Methods of Measurement and Improvement of Rheological Properties of Bauxite Residue

Lawrence J. Andermann Jr.
SUEZ – Water Technologies & Solutions
Feasterville-Trevose, PA, USA
Corresponding author: lawrence.andermann@suez.com

Abstract

The concentration and transportation of bauxite residue and bauxite slurry are two common challenges alumina refineries face today. Alumina refineries are seeing lower available alumina and increased gangue-minerals that make handling of bauxite residue more difficult. Difficulties in handling of bauxite residue can lead to a shorting of an alumina plant's working life due to the filling of bauxite residue waste lakes, or there can be difficulty in filtration of bauxite residue at the end of a counter current deceanting circuit. While synthetic polymers are necessary to achieve faster liquid-solid separation rates, polymers can impart negative rheological characteristics to slurries of bauxite residue or bauxite slurry. This paper will discuss the increasing rheological properties caused in part or total by the mineralogical components within bauxite residue, operational philosophies, unit-operation's design and equipment, and the addition of chemical additives. In addition, this paper will cover methodologies for measurements of rheological properties of bauxite residue and bauxite slurry.

Keywords: Rheology, Alumina, Bauxite Residue, Yield Stress, Slurry

1. Introduction

In alumina refineries and other mining processes, challenges exist in the dewatering and transport of slurries. Substrate characteristics and solution salt concentrations, as well as other factors, such as chemical treatment, affect liquid-solid separations and subsequent pumping of aqueous dispersions also known as mining slurries. Also, alumina refineries are processing bauxite (ore) that contain a higher content of gangue minerals that require higher polymer dosages. Polymers are necessary to achieve fast rates of liquid solid separation and maintain suitably high plant flows for economic viability, but these polymers impart negative rheological characteristics to the concentrated aqueous dispersions (bauxite residue in the Bayer process) that make transport and washing more difficult. Aqueous dispersions that have lower threshold energy (yield stress) and uninhibited flow (lower viscosity) result in consistently faster flow rates through mining processes, including alumina refineries. New rheology modification technology; when combined with any number of synthetic polymers, has been successful in bench-top, pilot, plant trials, and commercialized sites, yielding improved rheological characteristics of concentrated aqueous dispersions. Benefits to the preparation plants include:

- Higher levels of throughput
- Improved efficiency and productivity
- Lower energy costs
- Consistency of unit operations
- Avoidance of additional CAPEX

In this article, the author will provide results from bench-top experiments to full plant trials to show the efficacy of the combination rheology modifier and a synthetic polymer to provide value in achieving the mill or plants operational objectives.

2. Background

Rheology modifiers effectively treat process slurries, tailings and concentrates. Other benefits over treatment with flocculant alone, include increased settling rate, less scaling, and improved filtrate clarity.

Trials of the rheology modifiers focused on applications characterized by difficult to process aqueous dispersions due to ore quality, process material quality, nature of aqueous solution, under-designed unit operations. Multiple studies of aqueous dispersions have identified and characterized properties that have negative impacts on liquid-solid separation and transport. For example, Klein et al [1] outline factors that impact of the rheological properties of slurries;

- Solids concentration
- Particle morphology
- Particle size distribution
- pH
- Ionic strength of aqueous phase
- Chemical additive

Examples of unit operations that are affected by the aforementioned factors are:

- Pumping
- Transport
- Grinding
- Gravity concentration
- Flotation
- Mixing
- Leaching
- Thickening
- Tailings disposal

