Sandstone grinding in electromagnetic mill – case study

Anna Lis

1University of Agriculture in Krakow, Faculty of Production and Power Engineering, Institute of Agriculture Engineering and Informatics, Mickiewicza Av. 21, 30-120 Krakow, Poland

anna.lis@urk.edu.pl

Abstract. The article presents a comparison of the use of a ball mill and an electromagnetic mill for the grinding sandstones, taking into account the obtained grain fractions. The simplified principle of an electromagnetic mill operation has been described, as a relatively new device, which is increasingly gaining popularity. The same amount of feed was mixed with similar values of individual fractions in both devices. On the basis of the obtained results, the performance of both mills was compared and the effectiveness of using an electromagnetic mill was determined for further use.

1. Introduction

The milling process is currently used in many industries, from mineral processing to the chemical, cosmetic, construction and food industries. It is a very energy-consuming process, the aim of which is to bring raw materials to the appropriate grain size. Due to the widespread use of this process, solutions are still being sought to reduce energy consumption while increasing efficiency. The selection of the grinding device and its technical parameters determines the obtained degree of fragmentation, and the efficiency is strictly dependent on the type of feed [1-3]. In this industry, the most commonly used equipment for fine grinding operating through impact and abrasion are drum mills. In these devices, the rotating drum sets in motion balls or cylebs during the rotation hit the ground material due to the force of gravity causing its disintegration into smaller grains [4]. However, electromagnetic mills are becoming more and more popular. Currently, in many industries, attempts are being made to apply such a method of grinding [5]. In an electromagnetic mill, ferromagnetic grinding media are moved by a purposefully generated rotating electromagnetic field as a carrier of energy. The rotating magnetic field can be easily obtained using a three-phase power supply. It is also used in electric motors or electromagnetic stirrers. The basic elements of the mill are the exciter of the rotating magnetic field and the pipe constituting the working chamber located in its axis.

The advantage of grinding in an electromagnetic mill is the short grinding time and the possibility of conducting the process at low densities of the ground material [1, 6], and the effectiveness of the process depends on many factors related to both the construction of the installation and the nature of the material subjected to crushing and suitably selected process parameters, i.e.: the input grain size of the raw material, speed and intensity of the electromagnetic field, temperature, humidity as well as shape, size and material of grinding media [7]. However, the main determinant of a mill's performance is to obtain the smallest possible granulation in the shortest possible time [4]. So far, there have been
very few publications about electromagnetic mills, and in particular publications on the possibility of using such solutions on an industrial scale.

The purpose of this article is to present the possibilities of grinding sandstone in an electromagnetic mill, taking into account the obtained grain classes.

2. Material and methods
The sandstone powder was obtained as a by-product from an unused quarry located in southern Poland. Mineral composition of sandstone is presented in Table 1 and Figure 1. X-ray phase analysis classifies the test sample as sandstone with a dolomitic binder. Analysis of the grain size distribution of the sample showed a sand fraction at the level of 51%, a dust fraction of at the level of 23% and a clay (silt) fraction at the level of 26%. The samples used for grinding were pre-ground sandstone up to a diameter of 0.5 mm with a mass of 100g. Each experiment was repeated 10 times. Statistically significant differences between the results were evaluated on the basis of standard deviation determinations and on the analysis of variance method (ANOVA). Differences between averages were checked by the Duncan test. Significance was set at p = 0.05.

Table 1. Results of the quantitative XRD analysis [%] - Q - quartz; C - calcite; D - dolomite; Sy - siderite; Fl-K - feldspar; Pl - plagioclase; M - micas and illicit material; Ch - chlorite; Sil - sum of clay minerals

| Q  | Fl-K | Pl | C  | D  | Sy | M  | Ch  | Sum | Sil |
|----|------|----|----|----|----|----|------|------|-----|
| 40,3 | 6,5  | 8,1| 3,5| 15,5| 0,3| 20,5| 5,3  | 100,0| 25,8|

Figure 1. Results of the quantitative XRD analysis of blank probe

Based on a published work of fineness evaluation methods for different stone powder [8], the laser particle size method is suitable for the characterization of SP fineness. This work used a grinder (PM-100, Retsch, Germany) with the constant grinding time of 15 min and with the rotating speed of 650 rpm respectively to obtain the sand powder. The electromagnetic mill used for the comparative study was the author’s own construction based on published work. The working chamber had 75 mm in diameter and was made from austenite steel. The mill was supplied by current inductor I = 10 A. Steel grinding media with a total weight of 40g were used for grinding rocks in both devices.

3. Results and discussions
Figure 2 presents curves of the grain composition for the analyzed samples. To evaluate the effectiveness of the grinding process, substitute grain diameters were used.
Grain size investigations have shown the effectiveness of using an electromagnetic mill as a replacement for a ball mill. The grain analysis of the feed demonstrated no presence of grains with a diameter of less than 0.1 mm. The absence of clay fraction allowed determining the effectiveness of the grinding process. Grinding the feed in the ball mill eliminated the presence of the sand fraction and partly of the dust fraction. After finishing the grinding, a total of 21% by volume of clay fraction and over 50% of silty fraction were obtained. The grinding process carried out in the ball mill confirmed the results presented in the literature on the subject, which repeatedly indicate the need for a long time of grinding or returning unmilled fractions of the feed to the process. When using an electromagnetic mill, 71% clay fractions (so-called flours) were obtained, and grains with a diameter above 0.1 mm were completely reduced.

Statistical analysis of the obtained research results shows a direct, linear relationship between the analyzed variables, for \( p < 0.05 - 0.996 \). The analysis of the obtained correlation coefficient allows finding a comparable significance of the mesh size and fraction share. The coefficient for the correlation of these parameters is approx. 0.91 ÷ 0.93 relative to the grinder mass. The analyzed ratios demonstrate significance at \( p <0.05 \) for Duncan's test and significance at \( p <0.01 \) for ANOVA. Statistical tests have shown that the milling may affect the presence of fraction size.

4. Conclusions
The effectiveness of the grinding sandstones in a ball and electromagnetic mill was compared, using the same grain diameters and feed volume. The usefulness of an electromagnetic mill for grinding raw materials in order to obtain mineral flours was observed, obtaining 71% of the fraction with the grain size equal to or less than 0.25 μm. While for this size of grains in the ball mill, only 21% of them were obtained. Considering the smallest possible diameter of grains obtained during the grinding process, the electromagnetic mill turned out to be more effective.

Figure 2. Characteristics of the percentage share of the fraction depending on the grinding mill
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