COMPARISON OF THE RHEOLOGY OF BAUXITE RESIDUE SUSPENSIONS

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Abstract

The paper presents an overview on the rheology of bauxite residue suspensions. Comparative viscosity and yield stress data are presented for bauxite residues generated in Australia, Jamaica, Surinam, and the USA. A yield stress for optimum dry disposal is specified as is the concentration for minimum energy consumption for the pumping of the four different materials. The data show that bauxite residues can be characterised at two structural states: the initial and the equilibrium or time-independent state. Data can be collected and reproduced for different muds providing there is an understanding of the time dependent nature of the material. The four red mud samples obtained from around the world have been characterised in both the initial and final equilibrium state. A comparison shows that after the course particle fraction has been removed the US, Surinam, and three samples from Western Australia all show similar rheological characteristics in the reduced structural state. A fundamental understanding of the basic rheology of bauxite residue is necessary for establishing an optimal waste disposal strategy.

Introduction

The production of alumina via the Bayer process results in large amounts of waste being generated. If the bauxite ore used in the beneficiation process is of low quality, such as those found in Western Australia, the amount of waste generated can be twice that of the alumina produced. In 1994-95 approximately 25.5 million tonnes of bauxite residue was produced in Australia and almost 96 million tonnes produced throughout the world [1]. Furthermore, the waste generated is typically in the pH range of 12.5 to 13.5 [2] posing a potential hazard to the local environment. The disposal of such a tailing is therefore of critical importance and raises the question, how best to dispose of such a material.

Prior to 1985 the disposal of bauxite residue (red mud) in Western Australia was facilitated via wet disposal. Wet disposal involves disposing of the tailings at low concentrations, typically 10-30% (weight basis) by either point or line discharge [3]. The low capital cost of the operation makes this an attractive option, however, the large volume of waste produced can impact adversely on the environment. Many of the inherent problems associated with dilute slurry disposal can however be minimised provided the solids concentration of the slurry to disposal can be increased. This would reduce the dependence on slurry pond seals, provide a mechanically stable residue deposit, vastly reduce residue storage volume and provide early access to a completed residue area for rehabilitation. In 1985 Alcoa of Australia implemented semi-dry disposal as the preferred method of tailings disposal at the Pinjarra refinery [4]. Semi-dry disposal involves the dilute tailings being concentrated typically to between 40-60% (weight basis) before being deposited into a tailings area.

Deposition of the concentrated tailings can be facilitated in two basic forms. Firstly the tailings can be deposited from the periphery inwards, which allows a beach to develop such that a pool results in the centre of the tailings area. Alternatively the tailings can be deposited via a central discharge, as proposed by Robinski[5]; the method results in the tailings forming a cone and a pool around the perimeter of the tailings area. Prerequisite to the implementation of a concentrated disposal strategy is the determination if such a suspension can be handled at high concentrations. This includes the ability to pump the material over long distances with minimal expenditure of energy, and identifying potential problems associated with pipeline sanding, startup, and shutdown. Furthermore, the slope of the tailings deposition is dependant on the flow properties, in particular the yield stress in shear.

In order to achieve the high concentrations needed for semi-dry disposal without creating a processing bottleneck, flocculants are often employed to increase the settling rate of the fine particles. Moreover numerous flocculants are employed upstream of the residue area to enhance process efficiency. The extensive flocculation history leads to the red mud exhibiting unique rheological properties, namely, the time dependent or thixotropic behaviour evident in many red mud suspensions. The thixotropic behaviour however can be eliminated by extensively shearing the sample until a time independent or equilibrium state is reached.

By probing these properties a greater understanding of the flocculation and structural behaviour of red mud will be gained.

The current paper demonstrates how rheological data can be confidently and reproducibly obtained in the "as received" and "equilibrium state". Additionally the paper compares the results on the shear properties of four red mud samples obtained from Alcoa operations in Australia, US, Surinam and Jamaica.

Materials and Measurements

The time and shear dependent nature of red mud at high concentrations makes the rheological characterisation of the material difficult [2]. Red mud samples at high concentrations have been shown to exhibit a yield stress. Moreover the material is also shear thinning, that is, the viscosity decreases with increasing shear rate [6]. The effect of shear on the samples has also been investigated with the conclusion that the material is thixotropic in nature [7] which implies that the structure of the material (as measured by the yield stress or viscosity) can be broken down over prolonged periods of agitation or shear. Typically a steady state structure termed the "equilibrium state" is attained after a long period of agitation.

