 doi:10.20944/preprints201707.0036.v1

MODELING OF THE SPECIFIC BREAKAGE RATE BASED ON THE VISCOSITY FOR WET GRINDING

A. M. Osorio[1], O. Bustamante[2], G. Restrepo[1], G. Gonzalez[3] and J. M. Menéndez-Aguado[3]

1 Universidad de Antioquia; Calle 70 # 52-21, Medellín, Colombia,

2 CIMEX, Universidad Nacional de Colombia, Colombia.

3 Escuela Politécnica de Mieres, Universidad de Oviedo, España.

ABSTRACT

A rheological modifier was used to prepare solutions with viscosities of 1, 4, 6 and 8 cp, which exhibited Newtonian behavior. These solutions were later used to prepare suspensions of monosize quartz (53, 45 and 38 microns) at 60 % in solids. Monosize grinding tests in a laboratory ball mill were performed to determine breakage parameters, with different ball diameters. A model was developed to determine the specific rate of breakage in terms of the system rheology. With this model, it was demonstrated that an increase in suspending fluid viscosity until 6 cp, leads to an increased fracture rate and consequently affects the grinding degree. The above test is considered as an alternative for improving and optimizing such operations with excellent quality products with low energy and steel consumption, thereby minimizing environmental impact.

Keywords: grinding, rheology, breakage parameters, relative viscosity.

INTRODUCCIÓN

The importance of comminution operations in the Mineral Processing industry has bolstered in the last decades the search for a greater knowledge and the availability of better models (Zhang, 2016; Liang et al., 2016; Petrakis & Komnitsas, 2017) to get a better phenomenological processes description.

The rheological behavior of mineral slurries shows the level of interaction or aggregation among particles, and it is here that its importance as a variable in control processes such as slurry transportation, dehydration, and wet grinding stems from. [Muster and Prestidge, 1995]. Ball grinding is one the most used industrial comminution solutions [Klimpel, 1982;

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Ding *et al*, 2007], and it is a process that depends on different conditions such as mill dimension, the rotation speed, the filling degree, the size of the balls, and the feed and product size distribution.

The solids concentration and the viscosity of the slurry are parameters that have gained importance in recent years when trying to determine the operation conditions [Hiroto *et al*, 2004]. It seems proved that the slurry physic-chemical properties can be modified in wet grinding due to changes in physical and chemical conditions (such as size distribution, concentration of solids, temperature, shear rate, pH value, the use of grinding aids, etc.).

The main goal of this study was to set a model by means of dimensional analysis in order to determine the behavior of the specific breakage speed (S_j) for a ball grinding process in terms of the rheology of the system. In addition to this, it could be established a linear adjustment for the relationship between wet and dry specific breakage rates S_{jh}/S_{js}, based on the reduced viscosity, μ_r. Furthermore, within the validity interval of viscosity, it will be studied if an increment of viscosity can increase the specific breakage rate, and consequently the grinding degree.

METHODOLOGY

Equipment.

A Marcy scale was used so as to determine the specific gravity and prepare the suspensions, ASTM standard sieves to prepare the samples and determine the particle sizes, a Brookfield viscometer with accessories to determine the viscosity, a laboratory ball mill 0.16 m in diameter and 0.18 m long, and grinding charge made of manganese steel alloy, with different ball diameter: 2, 3 and 4 cm.

Grinding tests.

To carry out the grinding laboratory tests it was performed a monosize test with quartz slurries. Quartz monosizes were 53, 45 and 38 microns, and slurries with different viscosity fluids were prepared (1, 4, 6 y 8 centipoises). In addition, a series of independent grinding tests were carried out at each grinding time (0.5, 1, 3, 5 y 10 minutes). Each test was repeated for each ball size diameter.

The grinding parameters that were fixed during the tests are shown in Table 1:

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Table 1. Grinding operation conditions

Sample	quartz
Solids concentration, ϕ (%w/v)	60
Mill lentgh, L (m)	0.18
Mill diameter, D (m)	0.16
L/D ratio	1.16
Fraction of critical speed, ϕ_C	0.75
Ball filling fraction, J	0.3
Hole fraction, U	1.0
Normal porosity of bed	0.4

Model Development

Buckingham's Pi theorem was used to determine the final model [Langhaar, 1951; Curtis et al., 1982; Pobedrya and Georgievskii, 2006]. In addition, it was proposed a relationship for the wet specific breakage rate, S_{jh}, in terms of the variables that it is expected to have more influence on its behavior:

- viscosity of the suspending fluid, μ_l
- viscosity of the suspension, μ_s
- particle diameter, d_p
- dry specific breakage rate, S_{js}
- density of the grinding media, ρ_b.

