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Dry grinding kinetics of colemanite

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Abstract

The kinetics of batch dry grinding of colemanite from the feeds of sieve sizes −2.360+1.700, −1.700+1.180, −1.180+0.850, −0.850+0.600, −0.600+0.425 and −0.425+0.300 mm has been determined using a standard Bond mill. The specific rates of breakage (S_i) and primary breakage distribution ($B_{i,j}$) values, called grinding breakage parameters, were determined for those feed size fractions. It was determined that breakage of colemanite follows a first-order behavior for all feed sizes. The specific rates of breakage (S_i) values of colemanite increase with increasing feed size fractions. The specific rate of breakage parameters of colemanite were compared to quartz under the same experimental conditions and it was found that colemanite is broken faster than quartz in terms of the S_i and a_T values. Breakage function of colemanite was found to be non-normalizable (i.e. depended upon the feed particle size) similar to quartz ground under the same grinding conditions. In addition, colemanite produces finer material than quartz in terms of the γ value of $B_{i,j}$. It is also worth to mention here that to the authors' knowledge there are no publications about the grinding kinetics of colemanite.

Keywords: Ball mill; Breakage parameters; Grinding kinetics; Colemanite

1. Introduction

Boron compounds, of which Turkey has the largest reserves in the world with over 60% share, are very commonly used almost in all branches of industry in different ways. Huge portions of the Turkey's commercially recoverable boron reserves are colemanite, ulexite and tincal. Colemanite has a monoclinic crystal structure with a chemical formula of $2CaO \cdot 3B_3O_3 \cdot 5H_2O$ and the chief domestic source of borax and boric acid. It has many important uses such as in the production of glass, fibers, heat resistant materials, material processing, nuclear reactors, fire retardants, catalysis and detergents, etc. [1].

Size reduction of minerals by grinding is widely used in the preparation of raw materials for manufacturing above mentioned products. Grinding is an energy-intensive operation since some of the energy during grinding is converted to heat that is not utilized fully in grinding process. Thus, grinding is not very efficient operation and it needs to be taken cared of in detail.

Ball mill grinding has been used extensively in mineral processing and other industries for more than a century. However, the fundamental mechanism of grinding is not understood fully yet. The early comminution theories were based on the empirical relationships between the energy input and reduction ratios. Since these approaches underestimate the breakage kinetics and some other sub processes in ball milling, they caused some scale up problems in the industry. Therefore, in order to make the grinding more efficient, kinetics of breakage approach in the mills has been developed as applicable models [2].

The analysis of grinding in the ball mill uses the concepts of selection and cumulative breakage distribution functions. The selection function (specific rate of breakage) is defined as the fraction by weight of particles of given size i which are selected and broken per unit time of grinding. The value varies with size and denoted by S_i. The cumulative breakage distribution function, $B_{i,j}$, is defined as the fraction by weight of breakage products from size j which fall below size i, where $i \leq j$ [3].

The objective of this study is to analyze dry grinding kinetics of colemanite in terms of selection and breakage distribution functions values using a standard Bond mill. It is also worth to mention here that to the authors' knowledge there are no publications about the grinding kinetics of colemanite.

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2. Theoretical background

In the analysis of the materials breakage, it is useful to make the initial assumption that the breakage of each size fraction is first order in nature [4]. That is, the rate of disappearance of size 1 due to breakage is proportional to the amount of size 1 material in the mill hold up.

$$-\frac{\mathrm{d}[w_1(t)W]}{\mathrm{d}t}\propto w_1(t)W \tag{1}$$

Since the mill hold up, W, is constant, this becomes,

$$\frac{\mathrm{d}w_1(t)}{\mathrm{d}t}=-S_1w_1(t) \tag{2}$$

where S_1 is proportionality constant and it is called the specific rate of breakage, with units of time^{-1}. If S_1 does not vary with time,

$$w_1(t)=w_1(0)\exp(-S_1t) \tag{3}$$

that is,

$$\log[w_1(t)]=\log[w_1(0)]-\frac{S_1t}{2.3} \tag{4}$$

where $w_1(t)$ is the weight fraction of mill hold up that is of size 1 at time t. This equation denotes that $w_1(t)/w_1(0)$ vs. t should give a straight line on a log-linear co-ordinates and S can be determined from the slope of the line.

The formula proposed [2] for the variation of the specific rate of breakage S_i with particle size is,

$$S_i=a_T\left(\frac{x_i}{x_0}\right)^{\alpha}Q_i \tag{5}$$

where x_i is the upper limits of the size interval indexed by i, x_0 is 1 mm, a_T and α are model parameters that depend on the properties of the material and the grinding conditions. Q_i is a correction factor which is 1 for smaller sizes (normal breakage) and less than 1 (abnormal breakage) for particles too large to be nipped and fractured properly by the ball size in the mill. In abnormal breakage region, each size behaves as if it has some fraction of weak material and the remaining fraction of stronger material. Using a mean value for S_i in this region, values of Q_i are empirically described by

$$Q_i=\frac{1}{1+(x_i/\mu)^{\Lambda}},\qquad \Lambda\geq 0 \tag{6}$$

where μ is the particle size at which correction factor is 0.5 and Λ a positive number which an index of how rapidly the rates of breakage fall as size increases that is the higher the value of Λ, the more rapidly the values decrease.

The fragments produced by breakage mix back into the mill contents and, in turn, will be subjected to breakage action. The distribution of the fragments before the breakage occurs is called the primary daughter fragment distribution. The set of primary daughter fragments from breakage of size j can be represented by $b_{i,j}$, when material of size j breaks once, the weight fraction of broken products which appear in size i is the value $b_{i,j}$, where size i is smaller than size j. It is convenient to represent this information in the cumulative form,

$$B_{i,j}=\sum_{k=n}^{i}b_{k,j} \tag{7}$$

where $B_{i,j}$ is the sum fraction of material less than the upper size of size interval i resulting from the breakage of size j material. In non-cumulative form, $b_{i,j}=B_{i,j}-B_{i+1,j}$ [5]. Furthermore, $B_{i,j}$ can be estimated from a size analysis of the product from short-time grinding of starting mill charge predominantly in size j, by using the BII method [2,6],

$$B_{i,j}=\frac{\log[(1-P_i(0))/(1-P_i(t))]}{\log[(1-P_{j+1}(0))/(1-P_{j+1}(t))]},\qquad i>j \tag{8}$$

where j is the top size of the charge, $P_i(t)$ is the cumulative percentage undersize of the ith size interval at the short grinding time which gives no more than about 30% broken out of the top size interval.

3. Experimental

3.1. Materials

Colemanite concentrate sample was obtained from ETI Mine Emet Boron Works, Emet region of Kutahya, Turkey. −2.360+1.700, −1.700+1.180, −1.180+0.850, −0.850+0.600, −0.600+0.425 and −0.425+0.300 mm single-sized feed fractions of colemanite was prepared and used throughout the grinding tests.

The density of colemanite, measured by a pycnometer, was 2.05 g/cm^3, Mohr's hardness of colemanite, measured by a hardness pen, was 4 and the work index (Wi) of colemanite,

Table 1
Chemical composition of sample

Content	%
B_2O_3	46.85
CaO	21.04
Na_2O	0.07
SiO_2	3.77
As_2O_3	1.25
SrO	1.46
MgO	1.15
TiO_2	0.20
K_2O	0.18
SO_4	0.26
Fe_2O_3	0.28
Al_2O_3	0.85
LOI	21.78