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INFLUENCE OF SOLIDS CONCENTRATION, PARTICLE SIZE DISTRIBUTION, pH AND TEMPERATURE ON YIELD STRESS OF BAUXITE PULP

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Abstract

In Northern Brazil, bauxite pulp is transported through pipelines to the plant where alumina is produced. In slurry transportation through pipelines, knowing the yield stress value is essential for the pumps and pipeline design. Yield stress is the minimum shear stress and corresponds to the first evidence of flow. This rheological property is influenced by factors, such as: particle form, temperature, particle size distribution and interaction among the particles. Within the context above, the objective of this work is to verify the influence of solids concentration, particle size distribution produced by different grinding time, temperature and pH on the yield stress of bauxite pulp. It was verified that the yield stress of bauxite slurry increases as solids concentration and grinding time go up and decreases with temperature and pH.

Introduction

Brazil is a country with large territory and its mining activity usually takes place far from the production or consumption centers. Ore transportation by rail or road is expensive and lacks adequate infrastructure, which makes its transportation in the form of pulps through pipelines an attractive alternative.

The first bauxite slurry pipeline in the world is located in the North of Brazil and it aims at transporting the aluminum ore from the processing plant, located in Paragominas (PA), to the alumina production plant in the municipality of Barcarema (PA) through a 244 km long pipeline [1]. The mine and the pipeline are located in the State of Para, Brazil, as shown in Figure 1.

In slurry transportation through pipelines, it is important to get information on yield stress in order to carry out the pumps and pipeline project. Furthermore, high values of yield stress can retard solid particles from gravity settling for long periods of time [2].

Yield stress is the minimum value of shear stress and is the first evidence of flow, i.e., the value of shear stress when the velocity gradient tends to zero [3,4].

Yield stress is related to the internal structure of the suspension. For this structure to begin to flow it is necessary to overcome the minimum shear stress necessary to break the interparticle contact and the unions of aggregates or floccules. This structure is formed by particles whose electric charges are of opposite signs. The interparticle force of attraction of this structure is of the van der Waals type. The variables which influence yield stress are: solids concentration, particles size, shape, pH and the nature of the materials [5].

Thus, the purpose of this work is to study the effect of solids concentration, particle size distribution produced by different grinding time, pH and temperature on the yield stress of bauxite pulp.

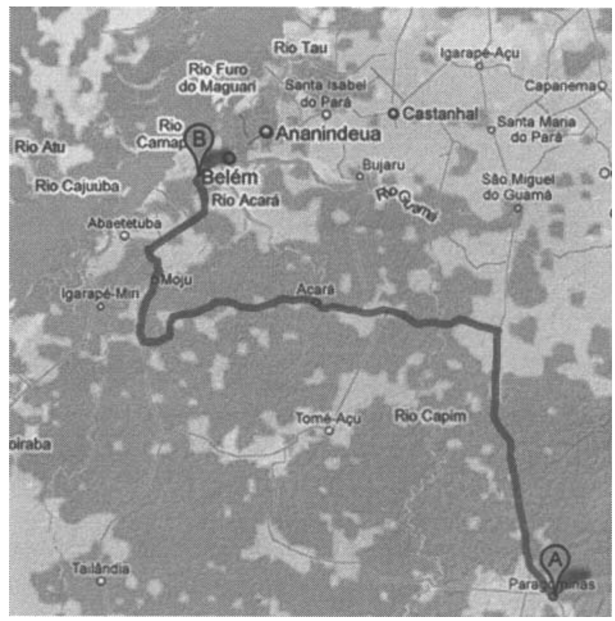

Figure 1. Map of Brazil and pipeline showing location of Mine and alumina plant.

Materials and Methods

The bauxite used in this work comes from North of Brazil and it is basically composed of the minerals gibbsite and kaolinite. The dressing process followed the methodology described by [6] and the steps consisted of crushing and grinding.

The particles size distributions studied were based on industrial conditions in pipeline transportation of bauxite located in Pará State, in which the particle size distribution is 6% plus 0.208 mm and 40-47% minus 0.043 mm [1]. The particle size distribution of the bauxite sample ground for 30, 35 and 40 min in a rod mill was determined through wet screening with the use of a set of Tyler sieves with openings from 1.2 to 0.037 mm.