Chemical additives, such as flocculants, coagulants, and dispersants, create particle to particle aggregation, networks. Another study depicts an increase in slurry viscosity as these structures develop [2]. As with other authors, the author of this paper propose that the morphology of networks resulting from chemical treatment without the use of rheology modifiers can negatively affect the rheological properties of these aqueous dispersions [3]. Rheology is the study of deformation of flow and matter, which included both viscosity, yield stress, etc. Viscosity is the internal friction of a fluid that gives the tendency to resist flow; that is defined as the ratio of the shear stress to the shear rate. Since mining slurries are non-Newtonian fluids, flow does not begin until the slurry's yield stress is exceeded. Yield stress is the critical shear stress that must be exceeded before irreversible deformation and flow may occur. In measuring yield stress, it is important that the yield stress be measured at the same point in the compaction regime. That is, measurements of yield stress should be taken at or near terminal compaction (point closest to maximum compaction attainable due to repulsive forces of polymer and other repulsive forces). Otherwise, there would be a variation in the results obtained in the rheological measurements; that is, workers have shown that with a variation of time, the magnitude of the rheological measurement changes. Yield stress is conveniently determined by a vane technique. The authors utilized the yield measurement to characterize treated and untreated slurry's rheological properties very similar to that used by Liddell and Boger for their work with yield stress measurements in concentrated suspensions [4,5]. Typically, rheologist test a combination of rheology modifiers with a range of synthetic flocculants, whereby the right flocculant and rheology modifier were chosen for a particular substrate that results in a network morphology that is conducive for flow, compaction, and sedimentation. The studies contained in this paper relied on empirical data obtained on the bench-top laboratory testing, pilot trials, and full-scale plant trials with the metrics of pumping rate, rake torque, underflow concentrations, etc., to show that the rheology modifier reduces rheological properties in mining slurries. In the case of the Bayer Process, washing efficacy is implied due to the increase solids concentration.

3. Method for Rheological Measurement

Many Rheologist in mining utilize vane rheometry for measurement of yield stress. Boger et al have used pioneered vane rheometry to investigate how process conditions and mineralology affects the rheology properties of Bingham Plastic Slurries of mining processes (Figure 1) [5].

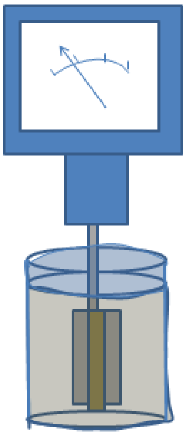

Figure 1. Rheometer using vane for measurement of a dynamic yield stress.

Most of the error associated with measurement of rheological properties such as yield stress revolve around measuring a slurr while the slurry has not reached terminal compaction (Figure 2). That is, at “terminal compaction” in solid-liquid sedimentation tests, the measurement of volume versus time will show a zero slope after time final (t_f). If measurements of rheological properties are taken before the slurry approaches terminal compaction, the researcher will obtain statistically problematic data.

Slurries within alumina refineries change with time and decrease of temperature; and degree of settling. To avoid this conditions that would skew the data, red-mud slurries are allowed to achieve atomosheric conditions and approach terminal compation before the rheological properties are measured.

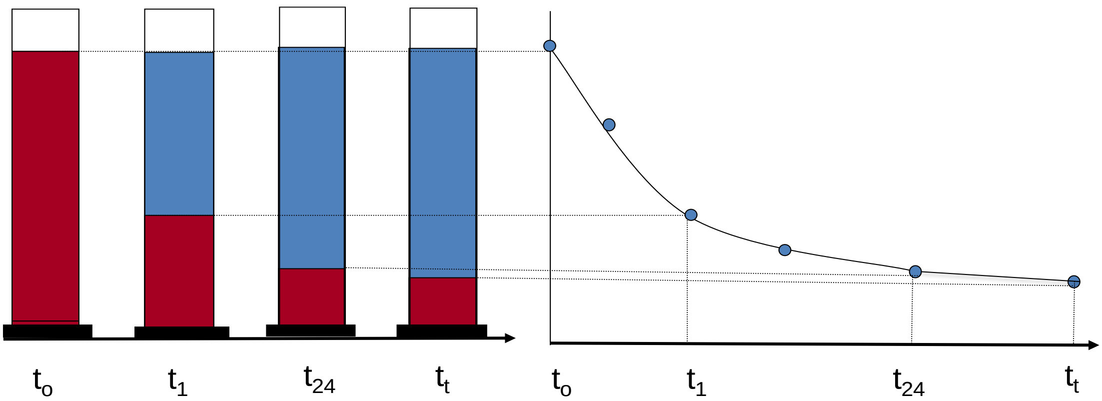

Figure 2. Achieving terminal compaction before measuring rheological properties.

After solid-liquid separation testing, slurries are transferred to rheometry cups to allow the slurry to approach terminal compaction before testing ensues. In as much, a researcher could observe the effect of speciality chemicals such as flocculants, viscosity modifiers, and rheology modifiers on the solid-liquid separation and rheological key performance indicators such as settling rate, compaction, turbidity, and yield stress.

