Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 34(2), ss. 113-120 Haziran 2019
Çukurova University Journal of the Faculty of Engineering and Architecture, 34(2), pp. 113-120, June 2019

Effect of Bimodal and Monosized Grinding Media on Dry Grinding of Barite

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Geliş tarihi: 11.04.2019   Kabul tarihi: 28.06.2019

Abstract

This study investigates the effects of the design of high-density zircon (ZrO_2) grinding media (1-3 mm) on dry grinding of barite ($BaSO_4$, d_{50}= 2.83 µm) in a vertical stirred media mill. Grinding experiments were carried out by using different proportions of finer grinding media (20 wt.%, 40 wt.% and 80 wt.%) and different size ratio of finer-coarser media (0.5 and 0.67). Besides, the surface areas (S_{bw}, m^2/kg) of grinding media on grinding performance were investigated. If the best two experimental results are compared, it is found that the S_{bw} of the bimodal and monosized media are very close together. The experimental results were evaluated based on the product particle size (d_{50}, d_{90}), and the geometric standard deviation of barite particles (d_{84}/d_{16}). The findings showed that the finer grinding media alone was not very effective.

Keywords: Vertical stirred media mill, Dry grinding, Media size, Barite

Baritin Kuru Öğütülmesinde Karışık ve Tek Tip Öğütücü Ortamın Etkisi

Öz

Bu çalışma dikey karıştırmalı bilyalı değirmende baritin ($BaSO_4$, d_{50}= 2,83 µm) kuru öğütülmesinde yüksek yoğunluğa sahip zirkon (ZrO_2) (1-3 mm) öğütme ortamı tasarımının etkisini araştırmaktadır. Farklı miktarda ince bilya (%20, %40 ve %80) ve farklı ince-iri bilya oranları (0,5 ve 0,67) kullanılarak mikron-altı öğütme gerçekleştirilmiştir. Ayrıca, öğütücü ortamın yüzey alanlarının (S_{bw}, m^2/kg) öğütme performansına etkisi araştırılmıştır. En iyi deney sonuçları karşılaştırıldığında, karışık bilya boyut dağılımının yüzey alanı ile tek tip bilya boyut dağılımının yüzey alanı birbirine çok yakındır. Deneysel sonuçlar ürün boyutu (d_{50}, d_{90}) ve barit tanelerinin geometrik standart sapması (d_{84}/d_{16}) dikkate alınarak değerlendirilmiştir. Sonuçlar, tek başına ince boyutlu öğütücü ortamın çok fazla etkili olmadığını gösteriyor.

Anahtar Kelimeler: Dikey karıştırmalı bilyalı değirmen, Kuru öğütme, Bilya boyutu, Barit

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1. INTRODUCTION

Grinding is one of the oldest production techniques ever used by humans and represents an extremely important area of research.

Nowadays, the importance of submicron particles and nanoparticles are increasing day by day. Barite is used as filler material in paint, paper, plastic and rubber, friction elements, glass and ceramics industries both as a cost reducing and functional filler. Due to the fact that it does not show chemical changes under heat and pressure, very low solubility in water and acids, with lack of magnetic properties, and cost-effective, the use in various industries has gradually increased. In the literature, there are many studies conducted and approved by the effect of the media size [1-8].

As stirrer speed increases, the possibility of media-particle collision increases in the main chamber. If the finer and coarser media are used in proper speeds, they are advantageous. When the finer media was used, the effects of media size and the product size distribution became finer [9]. This tendency continues up to a certain fine media size in proportion to the particle size. When the finer medias are used, the medias cannot catch the coarse particles. In addition, in the case of using finer medias, the reduction in the amount of energy released in collisions creates a negative effect on the breakage of coarse particles [9-12].

Mankosa et al. [9] indicated that as the finer media was used, the effects of media size and the product size distribution became finer, therefore less energy was utilized. Furthermore, Kwade et al. [2], Wang and Forssberg [13], Jankovic [14], and Mende et al. [15] also observed similar experimental results in their studies.

This experimental study investigated the performance of submicron grinding of barite by using bimodal and monosized grinding media. Grinding experiments were carried out on barite by using different proportions of grinding media sizes. The experiments were implemented by finer to coarser grinding media size ratio (0.5 and 0.67) and different amounts of finer grinding media (20 wt.%, 40 wt.% and 80 wt.%).