The zeta potential was determined in a DT 1200 equipment manufactured by *Dispersion Technology*. The suspensions were prepared with 10% bauxite and 0.01 M KCl. The zeta potential measurements were carried out in a pH range of 2.0 to 12.5. The pH was adjusted with diluted solutions of KOH and HCl

In order to study the influence of solids concentration, particles size distribution produced by different grinding times, temperature and pH on the yield stress of bauxite slurry, a matrix of experiments 2^{4-1} around mean values was performed (Table 1). The solids concentration studied was 50 and 60% (w/w), the grinding time of bauxite was 30 and 40 min, the pH studied was 7 and 12 and the temperature was 25 and 45°C.

Table 1. Experimental conditions following matrix experiments 2^{4-1} around mean values.

Run	T (°C)	GT (min)	SC (% w/w)	pH
1	25	30	50	7
2	45	30	60	7
3	45	40	50	7
4	25	40	60	7
5	45	30	50	12
6	25	30	60	12
7	25	40	50	12
8	45	40	60	12
9	35	35	55	9.5
10	35	35	55	9.5
11	35	35	55	9.5
T- Temperature; GT- Grinding Time; SC- Solids Concentration				

Measurements of yield stress were obtained from an ARES rheometer, manufactured by *TA instruments*. A geometry Vane was used. The tests were performed at 1 rpm for 200 s. Torque values were converted to shear stress by means of Equations 1 and 2. Yield stress is the maximum shear stress obtained at low speeds.

$$\tau_y = T_m / K \qquad (1)$$

$$K = \frac{\pi D_v^3}{2}\left(\frac{H}{D_v} + \frac{1}{3}\right) \qquad (2)$$

T_m – measured torque

Dv – vane diameter

τ_y = shear stress

H= vane height

Equation 03 was used to adjust the yield stress values of the bauxite pulps, having as its variables: temperature, grinding time of bauxite, solids concentration and pH.

$$Y = a_0 + \sum_{i}^{4} a_i X_i + \sum_{i<j}^{4} a_{ij} X_i X_j \qquad (03)$$

With Y as the dependent variable (yield stress), X_i the independent variables (temperature, grinding time of bauxite, solids concentration, and pH) and a_i and a_{ij} as the parameters.

Results and Discussion

Figure 2 illustrates the size distribution of bauxite ground for 30, 35 and 40 min, obtained through wet screening with a set of Tyler sieves with openings from 1.2 to 0.037 mm. It was verified that the bauxite ground for 30 min presented a size distribution similar to that of the bauxite transported in the pipeline located in the North of Brazil. The bauxite ground for 40 min had a higher amount of fine particles (<0.037 mm) than the bauxite ground for 30 and 35 min, at approximately 13 and 6%, respectively.

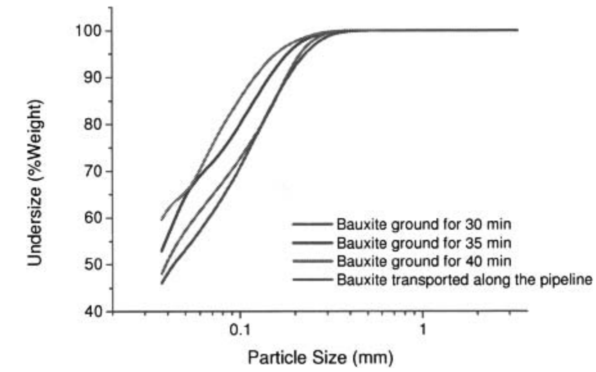

Figure 2. Size distribution of bauxite ground for 30, 35 and 40 min obtained through wet screening.

The zeta potential is useful to evaluate the electrical double-layer repulsive forces among particles in suspensions, as charge density and the potential of the particles depend on pH and ionic strength. Figure 3 illustrates the zeta potential of bauxite in relation to pH. It can be observed that the point of zero charge occurs at pH ≅ 10.5. At this pH the degree of particle flocculation is maximum. In the pH range between 7 and 11, the zeta potential is small. It is expected that in this range particle flocculation is high because the density of charge on the particles surface is small, which results in high attraction due to van der Waals forces. At pH 12 the zeta potential is higher, which means that the density of charge on the particles surface is large and the repulsive forces among particles are greater than the attraction forces of van der Waals and, consequently, the degree of flocculation is lower.