RESULTS AND DISCUSSION

Table 2 shows the specific breakage rates found for the different grinding tests, in the case of 2 cm ball diameter. The correlation coefficients show that the results of the tests follow a first order law. These values are similar to those mentioned by Tangsathitkulchai [2003, 2004], who found values of specific breakage rate for quartz grinding between 0.21 and 0.24 min^{-1}

Table 2. Specific breakage rates for the different tests.

Ball diameter (cm)		2		3		4	
Monosize (μm)	Suspension fluid viscosity (cp)	Sj (min^{-1})	R^2	Sj (min^{-1})	R^2	Sj (min^{-1})	R^2
53	1	0.112	0.9793	0.152	0.9771	0.205	0.9826
53	4	0.215	0.9843	0.171	0.9455	0.155	0.9612
53	6	0.220	0.9739	0.175	0.9892	0.252	0.9890
53	8	0.198	0.9860	0.213	0.9796	0.271	0.9809
45	1	0.108	0.9532	0.153	0.9640	0.044	0.9820
45	4	0.141	0.9814	0.151	0.9834	0.092	0.9869
45	6	0.178	0.9619	0.158	0.9620	0.177	0.9871
45	8	0.087	0.9567	0.165	0.9829	0.199	0.9896
38	1	0.057	0.9638	0.107	0.9797	0.030	0.921
38	4	0.113	0.9824	0.130	0.9891	0.077	0.9706
38	6	0.161	0.9885	0.155	0.9870	0.100	0.9780
38	8	0.044	0.9820	0.163	0.9723	0.053	0.9891

According to the analysis following Buckingham's Pi theorem, the next Π groups were determined:

$$\Pi_1 = \frac{S_{jh}}{S_{js}} \quad (1)$$

$$\Pi_2 = \frac{\mu_s}{\rho_b S_{js} d_p^2} \quad (2)$$

$$\Pi_3 = \frac{\mu_l}{\rho_b S_{js} d_p^2} \quad (2)$$

Being dimensionless parameters, the following relationship can be considered:

$$\frac{\Pi_2}{\Pi_3} = \frac{\mu_s}{\mu_l} = \mu_r \quad (4)$$

where μ_r is the reduced viscosity.

According to the expressions above, when plotting Π_1 versus Π_2/Π_3 (see Figure 1) we can study the behavior of wet specific grinding rate, S_{jh}, with the dry specific grinding rate, S_{js}, as a function of μ_r.

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Figures 1-3 show the behavior of the abovementioned relationship for the systems studied.

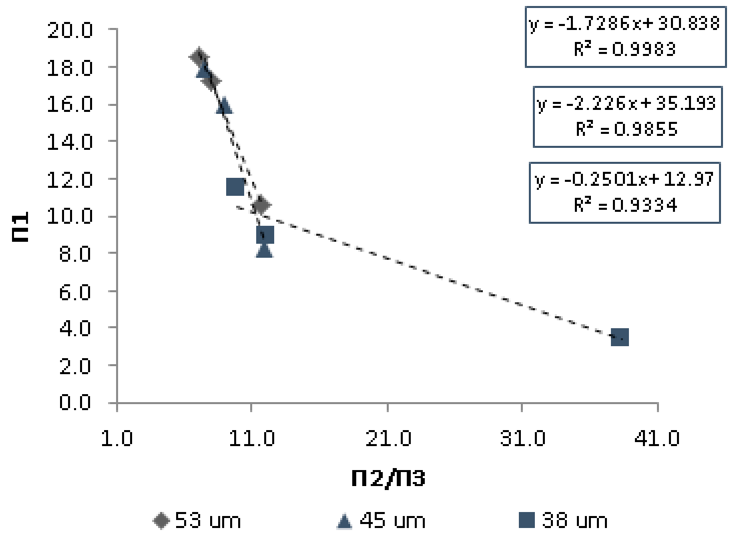

Figure 1. Fitting to the developed model, ball size 2cm.