The grinding results were interpreted by three parameters as product particle size (d_{50}, d_{90}), and the geometric standard deviation of barite particles (d_{84}/d_{16}).

2. MATERIAL AND METHOD

2.1. Material

Barite ($BaSO_4$, d_{50}= 2.83 μm) powders that were obtained from Barit Maden Türk (Osmaniye, Turkey) were used for the experiments. The cumulative particle size distribution of feed barite is illustrated in Figure 1. Table 1 shows the chemical composition of the barite feed measured by X-ray fluorescence (XRF), while Table 2 shows the physical characteristics of the barite feed.

A pycnometer was used to determine the specific gravity of the barite powders and found it to be 4200 kg/m^3.

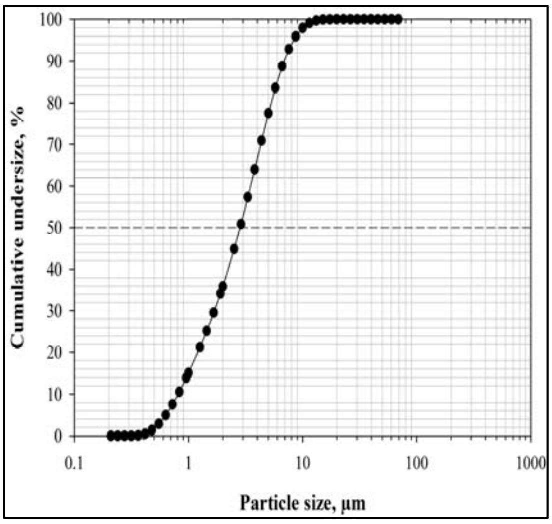


Figure 1. Cumulative particle size distribution of feed barite

Table 1. The chemical composition of the barite measured by XRF analysis (wt.%)

$BaSO_4$	$SrSO_4$	CaO	$CaSO_4$	SiO_2	Fe_2O_3	LOI (1050 C°)
91	1.75	0.50	0.75	2.50	0.45	3.05

Table 2. Physical characteristics of the barite feed

Specific Gravity (kg/m^3)	Mohs hardness	d_{16} (µm)	d_{50} (µm)	d_{84} (µm)	d_{90} (µm)
4200	3.0	1.08	2.83	6.2	7.14

2.2. Method

2.2.1. Vertical Stirred Media Mill

A vertical stirred media mill Standard-01 Model produced by Union Process type HD1 was used in grinding experiments (Figure 2). It contains a 750 ml grinding chamber was made of ceramic (Al_2O_3) for reducing the amount of wear on the mill from the materials.

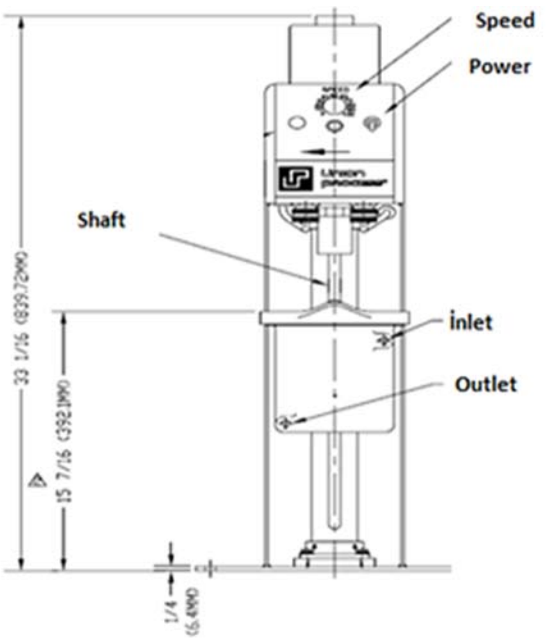


Figure 2. The schematic diagram of vertical stirred media mill

Furthermore the grinding chamber was also equipped with a water jacket for cooling purposes. The stirrer axis is fitted with colmonoy coated shaft and four colmonoy coated arms.

The high-density yttria stabilized zirconia (ZrO_2) grinding media that were utilized for the submicron grinding tests were purchased from Cenotec Co., Ltd., Korea. Table 3 shows some properties of grinding media.