A suspension will be stable when the repulsive forces dominate while the presence of strong attractive forces will cause particle aggregation. Thus, the suspensions prepared at pH 12 are more stable than the suspensions prepared at pH 7 and 9.5.

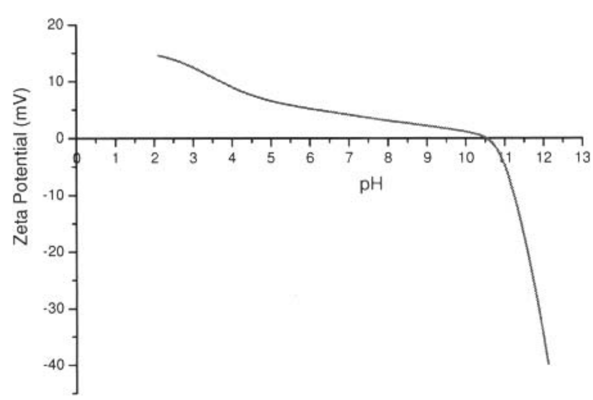

Figure 3. Zeta potential of bauxite particles.

The model parameters for yield stress used normalized independent variables [+1,-1] so that the values of the parameter could be associated with the variable effect. Estimates for model parameters were obtained with standard linear regression procedures [7]. Standard statistical tests of significance (t-test of student) were used to allow the evaluation of parameter significance. Whenever parameter significance was smaller than 5%, the parameter and respective effect would be removed from Equation 3. Regression results obtained for the yield stress determination are shown in Table 2.

Table 2. Values for model parameters (Equation 03).

Parameters	
a_o	**1.964 ± 0.064**
a_{SC}	**1.232 ± 0.082**
A_{GT}	**0.752 ± 0.082**
a_{pH}	-0.038 ± 0.082
a_T	0.073 ±0.082
a_{SC*GT}	**0.448 ±0.082**
a_{SC*pH}	0.188 ±0.082
a_{SC*T}	-0.023 ±0.082
R^2	0.946
SC-Solids Concentration; GT - Grinding Time and T-Temperature ** Significant effects in bold	

It is possible to observe from the correlation coefficient (Table 2) and the model fitting (Figure 4) that the model gave a good fit to the experimental parameters. The value of R^2 is larger than a confidence interval of 95% indicating a very good fit.

The model relating the yield stress (τ_0) and the statically signification preparation variable is:

$$\tau_o = 1.964 + 1.232 * SC + 0.752 * GT - 0.448 * SC * GT \qquad (04)$$

It may be concluded, by observing the parameters values in Table 2, that the yield stress depends mainly on solids concentration and the grinding time of bauxite and these variables show a direct relationship to yield stress. The remaining variables, pH and temperature, are not statistically significant. This means that the effects of temperature and pH are negligible compared to the yield stress measurement error.

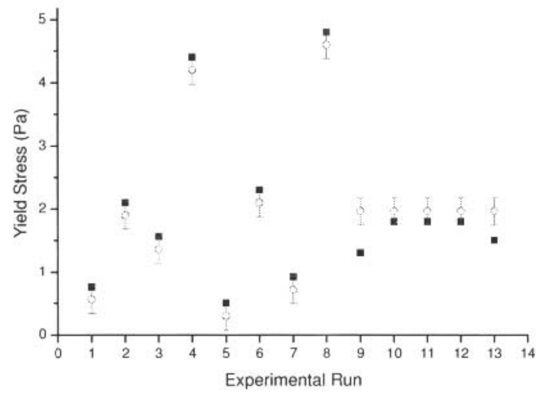

Figure 4. Comparison between (■) observed and (O) predicted yield stress.