Dynamic yield stress utilizes low revelations per minute (rpms) with a variation of angular velocity ranging from 0.01 rpm to 0.350 rpms. Each of the angular velocities will be held for a given time interval until. The dynamic yield stress utilizes both the elastic and plastic rheological data points taken from a graph that depics shear stress versus shear rat where the slope of the line is the yield stress. Most rhelogist utilze the Casson Model for yield stress measurements of Bingham Pastic Slurries emunating from mining and mineral processes.

4. Case Histories

Rheology modifiers have been used in combination with synthetic polymers in several mining processes such as alumina, phosphate, mineral sands, gold, copper, and coal preparation plants for tailings, concentrates, and ores. Bench-top laboratory trials, pilot plant trials, and full-scale plant trials with the rheology modifier series have demonstrated a reduction in yield stress between 12.5 – 57.8%, as illustrated in Table 1.

Table 1. Rheology modification performance of the combination of rheology modifiers and synthetic polymers compared to the use of synthetic polymers alone

Mining Segment	Type of Slurry	Feed Solids %(W/W)	Final Solids %(W/W)	Flocculant Only Yield Stress, N/m^2	Flocculant and Rheology Modifier Yield Stress,N/m^2	Percent Reduction (%)
Coal	Tailings	3.9	25	30.8	21.0	31.82
Gold	Concentrate	16.5	53	255.0	223.0	12.55
Phosphate	Ore	13	62	62.1	26.2	57.81
Alumina	Bauxite Residue	4	36	310.0	195.0	37.10
Mineral Sands	Tailings	3	25	9.2	7.8	15.23

4.1 Laboratory Trial

For the tailings of coal process plants, rheology modifiers were used in combination with typical copolymers of polyacrylate/polyacrylamide flocculants. Yield stress of underflow solids was used as the metric for determining the amount of reduction in rheological properties of slurries that were treated with the rheology modifier plus synthetic flocculant as well as slurries treated with only synthetic flocculant. Previous studies conducted have shown an experimental relationship between yield stress and underflow solids concentration after treatment with a synthetic polymer which correlates to other studies that are found in literature. To maintain flow rates or increase solids, coal preparation plants will often increase the synthetic polymer dosage, resulting in higher rheological properties such as yield stress. The authors replicated this approach to achieve higher coal tailings concentrations; however, the results were unfavorable in terms of the magnitude of the resulting yield stress due to the increase in underflow solids. In these laboratory trials, 4%(W/W) feed solids were used at a slightly alkaline pH of 8. The tailings were dosed between 10 – 40 grams per ton on a dry solids basis. An increase in Dosage resulted in an increase in compaction (Figure 3). With an increase in compaction, the resulting yield stress also increased in a classical exponential relationship between yield stress and compaction (Figure 4). Other studies have shown similar exponential relationships between yield stress and percent solids [6,7]. For a polymer dosage of 15 grams per ton synthetic polymer, increasing the rheology modifier dosage to the synthetic polymer dosage decreased yield stress (Figure 5). With the synthetic polymer and rheology modifier at about 60% ratio, there was about a 30 percent decrease in yield stress. When flocculant was used alone at higher flocculant dosages, the experimental data has shown a six-fold increase yield stress as opposed to a decrease in yield stress when the combination of the rheology modifier and synthetic polymer were used as a two-product solution.