Table 3. Properties of grinding media

Density (kg/m^3)	Bulk density (g/cm^3)	Hardness (Hv)	ZrO_2 (%)	Y_2O_3 (%)	Others (%)
6000	3.7	1200	93	5	2

2.2.2. The Grinding Conditions

The experimental conditions that were used in this study may be seen in Table 4. For example, B2 was carried out with a finer to coarser media size ratio of 0.67 by mixing 20 wt.% of finer (2 mm) grinding media into coarser media (3 mm). This study, considered the grinding media size of (3 mm) as coarser media, while grinding media of sizes 2 mm and 1 mm were considered as finer media. Different proportions of 20 wt.%, 40 wt.%, and 80 wt.% finer media were used.

The solid mass fraction, stirrer speed, dispersant concentration, grinding media loading and grinding time were fixed at 0.06, 600 rpm, 0.5 wt.%, 60% and 20 min, respectively.

Triethanolamine (TEA) was used as grinding additive. TEA has polar organic compound with amino, hydroxyl and other groups that has a strong adsorption. The density of this chemical is 1.126 g/cm^3. The chemical additive concentration was kept constant at 0.5% of barite.

Table 4. Experimental conditions used in the different runs

Run number	Grinding media size (mm)	Size ratio finer to coarser grinding media	Proportion of finer grinding media (wt.%)
B1	3	0	0
B2	3+2	0.67	20
B3	3+2	0.67	40
B4	3+2	0.67	80
B5	2	1	100
B6	2+1	0.5	20
B7	2+1	0.5	40
B8	2+1	0.5	80
B9	1	1	100

2.2.4. Calculations

The particle size distributions of the feed and the ground products were measured by laser diffraction using HELOS (H3387, Sympatec, Germany). Each test was repeated three times and the values reported are a mean average.

In this study, the geometric standard deviation of barite particles was calculated by the following equation:

$$\sigma=\sqrt{\frac{d_{84}}{d_{16}}} \tag{1}$$

Where d_{84} diameter for which 84% of the sample is finer than d_{84}, and d_{16} diameter for which 16% of the sample is finer than d_{16} [16].

Calculation of the surface area for monosized and bimodal grinding media were evaluated using Eq. 2. The surface area (m^2/kg) (S_{bw}) derived from Kotake et al. [17] is:

$$S_{bw}=\frac{6}{\rho}\sum_{i=1}^{n}\frac{f_i}{D_{bi}} \tag{2}$$

Where S_{bw} (m^2/kg) is the surface area for monosized and bimodal grinding media, D_{bi} is the media diameters, f_i is the mass fraction for each media diameter, and ρ (kg/m^3) is the true density of grinding media.

2.2.5. Analysis

The X-ray fluorescence (XRF) analysis of the feed was realized using a ZSXminill X-ray Spectrophotometer. A Zeiss Evo LS 10 microscope was used to obtain the SEM pictures of the barite feed and the best result.

PANalytical Empyrean was used to recover X-ray diffraction (XRD) patterns and examine the crystal buildup of the feed and best result. Patterns in the diffraction angle range of 2Θ= 5-70° were enrolled by using Ni-filtered CuKα (λ=0.15418 nm) radiation with a measuring time of 8 s at each angle.

3. RESULTS AND DISCUSSION

3.1. The Effects of Bimodal and Monosized Media on the Particle Size of Barite

In Figure 3, the d_{50}, d_{90} and the geometric standard deviation (d_{84}/d_{16}) of barite particles are shown as a function of bimodal and monosized media.

When grinding experiments were carried out with coarser media (3 mm), the product particle size (d_{50}, d_{90}) and the geometric standard deviation of barite particles (d_{84}/d_{16}) were obtained as about 2.05 µm, 5.17 µm and 2.12, respectively (B1).