In the present case the yield stress is measured using the vane technique [8,9]. The technique uses a slowly rotating four-bladed vane. As the vane is rotated from a standing start, the maximum torque generated may be directly related to the shear yield stress.

Shear stress-shear rate measurements were made using a capillary rheometer. This technique has previously been shown to provide reliable data for red mud samples over a wide concentration range [2]. The shear stress- shear rate data were then fitted to a power law model and the viscosity determined.

The red mud samples studied were obtained from various Alcoa Alumina Refineries. Because of the different processes employed at the various locations it is impossible to obtain samples that have experienced the same process history. In some cases the red mud has been thickened with the aid of a filter or thickener and in others the material was simply allowed to settle to higher concentrations. All the materials tested however are representative of the final discharge material.

Results and Discussion

Before conducting a study into the rheological properties of red mud suspensions it is first necessary to gain an understanding of the thixotropic nature of the material such that reproducible measurements can be made with confidence. Figure 1 illustrates the shear stress - apparent shear rate data obtained for an Australian red mud sample. The sample was mixed with the aid of an anchor agitator rotating at 40 RPM in a close clearance vessel. The sample was removed intermittently during this process and the data illustrated in Figure 1 collected.

Each data set illustrated in Figure 1 is the result of at least two runs through the capillary, each run with a tube having a different L/D ratio. Evident from the figure is the reproducible nature of the runs indicating that a material property is being measured that is independent of the tube dimensions. Another point to note is that although the material is time dependent the length of time and shear rate experienced by the sample whilst making a measurement is insufficient to cause any measurable decrease in the flow properties. This is an important conclusion as it enables reproducible measurements to be made.

Also evident from Figure 1 is the reproducible nature of the as received or initial state, for the first 150 minutes of mixing there is no measurable difference in the shear stress shear rate behaviour of the sample. However, beyond this point the material begins to break down in structure, with a lower shear stress being measured for a given shear rate. Finally after approximately seven days of mixing a time independent or equilibrium state is reached. From Figure 1 a conclusion can be made that reproducible measurements can be made in both the as received and equilibrium structural states.

One possible explanation for the observed breakdown in structure is that during the flocculation process the individual particles are bound together by the polymeric flocculant, also trapped in the flocs is water which becomes immobilised in the floc. The shearing action serves to break up the floc structure thereby liberating the water and giving rise to the observed lower shear stress at a given shear rate.

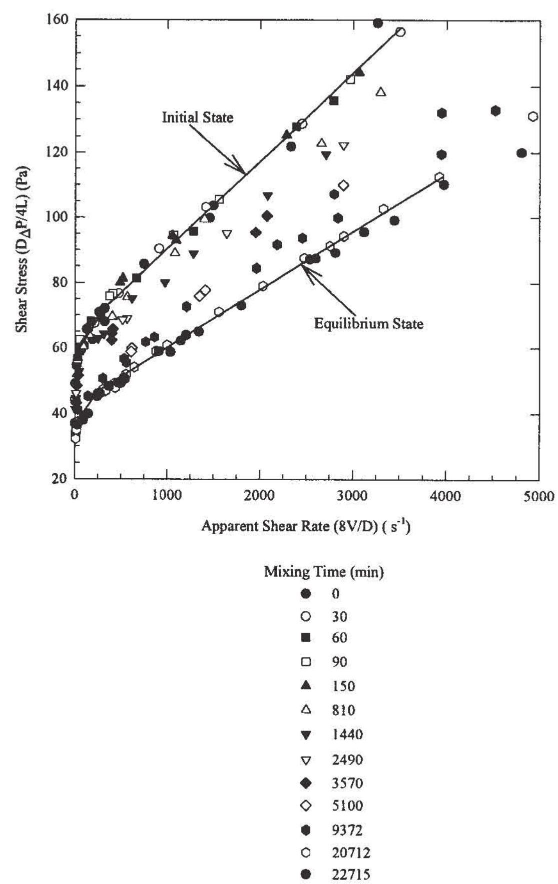

Figure 1: Shear stress - apparent sear rate data for various mixing times.

