GRINDING TIME FOR CONTROL OF THE SIZE FRACTION OF PRODUCTS IN THE ATTRITION MILLING

Jai Koo Park, Young Jeong, Jeong Il Yang and Moon Young Jung

Dept. of Resources and Environment Eng., CPRC, Hanyang Univ., Seoul, Korea
*KIGAM, Taejon, Korea
**Dept. of Mineral & Energy Resource Eng., Semyung Univ., Jaechon, Korea

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Abstract – Grinding tests for garnet were carried out by using an attrition mill under wet processes. Effects of feed filling ratios and a chemical agent (sodium hexametaphosphate, SHP) were investigated on the grinding time of the garnet. The progeny particles obtained were screened into various particle size intervals, which were 100 mesh over, 100/400 mesh and 400 mesh under. In order to estimate the mass fraction of the particles in a given particle size interval, mathematical models were derived from the first-order reaction model, then compared to experimental data. It was observed that variation of the feed filling ratio did not show a significant effect on the mass fraction of the product. The chemical agent was, however, effective so that the mass fraction could be controlled by adjusting the content of SHP.

Key words : Attrition Mill, Sodium Hexametaphosphate, Grinding Time, Mathematical Model, Feed Filling Ratio

INTRODUCTION

Many grinding process models have been suggested for estimation of the size distribution of products. The grinding process model was first based on the differential size-mass balance, then extended by applying matrix algebra, the concept of stages of breakage [Harris, 1966] and a continuous probability formulation [Kelsall et al., 1968; Berube et al., 1979]. Application of this concept to experimental data has been demonstrated successfully [Hwang and Lee, 1991; Kapur and Agrawal, 1970]. The mathematical models suggested in these demonstrations contained two main functions: the breakage function \( B \) and the selection function \( S \). These functions have been applied for estimating the grinding behavior of industrial milling processes with both wet and dry conditions. An attrition mill is a highly effective device for the rapid grinding of solid materials. This milling method was developed by U.S. Bureau of Mines in the early 1960s.

Garnet has been used as the grit of abrasive materials, rock cutters and sandpapers. Recently, garnet has been of great use as the abrasive material for manufacturing Braun tubes of televisions and monitors. Since the electric industry has grown, the demand for garnet as the abrasive material has increased. In Korea, though garnet is deposited in Chungchongdo as associated minerals in granite, the garnet material for domestic needs has depended entirely on imports because of the lack of refining and separation techniques. The particle size of the garnet grits ranges between 100 and 400 mesh. Therefore, three size intervals (100 mesh over, 100/400 mesh, 400 mesh under) were considered in order to control the mass fraction of 100/400 mesh. Experimental data were compared to simulated results obtained from the first-order equation. In this report, we have attempted to develop a grinding technique which makes the mass fraction of a given particle size controlled by a chemical grinding agent and a grinding process model giving an optimum grinding time. The effects of slurry densities and grinding agent contents were investigated in relation to the rate of grinding and the variation of the mass fraction at a given size interval.

BATCH GRINDING MODEL

1. Grinding Model of First-order Equation

A grinding model consists of selection functions leading to the probability of particles to be ground and breakage functions leading to the size distributions after instantaneous grinding. By a standard screening, a mixture of particles with various sizes can be separated into several size intervals, \( i, j, \ldots, n \). These variables take values between 1 for the mass fraction of particles retained on the coarsest screen 1, and \( n+1 \) for the fraction of particles passing through the finest screen \( n \). The breakage function \( B_{ij} \) is the probability of particles to distribute from a size interval \( j \) to \( i \) by grinding and is related to the cumulative mass fraction of each size interval. The selection function \( S_{ij} \) for a size interval \( j \), is the rate of breakage of that size \( (\text{min}^{-1}) \). The grinding functions \( S \) and \( B \) of a specific material depend on its physico-mechanical properties and experimental grinding conditions.

If \( m_i(t) \) represents the mass fraction of a size interval \( i \) at
a milling time of \( t \), the mass balance equation can be written as below.

\[
\frac{dm_i}{dt} = -K_i m_i(t) + \sum_{j=1}^{i-1} V_{ij} m_j(t) \quad (i>j)
\]  

Here \( K_i \) is the breakage rate constant of the size interval \( i \), \( V_{ij} \) is assigned to \( S_j B_j \), and \( m_i(t) \) is the mass fraction of the size interval \( i \) at the milling time of \( t \). With increasing the grinding time, initial particles at each size interval are ground and pass through a smaller size interval. At the milling time \( t \), a part of the particles ground reach the size interval \( i \). The fraction of the particles at the size interval \( i \) is, therefore, the sum of the fractions of particles produced from each upper size interval \( (<i) \). This grinding phenomenon will simultaneously occur in all size intervals. As a result, the mass fraction of the size interval \( i \) at \( t \) is obtained by subtracting the cumulative mass fraction of particles passing through the screen \( i+1 \) from the cumulative mass fraction of particles on the screen \( i \). Fig. 1(a) shows this material balance. When the number of the size intervals of interest is few, the grinding model can be simplified from the mass balance equations of each size interval, which can be derived from the conventional grinding equation such as Eq. (1).

Fig. 1(b) illustrates that particles at the interval 1 shift to the lower interval by grinding, that is the first-order grinding model having two size intervals. If the size intervals 1 and 2 are supposed to be one size interval in (c) with first-order grinding, the model (a) can be explained by two equations derived from (b) and (c) by the first-order concept. Eqs. (3), (5) and (6) describe the grinding behavior in the mill.

In Fig. 1, a change in the fraction of the size interval 1 can be represented by Eq. (2)

\[
\frac{dm_1}{dt} = -K_1 m_1(t)
\]  

Eq. (2) is derived from Eq. (1) by eliminating the \( \Sigma \) term for \( i=1 \) for the size interval 1, and the \( \Sigma \) term equals to zero. If \( K_i \) is constant at any grinding time, Eq. (2) is integrated to Eq. (3).

\[
m_i(t) = m_i(0) e^{-K_it}
\]  

In Eq. (3), \( m_i(t) \) expresses the mass fraction of the size interval \( i \) at the grinding time of \( t \). \( m_i(0) \) is the initial mass fraction of the size interval \( i \). \( K_i \) is the rate constant for the size interval \( i \).

If the initial size interval is expanded into a new size interval including the original size intervals 1 and 2, a change of the mass fraction of this new interval can be written by Eq. (4).

\[
m_i(t) + m_2(t) = (m_i(0) + m_2(0)) e^{-K'_{i+1}t}
\]  

Here \( K_{i+1} \) is the rate constant for the new interval. If total feed amounts in the mill have a unit that equals to \( m_1 + m_2 + m_3 \), the change of the mass fraction in the interval 3, \( m_3(t) \), is followed by Eq. (5).

\[
m_3(t) = 1 - (m_i(0) + m_2(0)) e^{-K'_{i+1}t}
\]  

From Eqs. (3) and (4), the change of the mass fraction in the interval 2, \( m_2(t) \), is represented by Eq. (6).

\[
m_2(t) = (m_i(0) + m_3(0)) e^{-K'_{i+1}t} - m_i(0) \cdot e^{-K'_{i+2}t}
\]  

2. Determination of Rate Constant

The rate of disappearance, by breakage, of material from a given size interval is given by Eqs. (3) and (5) where \( K_1 \) and \( K_{12} \) are the breakage rate constants for the given size interval. Milling rates for the garnet powder were determined from cumulative size distribution curves as shown in Fig. 2.