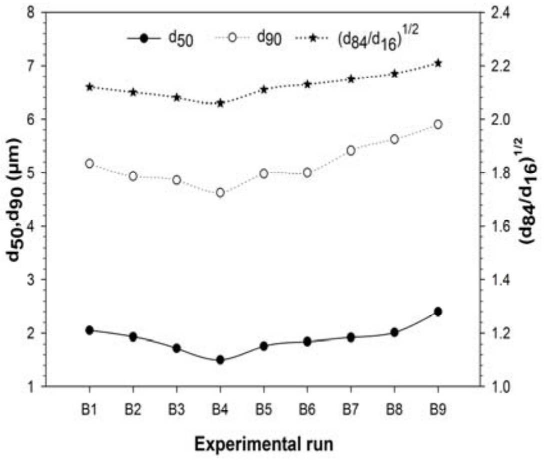
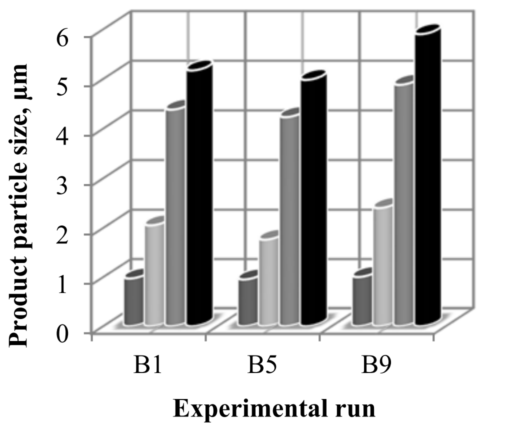


Figure 3. d_{50}, d_{90} and (d_{84}/d_{16}) as a function of bimodal and monosized media

When 20 wt.% of finer media of size (2 mm) was combined with 3 mm media, the product particle size (d_{50}, d_{90}) and the geometric standard deviation of barite particles (d_{84}/d_{16}) were obtained as about 1.93µm, 4.93 µm and 2.09, respectively (B2). When the coarser media were mixed with higher amounts of finer media, the observed results were improved (B3 and B4). This clearly showed that addition of finer media improved the grinding performance [3].

By adding higher ratios of finer (2 mm) media to coarser media (3 mm), further improvements were obtained the grinding results (B4). The product particle size (d_{50}, d_{90}) and the geometric standard deviation of barite particles (d_{84}/d_{16}) were obtained as about 1.5 µm, 4.62 µm and 2.06, respectively. The product particle size (d_{50}, d_{90}) and the geometric standard deviation of barite particles (d_{84}/d_{16}) were obtained nearly 1.76 µm, 4.98 µm and 2.11, respectively in B5. However, when 20-40-80 wt.% of finer media of size 1 mm was mixed 2 mm media, the product sizes increased (B6-7-8).

When grinding was carried out with only the finer media size of 1 mm, the mean particle size (d_{50}) was about 2.4 µm (B9).



	B1	B5	B9
d16	0.97	0.95	1
d50	2.05	1.76	2.4
d84	4.38	4.23	4.88
d90	5.17	4.98	5.9

Figure 4. Effect of monosized grinding media on product particle size of barite

Figure 4 shows the effects of monosized media (1, 2 and 3 mm), (B1, B5 and B9) on the particle size distribution. B5 provided the best product particle size.

3.2. SEM Analysis

Secondary electron images of the feed and the best result of barite obtained from the scanning electron microscope (SEM) are seen in Figure 5. The particle size irregularities of the barite before grinding are seen in the Figure 5a.

When 80 wt.% of finer media of size (2 mm) was combined with 3 mm media, the positive effect of grinding on particle size was evident (Figure 5b).

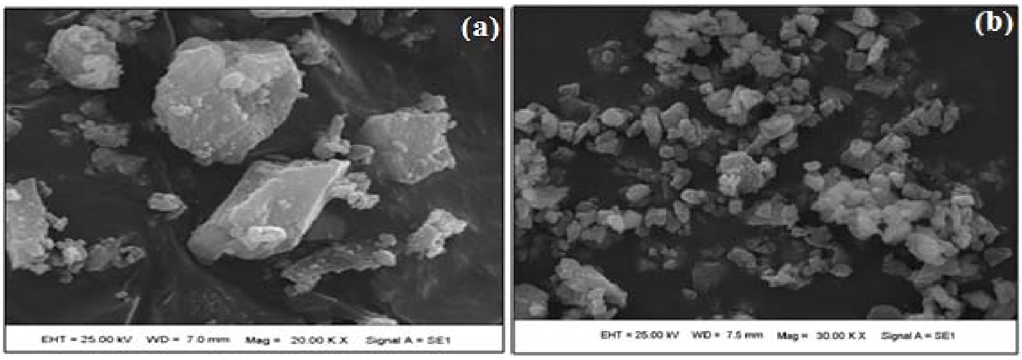


Figure 5. SEM images of barite: (a) feed and (b) the best result (B4)

