltage (V)	150	150	150
Bentonite 8.25%	2.26 l/s		
Sound speed (m/s)	1628		
PRF (kHz)	4.75		
Angle probe	20^0		
Frequency (MHz)	4		
Cycles	2		
US Voltage (V)	60		

5.3 Velocity profiles in pipe

The following velocity profiles in Figures 4-6 were obtained for the kaolin suspension at flow rates of 2.8, 1.9 and 1.3 l/s respectively.

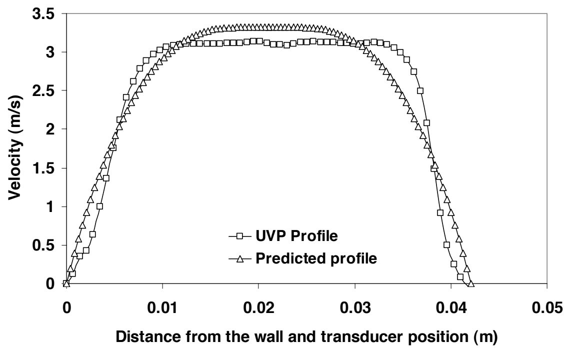

Figure 4: Velocity profile in 42 mm pipe for kaolin at flow rate of 2.8 l/s.

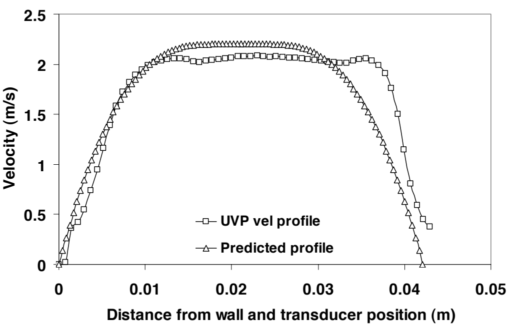

Figure 5: Velocity profile in 42 mm pipe for kaolin at flow rate of 1.9 l/s.

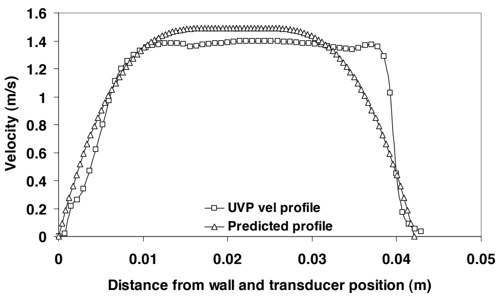

Figure 6: Velocity profile in 42 mm pipe for kaolin at flow rate of 1.3 l/s.

From the above profiles it can be seen that if the instrument is set up properly the ultrasound signal is able to penetrate the fluids at least to just about the end of the plug. The kaolin attenuates the signal more than the Bentonite. With higher concentrations and larger pipe diameters this could present a problem. This could however be overcome if two transducers were used.

5.4 Velocity profile in Flume

The tests in the flume were more of an exploratory nature and the intention was to determine how well the UVP profile would function in the Bentonite suspension. The setup was somewhat crude and the following profile will show that the attenuation in the Bentonite is minimal and the whole flow depth was easily penetrated.

In Figure 7 the velocity profile for the Bentonite suspension is presented.

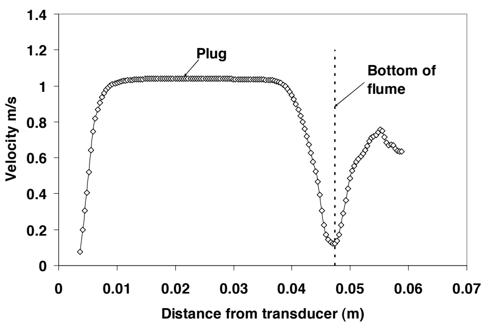

Figure 7: Velocity profile in 75 mm wide flume for Bentonite at flow rate of 2.26 l/s.

6 CONCLUSION AND RECOMMENDATIONS

The initial results obtained have been very encouraging and we are confident that the instrument will assist us in obtaining velocity profiles of complex non-Newtonian mineral suspensions. This opens a number of new avenues of research to us. Some of these are in-line measurement of rheology which has already been shown to be feasible by Ouriev and Windhab and Wiklund *et al*. [3-6]. Flow velocity profiles through various geometries now also becomes a possibility as well as establishing accurate flow profiles in different flume cross-sections.

What will be essential is to test the attenuation of the ultrasound signal in different concentrations of the suspensions so as to better understand the limitations of the instrument.

The initial tests have however given us a window of opportunity to examine the flow of viscous mineral suspensions in different flow configurations.

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