PATERSON, A., GOOSEN, P., PAULSEN, E., and KRAUSE, B. Variable rheology of heavy mineral tailings. *Heavy Minerals 2003,* Johannesburg, South African Institute of Mining and Metallurgy, 2003.

Variable rheology of heavy mineral tailings

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Ticor South Africa is currently involved in the mining and processing of a heavy mineral ore deposit at Hillendale Mine on the KwaZulu-Natal north coast.

The orebody is characterized by a high ultra fine fraction (-45µm) that has a variable rheological behaviour when subjected to shear and hydration. Experience at Hillendale has shown that the ultra fine mineral tailings are sensitive to shear history in terms of shear intensity and shear duration as well as hydration history.

This phenomenon expresses itself right through the primary beneficiation process influencing the mineral separation, but is especially prevalent on the residue disposal i.e. slurry transport and deposition on the tailings impoundment.

Tube viscometer test work was conducted on the flocculated fine tailings that indicated that there was a change in rheology as a result of shear.

This paper presents the results of the on-site test work conducted at the mine to measure the rheology at various stages in the process.

Introduction

Background

Hillendale Mine near Empageni in KwaZulu-Natal is recovering heavy minerals from dune deposits. The run-of-mine ore (ROM) has a high fine fraction with typically 18% -45 µm, which reports to the 'residue' stream (fine tailings). Operating experience has shown that there is considerable variation in the rheological properties of the residue. These changes may be directly related to the particle size distribution of the residue. The fine residue tailings generated are further affected by flocculent type and dosage rates, water quality, and shear in the pumping process.

The change in rheological properties throughout the process affects both mineral recovery and residue disposal. It has particular implications at the residue disposal site, which requires that material is transported and deposited as stiff as possible. Slurry at high solids concentrations with a high yield stress will have a steeper beaching angle than slurry with a low yield stress and low solids concentration. Extensive work has been done by the mine to maximize the solids concentration pumped to the disposal site in order to maximize the yield stress. The effect of pump shear on the residue rheology was, however, uncertain and there was concern that the shearing action in the centrifugal thickener underflow pump was reducing the yield stress. This paper presents the work done to investigate the effect of pump action on the rheology of the residue.

Basic flow sheet

The ROM is mined using high pressure water monitors, and pumped to a central location using centrifugal pumps. From this point the ore is gravitated in an open channel to the mining sump, where it is then transferred to the primary wet plant (PWP). Heavy minerals are recovered in the spiral circuit, and sand and residue waste streams are produced. Sand tailings are pumped to the dune rehabilitation site, and the residue is sent to the thickening facility. High rate thickeners are used to increase the solids concentration to approximately 28% by mass. The thickener underflow is pumped to a central surge tank using centrifugal pumps, and then pumped to the residue disposal site using positive displacement pumps.

Test programme

The residue slurry is known to be sensitive to extended wetting and the flocculent used also decays with time. Samples cannot therefore be collected and transported to test facilities for testing as their properties may change. Fresh samples should be tested on site to ensure that representative rheological data is obtained. A test programme was developed to take samples at different points in the process during a 12-hour period, and to measure the rheology on site. Samples were regularly taken from the following locations:

- Thickener underflow pump suction
- Thickener underflow pump discharge
- Positive displacement pump suction.

Samples were also collected from a pilot thickener plant with both centrifugal and peristaltic underflow pumps (to investigate the effect of the different pump actions on the slurry). Samples were taken from the suction and pump discharge.

Measurement of rheology

The rheological properties of the samples were measured in a tube viscometer. The tube viscometer comprised a pressure vessel connected to a tube of known dimensions (2 metres in length and 6 mm and 8 mm inner diameter). The sample was loaded into the pressure vessel and discharged through the tube at a controlled flow rate (Q_m). Pressure loss and flow rate were recorded, allowing the velocity and wall shear stress to be determined directly. The measured data is presented in a conventional pseudo-shear diagram, which is a plot of pseudo-shear rate (Γ) versus wall shear stress (τ_o), where:

$$\Gamma = \frac{8V}{D} \quad [1]$$

$$\tau_o = \frac{D\Delta P_f}{4L} \quad [2]$$

and V = mean mixture velocity (m/s) = Q_m/A
D = internal pipe diameter (m)
ΔP_f = pipeline pressure loss due to friction (Pa)
L = pipeline length (m).

A typical data set and pseudo-shear diagram is shown in Figure 1.