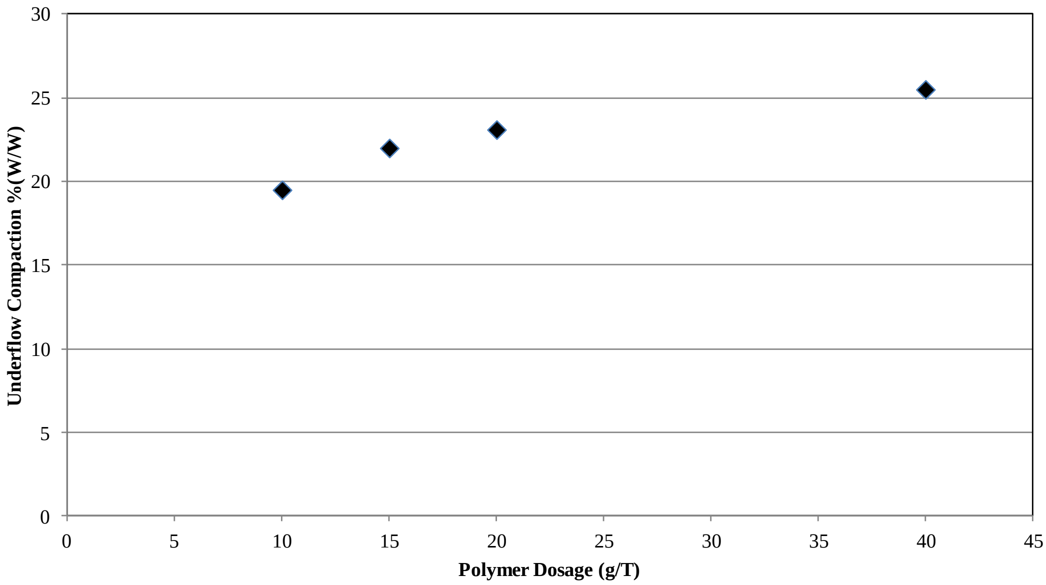

Figure 3. Coal tailings treated at 4%wt feed solids with increasing amounts of synthetic polymer – compaction versus polymer dosage

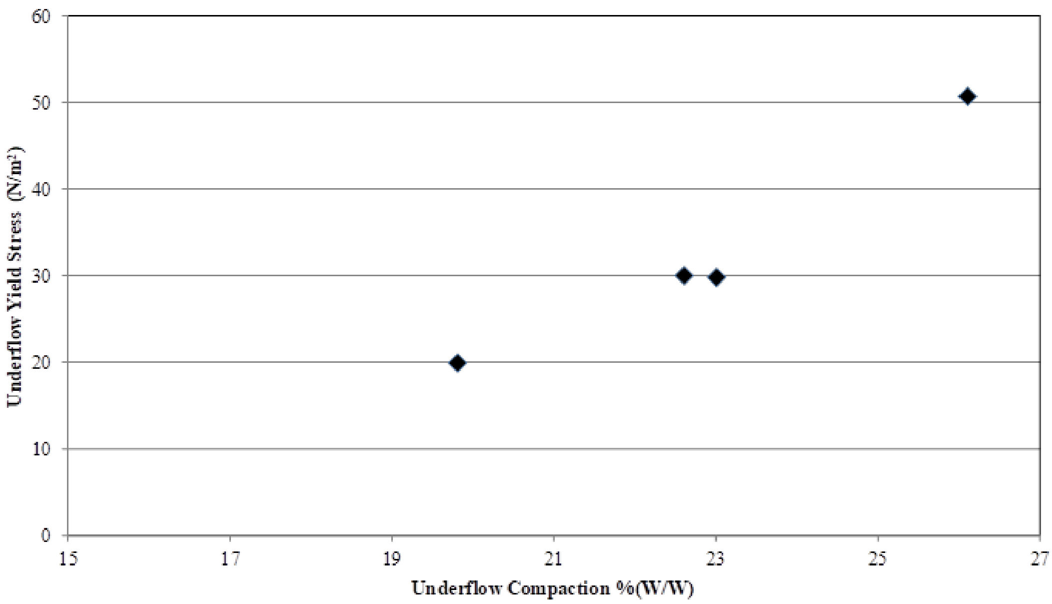

Figure 4. Coal tailings treated at 4%wt feed solids with increasing amounts of synthetic polymer – yield stress versus underflow compaction