Now that reproducible results can be made in the initial and reduced structural states samples can be characterised in order to determine any differences in structure. The shear rheology of particulate suspensions is a strong function of the solids concentration, and as a consequence the flow properties should be examined at various concentrations to identify any differences between the samples. Firstly the four samples were tested in terms of their yield stress behaviour in the initial state.

Figure 2 illustrates the yield stress concentration behaviour of the four red mud samples. The results were conducted in the initial structural state and are typical of many mineral suspensions, the yield stress increasing exponentially with increasing concentration. The results in Figure 2 illustrate that, of the four samples, the US sample demonstrates the most favourable flow properties. That is, the US sample exhibits the lowest yield stress for a given concentration. The Surinam sample exhibits a slightly higher yield stress, particularly at higher concentrations. Finally the Australian sample displays a higher yield stress and the Jamaican sample exhibits the highest yield stress for a given concentration.

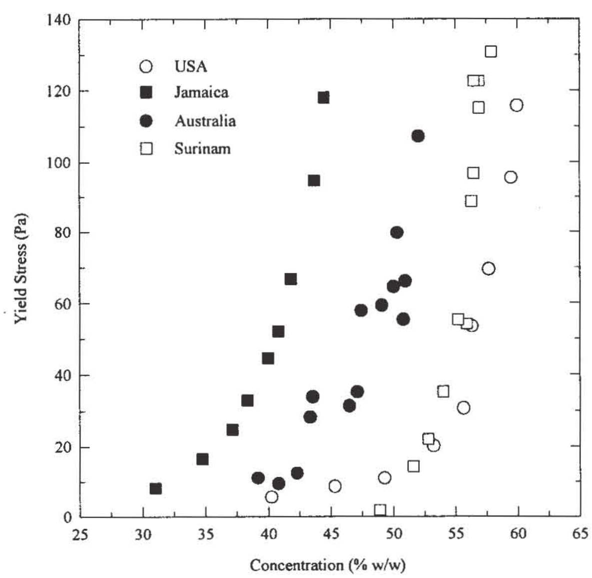

Figure 2: Yield stress as a function of concentration for various red mud samples.

Based on experience of semi-dry or thickened disposal to be implemented a yield stress in the order of 100 Pa is suitable, which represents a concentration of 42, 50,55 and 58% w/w for the Jamaican, Australian, Surinam and US samples respectively. At a yield stress of 100 Pa the material has enough structure to form a beaching angle such that central or peripheral discharge can be implemented, yet the value is not large enough to cause the material to form a steep slope such that the material is deposited only around the discharge point.

Another consideration in determining the feasibility of a concentrated disposal strategy is that the material can be practically and economically transported. Figure 3 illustrates the pumping energy requirements for the four samples. Pressure drop requirements have been calculated using shear stress-shear rate data at various concentrations. For laminar flow conditions the shear stress is a unique function of shear rate and hence pressure drop can be directly calculated for a given shear rate. For turbulent flow conditions the method proposed by Dodge and Metzner[10] has been adopted to predict the pressure drop. The calculations have been based on a constant flowrate of 150 kg/s (dry weight) and a pipeline diameter of 0.4m.

Figure 3 demonstrates that for each of the samples there exists a minimum in the energy requirement for pumping. The minimum occurs at 30, 44, 48 and 51 % w/w for the Jamaican, Australian, Surinam and US samples respectively. The minimum represents the optimum processing concentration when considering pumping energy requirements. At lower concentrations than the minimum, the flow regime is turbulent and the pressure drop increase arises due to the large volume of material that needs to be transported, the majority of which is water. At higher concentrations than the minimum the flow regime is laminar and the increase in the pressure drop is due to the viscous nature of the material. In addition to the energy requirements for pumping consideration should be given to the corresponding yield stress if concentrated waste disposal is to be implemented. Interestingly the optimum concentration for pumping is generally in the range where the material begins to exhibit a rapidly increasing yield stress with concentration.