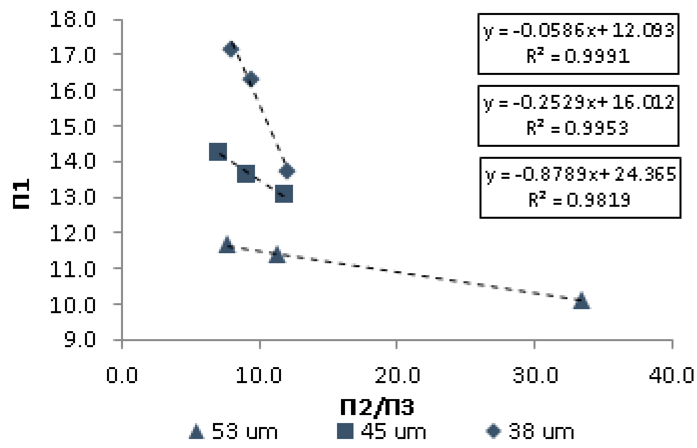

Figure 2. Fitting to the developed model, ball size 3cm.

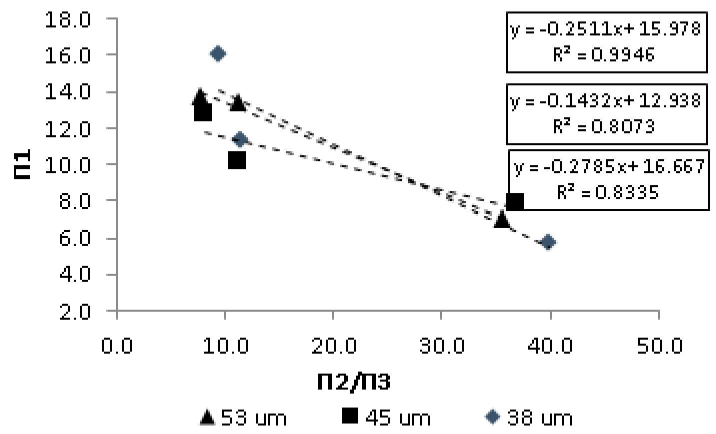

Figure 3. Fitting to the developed model, ball size 4cm.

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It can be observed that there is a reduced viscosity range for which the relationship between the specific fracture rates could be seen as linear. The coefficients of the models that represent each studied system and the suspending fluid viscosity range for which it is valid are shown in Table 3 below.

Table 3. Linear adjustment parameters for the relationship **S_{jh}/S_{js} as a function of μ_r**

Ball size (cm)	**Monosize (µm)**	**a**	**b**	**R^2**	**Range of linearity**
2	53	-0.2511	15.9780	0.9946	1-6 cp
	45	-0.1432	12.9380	0.8073	1-6 cp
	38	-0.2785	16.6670	0.8335	1-6 cp
3	53	-0.0586	12.0930	0.9991	1-6 cp
	45	-0.2529	16.0120	0.9953	4-8 cp
	38	-0.8789	24.3650	0.9819	4-8 cp
4	53	-1.7286	30.8380	0.9983	4-8 cp
	45	-2.2260	35.1930	0.9855	4-8 cp
	38	-0.2501	12.9700	0.9334	1-6 cp

In the light of these results, it has been proved that the viscosity of the suspension fluid influences the specific breakage speed. The explanation to this phenomenon can be found in that within a given range, an increase in the viscosity increases the chance of particle breakage as the mobility within the slurry decreases. Besides, when the viscosity is increased over a given range, the positive effect of the grinding of particle mobility is reduced due to the energetic dissipation in the movement of the balls, resulting in an inefficient fragmentation process. Thus, it could be thought that for certain grinding conditions there is a fluid viscosity that maximises the breakage speed. A deeper insight in this behaviour could be an interesting way to optimize the grinding process from the point of view of energetic efficiency.

CONCLUSIONS

As a result of the studies undertaken, the influence of the viscosity of the fluid is clear; that is the influence of the slurry over the specific breakage speed. For the test conditions, that relation could be established using the dimensional analysis by means of Pi-Buckingham's theorem for different grinding conditions. Further research should be carried out to check the

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existence of an optimal viscosity that maximises the breakage speed, and its relationship with the other operation parameters.

ACKNOLWLEDGEMENT

Authors thanks to COLCIENCIAS, the University of Antioquia (Colombia) and OPTIMORE H2020 project (Grant n. 642201) for financial support.

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