The slurry is best modelled using the yield pseudo-plastic model in which the yield stress (τ_y), fluid consistency index (K), and flow behaviour index (n) are determined iteratively from a pseudo-shear diagram (Γ and τ_o known) using the following relation (Govier and Aziz, 1972):

$$\Gamma = \frac{8V}{D} = \frac{4n}{\tau_o^3}\left(\frac{1}{K}\right)^{\frac{1}{n}}\left(\tau_o - \tau_y\right)^{\frac{n+1}{1}} \left[\frac{\left(\tau_o - \tau_y\right)^2}{3n+1} + 2\tau_y\frac{\left(\tau_o - \tau_y\right)}{2n+1} + \frac{\tau_y^2}{n+1}\right] \quad [3]$$

The rheological parameters established for each residue sample are correlated against the volume concentration of solids (C_v), determined from the following relation:

$$C_v = \frac{S_m - S_w}{S_s - S_W} \quad [4]$$

where S_w = 0.9982 , relative density of water at 20°C
S_m = slurry relative density
S_s = solids relative density, 2.61.

Effect of pump shearing

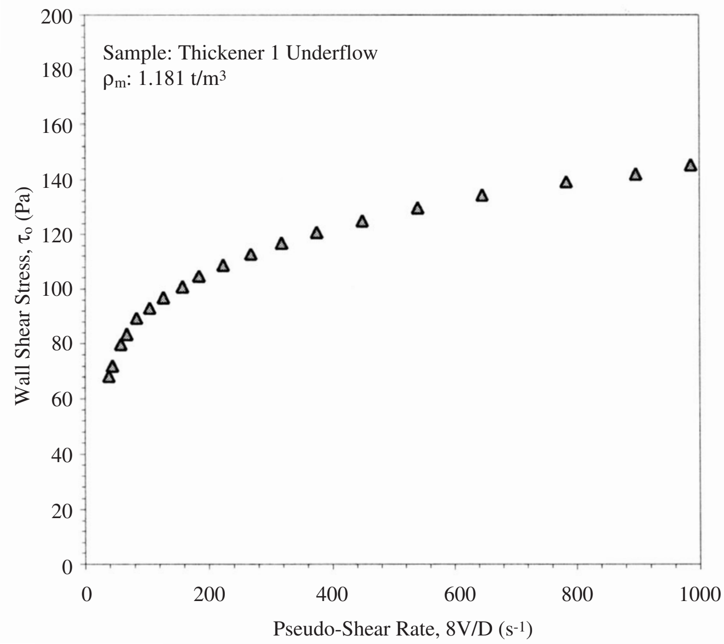
The analysis of the tailings was based on the thickener underflow pump suction and discharge data only. The combined measured suction and discharge pseudo-shear diagram for a typical thickener (thickener No. 2) is shown in Figure 2. It is seen that the slurry at the suction side has a slightly lower yield stress than the discharge slurry. This is attributed to shearing of the slurry and generation of ultra fine particles. The suction and discharge data have been modelled separately to account for these differences.

From Figure 2 it is evident that the residue slurry is found to be *shear thinning* i.e. the apparent viscosity decreases with increasing shear rate. Furthermore it may be seen that for similar slurry densities the rheology increases from the suction to the discharge. This would imply that the slurry exhibits time dependent behaviour in which the rheology increases with exposure to shear.

Results obtained for a sample from the pilot plant pump suction and centrifugal and peristaltic pump discharge are presented in Figure 3. From the results it is evident that both the centrifugal pump and peristaltic pump increase the slurry rheology when compared with the data obtained from the common suction manifold. This is more pronounced in the centrifugal pump and is attributed to higher shear intensity in the centrifugal pump.

Figure 4 presents the slurry yield stress, Figure 5 the fluid consistency index, and Figure 6 the flow behaviour index as a function of solids concentration by volume. All the parameters are based on the underflow pump suction and discharge data. The rheological parameters were determined from the measured data using Equation [3].

Since there is a difference between the pump suction and discharge samples, these are identified separately on the graphs. From these charts it is observed that the yield stress for the discharge data is generally higher than the suction data; however, the fluid consistency index and flow behaviour index parameters remain relatively constant.



Pseudo-shear Rate (s^{-1})	Wall Shear Stress (Pa)
986.0	145.0
896.8	142.0
783.7	139.1
645.7	134.3
539.9	129.6
449.1	125.0
374.9	120.7
318.1	116.8
267.9	112.8
222.9	108.6
183.9	104.6
157.5	100.8
126.3	96.9
104.3	93.0
83.4	89.2
67.2	83.4
57.6	79.6
44.2	72.0
38.3	68.2