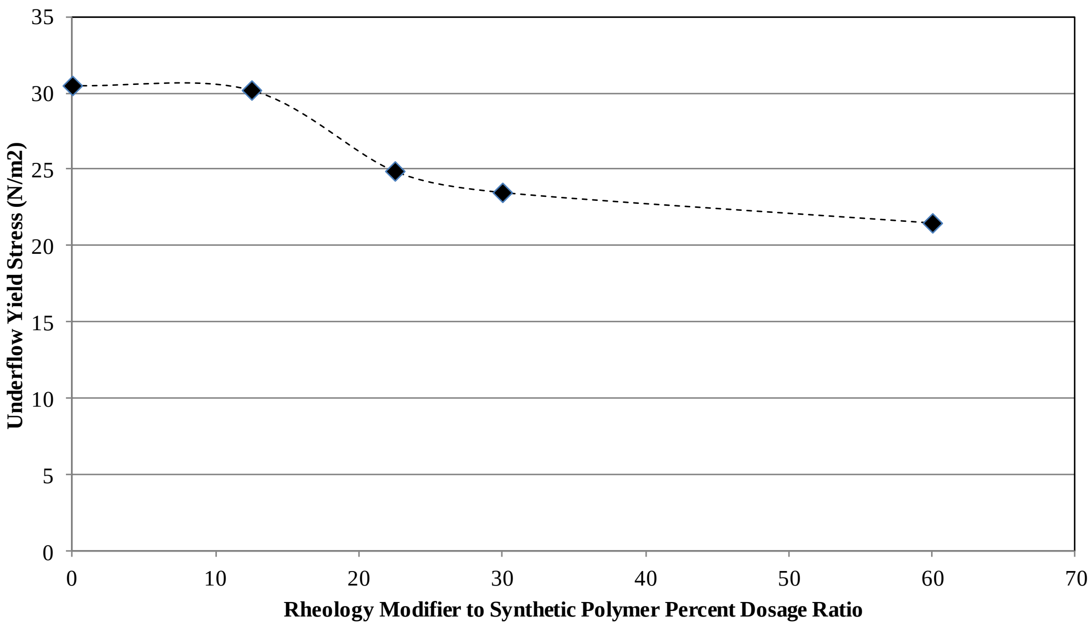

Figure 5. Coal tailings treated at 4%wt feed solids with same synthetic polymer dosage and increasing amount of rheology modifier– yield stress versus ratio of rheology modifier dosage to synthetic polymer dosage in percent format

4.2 Plant Application of Rheology Modifiers (Plant No.1 - Jamaican bauxite residue)

In alumina refineries, residues are termed "bauxte residue" and refineries often have difficulty compacting the bauxte residue due to mineralogy and prevailing process conditions. Throughput in the alumina refinery's counter current decanter circuit (CCDC) can be negatively affected by the degradation of the ore. This degradation makes it more difficult to achieve the desired solid concentrations in the bauxte residue lakes, thus increasing the footprint of the lakes to achieve the same dewatering rate. For example, Jamaican bauxite contains high amounts of goethite as well as other minerals that affect the liquid solid separation. It has been shown that a slight increase in volume fraction of goethite that there was an increase in yield stress. Mineralogy plays an important role not only in the separation efficiency but also in the resulting rheological properties of the slurries. Plant trial data show the effect of treating bauxite residue with rheology modifier on the rake torque of a high rate thickener versus using synthetic flocculant alone. With treatment using a rheology modifier and synthetic polymer combination, the refinery experienced a 24% increase in solids with almost a 50% reduction in rake torque. Moreover, with the application of a rheology modifier and synthetic polymer combination, bauxte residue drying time did not increase. Furthermore, at lower bauxite residue concentrations, the bauxite residue lakess will fill-up at faster rates thereby causing the alumina refinery to rasie the bauxite residue lake levee with additional lifts. Once a certain height is achieved on the bauxite residue lake's levee is achieved, then new levees must be constructed. The additional lifts or new construction can be expesive costing into the tens of millions of dollars.In addition, difficult to settle bauxite residue may not have good solid-liquid separation characteristics which most times have implications on filtration at the end of an alumina refinery's counter current decantation circuit, and this may affect the ability of the alumina refinery to efficently handle and dry-stack the bauxite residue.

4.3 Plant Application of Rheology Modifiers (Plant No.2 - Jamaican bauxite residue)

A plant trial that saw up to 50% of a bauxite reserve of Jamaican bauxite saw large rheometer demonstrated the efficacy in increasing underflow solids were increasing with a decreasing rake torque (Figure 6). Historically, the alumina refinery could only process up to 15 percent of this difficult to process bauxite before the underflow would not be able to be pumped as well as overloading the rakes in the clarification circuit of the Bayer Process. The initial solids were on the level of magnitude of about 200 grams per liter without the use of a rheology modifier, and the level of magnitude of underflow solids was as high on a consistent basis of about 350 grams per liter; this change in magnitude of the underflow solids represents about percent change greater than 60 percent.