3.3. XRD Analysis

The effects of grinding on structural properties of barite were researched by X-ray diffraction analaysis (Figure 6). The diffraction peaks of {h k l} values {101}, {111}, {021}, {210}, {121}, {211}, {002} and {311} demonstrated in the XRD patterns are characteristics of a typical orthorhombic structure of $BaSO_4$. As compared to the Joint Committee Powder Diffraction Standards (JCPDS), the main chemical component of the barite was $BaSO_4$. Reduction in diffracted peak intensity of the peaks was observed compared to the untreated sample that clearly indicates that amorphization has been effected during grinding. But, any change was not observed in the peak areas of ground sample.

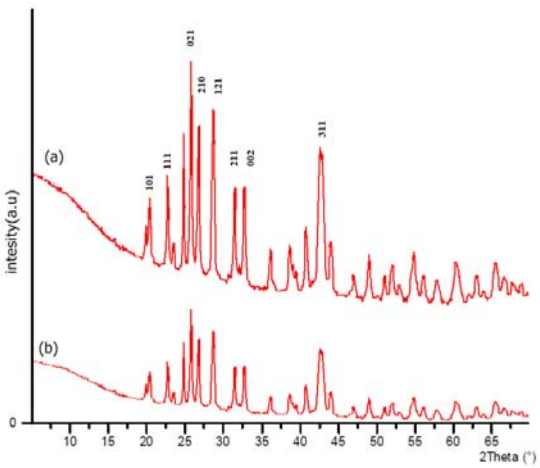


Figure 6. XRD patterns of barite: (a) feed; (b) the best result (B4)

3.4. The Effects of Surface Area of Grinding Media on the Particle Size of Barite

The most effective grinding in the media mill was achieved by an increased number of collisions between grinding media and particles. Figure 7 shows the experimental run versus surface area (S_{bw}). From the results, maksimum surface area (S_{bw}) was obtained with experimental run B9. But when 1 mm grinding media was used at 600 rpm, the effects on particle size were very little. If the best two experimental results are compared (B4 and B5), it is found that the S_{bw} of the bimodal media (B4) and monosized media (B5) are very close together.

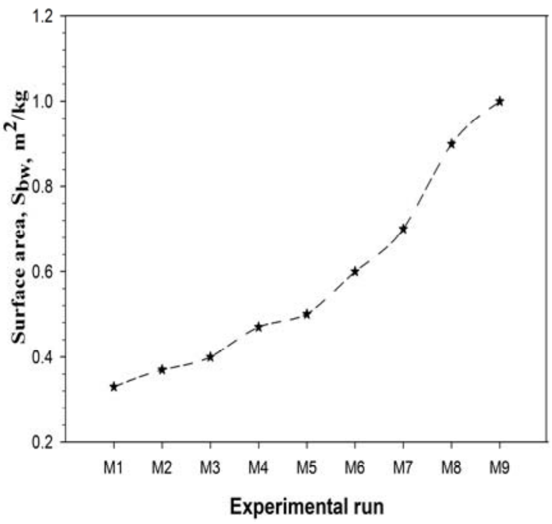


Figure 7. Surface area (S_{bw}) for monosized and bimodal grinding media

4. CONCLUSION

In this experimental study, the influence of monosized (1, 2 and 3 mm) and bimodal (1-3 mm) media size grinding design on dry grinding of barite were examined. The performance of different size ratio of finer-coarser media alone (0.5 and 0.67) were investigated. Experimental results show that the finer grinding media was not very effective. Much smaller product particles with finer grinding media can be obtained with a high stirrer speed. As seen from SEM images, the best result for the product particle sizes (d_{50}, d_{90}), and the geometric standard deviation of barite particles (d_{84}/d_{16}) were obtained with bimodal media 1.5 µm, 4.62 µm and 2.06, respectively (B4). If the best two experimental results are compared (B4 and B5), it is found that the S_{bw} of the bimodal media (B4) and monosized media (B5) are very close together. As an overview, proper selection of media size improves the grinding efficiency.

5. ACKNOWLEDGMENT

The author would like to thank Barit Maden Türk (Osmaniye, Turkey) for providing the sample.

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