Figure 1. Typical data and pseudo-shear diagram

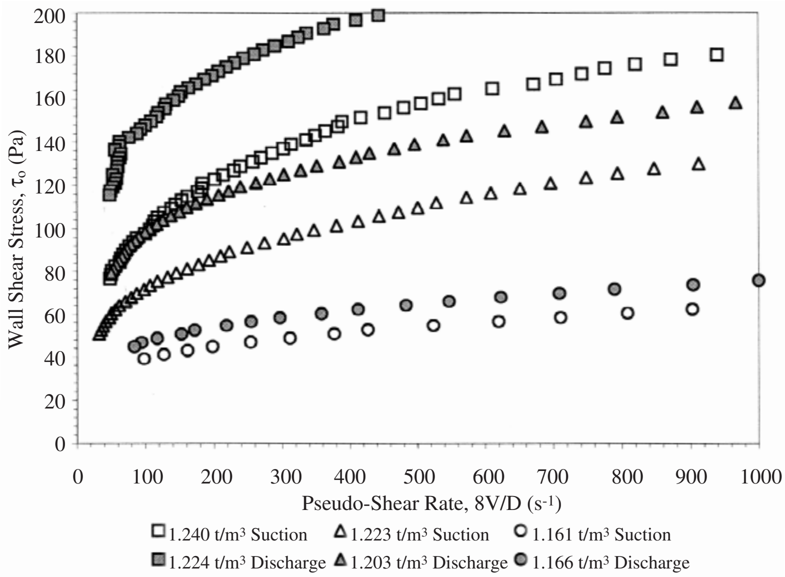


Figure 2: Test tesults for thickener No. 2 suction and discharge

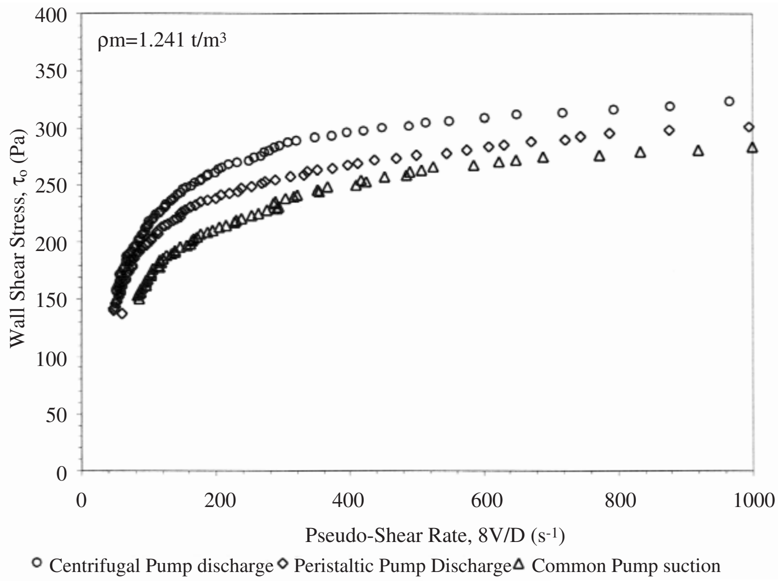


Figure 3: Test results for the pilot plant at one density

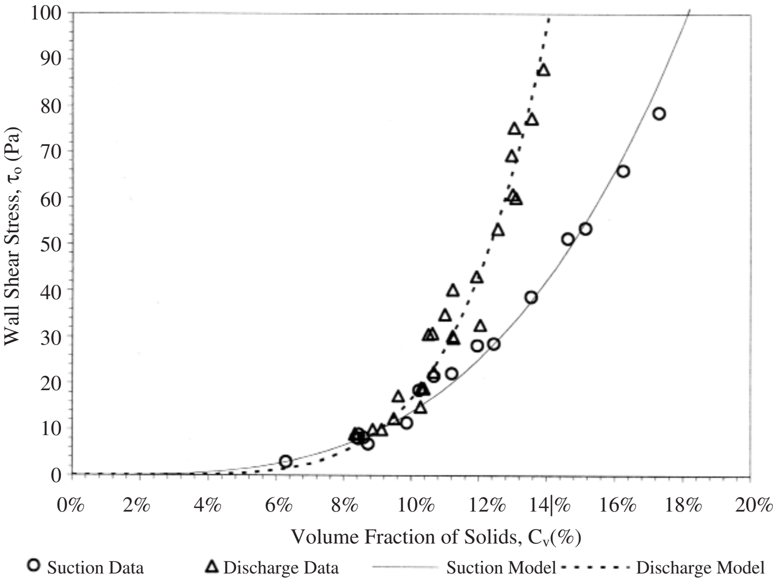


Figure 4: Slurry yield stress versus solids concentration by volume

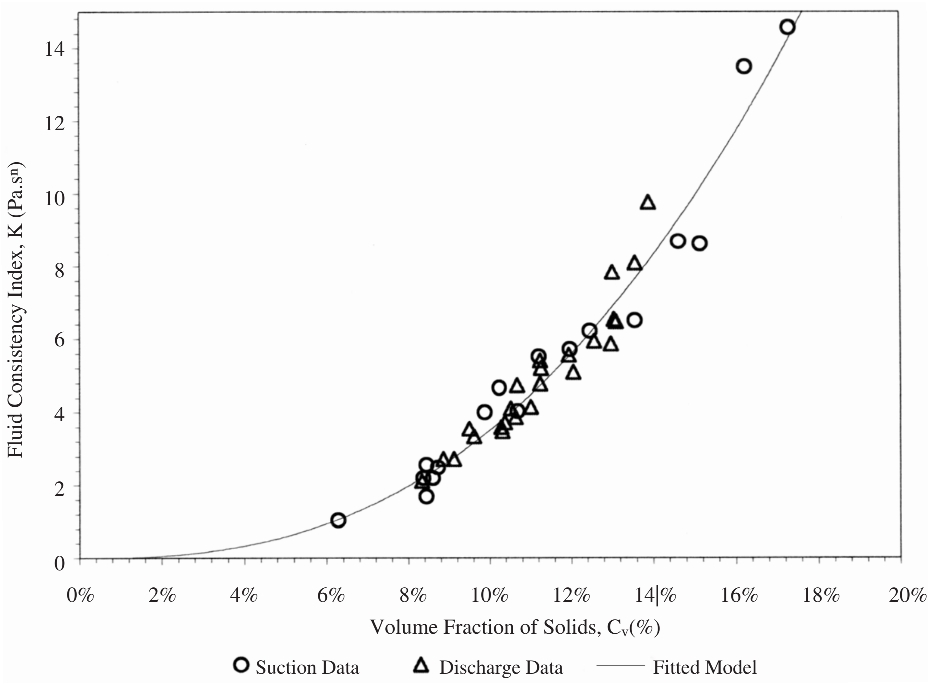


Figure 5. Fluid consistency index versus solids concentration by volume

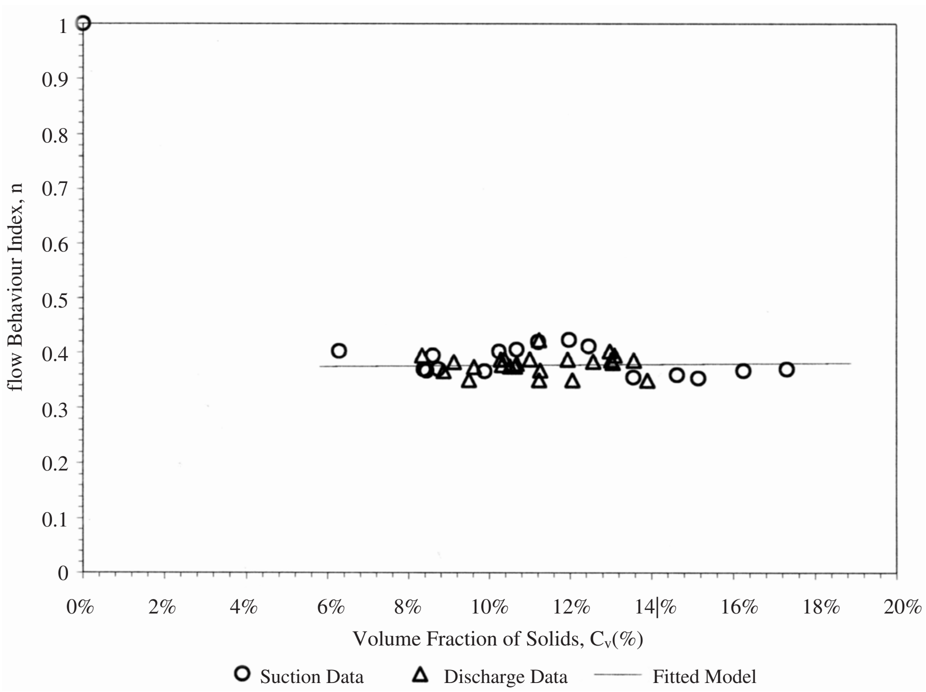


Figure 6. Flow behaviour index versus solids vehicle concentration by volume

Conclusions

- The residue slurry behaves as a time dependent yield pseudo-plastic fluid i.e. it exhibits shear thinning behaviour, and the rheology increases with exposure to intense shearing (as in a centrifugal pump)
- The rheological parameters have been determined as functions of the volumetric concentration of solids
- The slurry rheology tends to increase as it passes through a pump (increase in yield stress). The increase in rheology is attributed to the generation of fine particles during shear. This effect is decreased considerably as the density decreases
- The rheology of the slurry measured at the discharge of a centrifugal pump is greater than the rheology measured at the discharge of a peristaltic pump on a common manifold. The difference is attributed to the more intense shear in the centrifugal pump
- Finally it is concluded that pumping the residue in a high shear pump, such as a centrifugal pump, will not reduce the residue yield stress but rather increase it.

References

GOVIER, G.W. and AZIZ, K. *The flow of complex mixtures in pipes.* Von Nostrand Reinhold Company, 1972.