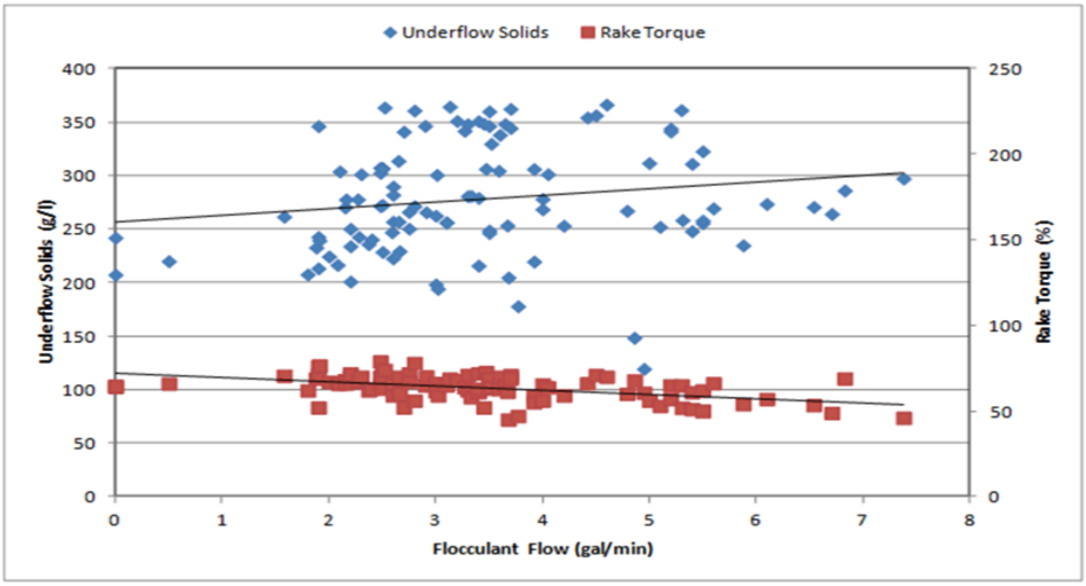

Figure 6. Alumina refinery plant trial with residue from Jamaican bauxite (high goethite concentration); underflow solids/rake torque versus flocculant flow aka dosage

With lower rheological properties of the treated bauxite residue, it would be thought that the bauxte residue would not have a slump. However, the treated material has a controlled flow with a slope that has not historically been seen for this type of ore reserve (Figure 7). The left picture was taken at the beginning of the trial, and the picture on the right was taken with the system came to equilibrium at the higher underflow solids.

Figure 7. Alumina refinery plant trial with Jamaican bauxite residue that encompassed utilization of a bauxite with a high goethite concentration; slump of untreated bauxite residue (left) and treated bauxite residue (right)

5. Summary

Return on investment calculations were part of each investigation by the authors to demonstrate the value of using the new rheology modifier technology. Return on investment due to use of the rheology modifier for alumina refineries, preparation plants, mills, or refineries were estimated in some cases to be greater than $20 million per annum due to energy savings, reduced maintenance costs, washing efficiencies, scale prevention, life span of tailings repositories, optimized chemical spend, and increased production. The return on investment also benefited from reduced capital expenditure by eliminating the additional thickeners, bauxite residue lakes, and pumping equipment. Capex in some of the case studies were as high as $100 Million.

6. References

1. B. Klein and M. Pawlik, "Rheology modifiers for mineral suspensions", *SME Annual Meeting,* 2004, pgs 1-7.
2. D. J. Hallbom, "Pipe flow of homogenous slurry", *Ph.D. Dissertation, University of British Columbia,* 2008.
3. S. J. Adkins and D. T. Smith, "Rheology Aids for effective mud disposal", *Light Metals* 2002.
4. P. V. Liddell and D. V. Boger, "Yield stress measurements with the vane", *J. Non-Newtonian Fluid Mech*., Vol. 63, 1996, pgs 235-261.
5. Q. D. Nguyen and D. V. Boger, "Yield stress measurements for concentrated suspensions", Journal of Rheology, Vol. 27, 1983, pgs 321-349.
6. D. Spitizer and Qi Dai, "Effect of Flocculant Molecular Weight on Rheology", *Light Metals 1996*, pgs 11-15.
7. H. Heller and R. Keren, "Anionic polyacrylamide polymers effect on rheological behavior of sodium montmorillonite suspensions", *Soil SCI SOC AM J, Vol 66, January-February 2002,* pgs 19-25.