Figure 5 illustrates the values of yield stress from the bauxite slurry obtained under different conditions of solids concentration, grinding time, temperature and pH. It was verified that the experimental conditions that favored a higher value of yield stress of the bauxite pulp was 60% (w/w) solids, bauxite ground for 40 min, 25°C and pH 7.

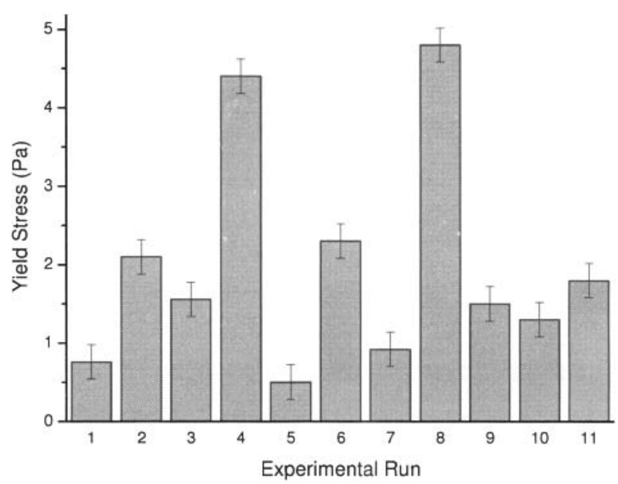

Figure 5. Values of yield stress of bauxite pulp obtained under different conditions of solids concentration, grinding time, temperature and pH.

It can be stated that yield stress increases when solids concentration and grinding time of bauxite increase and when temperature and pH decrease. This behavior can be explained by the following:

1. The increase of solids concentration results from the decrease of the water layer between particles, so the inter-particle distance is smaller in a denser slurry which produces an increased attractive potential and a larger probability of collisions among particles, resulting in more particles attracting one another and a high close-packing of particles [8,9,10].

2. The increase of bauxite grinding time allows a bigger production of fine particles (< 0.037 mm) which accentuates the strong particle-particle interaction due to the van der Waals forces of attraction, forming flocs or aggregates of low packing density and the formation of chain or networks of particles (Figure 6) that reduces the fluidity of the suspension. For the suspension to flow, it is necessary to apply a greater force to break the packing particles network, such as that shown in Figure 7. In this Figure the state of the network of very voluminous particles packing is similar to a "sponge".

3. When the pH is between 7 and 11, the zeta potential is low which means a high charge surface density and strong *van der Waals* attraction forces among the particles and the formation of flocs. At pH 12, the zeta potential is higher and the yield stress is low because the net attractive force decreases due to the increase of the surface charge density. When this repulsive force exceeds the van der Waals attraction at a pH far from the IEP, dispersed suspensions are usually generated (Figure 7).

4. The yield stress increases as temperature decreases because the viscosity of dispersant phase (water) increases.

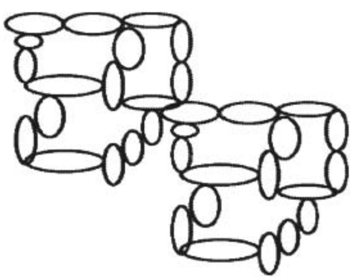

Figure 6. Configuration of maximum packing fraction, particles forming networks of particle-particle contact (flocs or aggregates) due to the *van der Waals* forces of attraction.

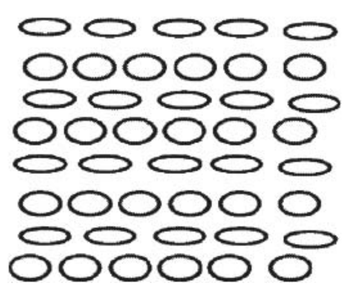

Figure 7.Configuration of minimum packing fraction; disperse particles due to repulsive forces.

Conclusion

A bauxite slurry prepared at pH 12 is more stable than that prepared at pH 7 because the bauxite particles have a higher surface charge at pH 12. Thus, the repulsive forces between particles are higher at this pH.

The parameter that has the greatest effect on the yield stress of the bauxite pulp is solids concentration, followed by grinding time, pH and temperature.

The yield stress of the bauxite slurry increases with increase of solids concentration, grinding time of the bauxite and with decreasing temperature and pH.

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