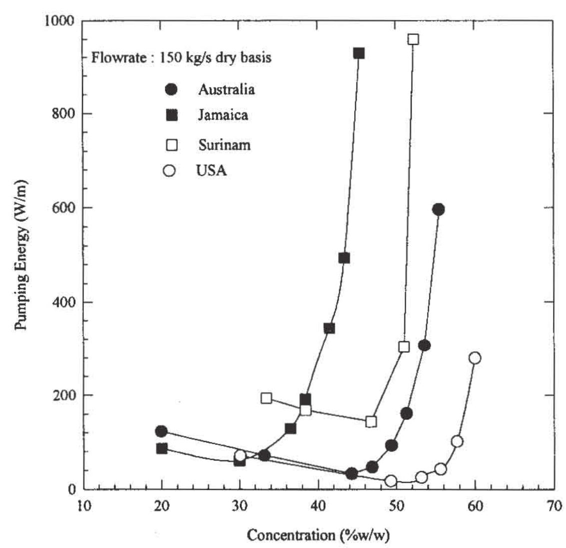

Figure 3: Pumping Energy requirement as a function of concentration for various red mud samples.

The observed differences in the samples can be largely attributed to three effects: the flocculation history experienced by the sample during processing, the shear history of the samples experienced before they arrive for analysis, and the different particle size distributions. Primarily the Surinam and US samples have larger particles while the Jamaican samples have a distinctly smaller particle size. These effects can however be negated to some extent. Firstly the effects of flocculation and shear history can be removed by shearing the samples to equilibrium, this has the effect of breaking the floc structure and reduces the sample to a time independent state as mentioned previously. Secondly the effect of the larger particle size of the US and Surinam sample can be removed by sieving the sample through a 150 μm sieve.

Figure 4 shows the results of six different red mud samples. Three samples are shown from Australia, namely Kwinana, Pinjarra and Wagerup. All samples have firstly been sheared to equilibrium and then sieved through a 150 μm mesh and the coarse fraction discarded. Viscosity profiles were then determined at a constant solids concentration of 48% w/w. Figure 4 shows the viscosity as a function of shear rate for the five samples in the reduced structural state after screening.

Interestingly, the three samples from Western Australia all collapse onto the one curve as does the data for the US, while the Surinam samples exhibits a slightly higher viscosity, particularly at higher shear rates. The results indicate that the materials are very similar in nature once the effects of thixotropy and particle size have been removed. This realisation has important processing implications as the muds, on a fundamental basis are all alike, the only difference being imposed by processing. These effects may include different flocculants and different flocculation history, and different grinding methods resulting in a different particle size distribution, which may also relate to the nature of the original ore body.

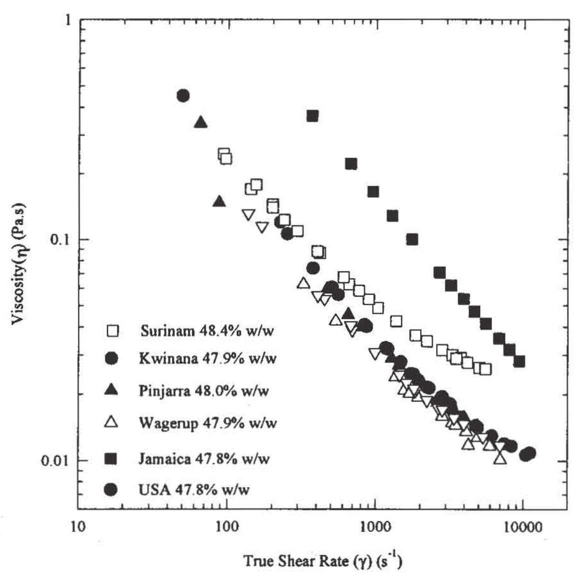

Figure 4: Viscosity - true shear rate behaviour of various red mud samples once they have been sheared to equilibrium and sieved.

From the results presented it is clear that red mud samples can be characterised in two structural states, the initial or as received state and an equilibrium or time independent state. Data can be collected confidently and reproducible provided an understanding of the time dependent nature of the material is made. Furthermore these properties can be exploited when implementing a concentrated disposal strategy. Four red mud sample obtained from around the world have been characterised in these two states. A comparison of these muds has shown that after the coarse particle fraction has been removed the US, Surinam and three samples from Western Australia all show the same rheological characteristics in the reduced structural state.

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