Advanced Powder Technology 25 (2014) 1672–1678

Contents lists available at ScienceDirect

Advanced Powder Technology

journal homepage: www.elsevier.com/locate/apt

Original Research Paper

Investigation on pre-weakening and crushing of phosphate ore using high voltage electric pulses

Seyed Mohammad Razavian, Bahram Rezai *, Mehdi Irannajad

Department of Mining and Metallurgical Engineering, Amirkabir University of Technology, Tehran, Iran

ARTICLE INFO

Article history:
Received 19 October 2013
Received in revised form 12 April 2014
Accepted 10 June 2014
Available online 30 June 2014

Keywords:
High voltage electric pulse crusher
Comminution
Phosphate ore
Energy efficiency

ABSTRACT

Mechanical size reduction processes in the mineral processing industry are energy intensive. In this study, a novel High Voltage Electric Pulses Crusher (HVEPC) was designed and developed to pre-weaken and crush a phosphate ore. To compare the effectiveness of the new HVEPC in crushing with the conventional crushers, several rock samples of a phosphate ore were used and the effect of the capacitor, the voltage level and voltage rise time on the phosphate ore breakage was investigated. Comparing the particle size distribution of the crushed samples using both the HVEPC and the conventional crushers revealed the difference between their breakage mechanisms. The final results showed that applying the high voltage pulses at specific energy of 3–5 kWh/t could significantly increase and extend the cracks and microcrakcs inside the rocks and consequently lead to decline in the Bond crushability and Abrasion indices of the crushed samples by 10.6% and 28.1%, respectively.

1. Introduction

Comminution, particularly in finer sizes to achieve the required degree of liberation or specific surface, is a critical unit operation in terms of energy consumption and process optimization. Several research have shown that the specific energy consumption in comminution varies from a few kWh/t for crushing to 10–60 kWh/t for AG/SAG and ball milling, and over 100 kWh/t for ultra-fine grinding [1]. Sustainable development and use of new raw materials require new, better and more efficient processes. Accordingly, in the field of comminution, it is important to consider new methods based on lower energy consumption and higher degree of liberation. Studies have shown that conventional mechanical comminution methods are largely based on application of compressive force, resulting in high energy dissipation and slime production. It is known that developing the tensile force based methods could significantly decrease the slime production while reducing energy consumption. Therefore, several novel comminution methods such as High Pressure Grinding Roller (HPGR) [2], microwaves treatment [3,4], Electro Hydraulic Disintegration (EHD) [5] and Electrodynamic Disintegration (ED) [6] have recently been studied and presented.

In this study, one of the novel comminution methods based on particle disintegration using high voltage electric pulses was investigated. The history of research in this field is mainly related to the works done by Andres [7–10]. According to Andres [7], the idea of using electrical disintegration methods was firstly developed by Yutkin [11] in 1955 when he found that electrical current can crush the suspended particles during electrolyzing water. Andres et al. [9] investigated various minerals including oxide ores such as hematite, PGM, Cu-containing sulfides complexes and Pentlandite. The experimental results indicated that higher percentage of the liberated minerals and lower fine particles in electrical comminution exist in comparison with the case of mechanical comminution. Cabri et al. [12–22] at the Institute of CNT-MN in Canada have also investigated electrical and electrohydraulic disaggregation and especially the development of instruments in practical field of mineral processing. Lastra et al. [13] compared the liberation study of minerals in Merensky reef samples crushed by electrical and conventional crusher, and showed that the liberation of chromite, Pentlandite, pyrrhotite and PGM using electrical crusher was higher than that obtained by conventional jaw crusher. Ito et al. [23] found that electrical disintegration on samples containing coal represents a higher degree of liberation than mechanical grinding. However, there is limited information about energy consumption in electrical disintegration method.

The most comprehensive activity carried out on electrical comminution in the past four years with the aim of energy

* Corresponding author. Tel.: +98 2166460707; fax: +98 2166419728.
E-mail addresses: rezai@aut.ac.ir, b_rezai@hotmail.com (B. Rezai).

http://dx.doi.org/10.1016/j.apt.2014.06.010
0921-8831/

consumption optimization was in JKMRC (Julius Kruttschnitt Mineral Research Center) [1,24–26]. The activities of JKMRC have been conducted in two major areas using high voltage pulses: particle pre-weakening and mineral liberation which both focused on improving energy efficiency. These studies showed that the ores treated by high voltage electric pulses with low specific energy input (a few kWh/t) developed cracks and microcracks in the rock, and became weaker than untreated particles. Comparison of Bond work indices showed that the electrical treatment can reduce the energy consumption in downstream grinding processes by up to 24%. Moreover, research conducted in JKMRC showed that higher mineral liberation can be achieved in the electrical comminution [1]. In other words, lower consumption of energy in the electrical method can result in proper liberated minerals. Wang et al. [24] studied the factors affecting the electrical grinding for six ores. In this study, parameters such as feed particle size, undersize aperture, failure potential and energy input were considered. In addition, numerical simulations were used to show the distribution and intensity of the electric field around and within the particles. Accordingly, the electrical comminution is strongly dependent on the electrical characteristics of the ore. Dal Martello et al. [27] investigated the effect of the electrical comminution in reducing impurities in quartz ore to produce silicon for solar cells application. Comparing the magnetic separation efficiency of the samples produced by the mechanical and electrical methods showed a significant decrease in iron impurities content of the samples crushed using the electrical methods.

Dodbiba et al. [28] used both mechanical and electrical comminution for recovery of indium from LCD screens disposed of by leaching, and reported the results. They concluded that sample preparation using electrical comminution was more efficient and environmentally friendly than mechanical comminution.

In this paper, the effect of high voltage electrical pulses on phosphate ore comminution is presented. Phosphate ore was chosen because its comminution inherently produces a high level of slime which disrupts the downstream processes and reduces the quality of the final product. In this study, a high voltage electrical pulses unit was designed, developed and tested to investigate the effect of the instrumental parameters on failure and comminution of phosphate ore and compare the results with the mechanical comminution (crushing and grinding).

2. Materials and methods

2.1. Materials tested

The sample used in this study was obtained from the Esfordi phosphate mining complex located in Bafgh, Iran. About 400 tons of a representative sample from different zones of the mine were collected and crushed in the crushing plant. The samples were then further homogenized in the blending room and approximately 100 tons were sent to IMPRC for the laboratory and pilot scale tests.

The particle size distribution of this sample showed that 80% of particles were smaller than 9.6 mm, 25% were finer than 150 μm which is the acceptable size for the downstream process and 11.5% were finer than 38 μm.

Mineralogical studies were done on the thin-smooth polished sections prepared from the main sample and analyzed using a polarizing optical Zeiss Axioplan 2 microscope with light reflection and transmission. These studies showed that the major minerals present in the sample are apatite, hematite and quartz. Hematite is mostly inter-locked by contact and in some cases as 0.1–0.01 mm inclusions in other minerals. Apatite is interlocked with hematite, calcite and quartz mainly of double type and less frequently triple type which decreased with particle size. The result of the XRF analysis done on the sample using Fillips Magic_pro instrument is given in Table 1.

2.2. Crushability work index measurement

Particles of broken phosphate rock passing a 75 mm square gird and retained on a 50 mm square were mounted between two opposing equal 13.6 kg weight which swing on bicycle wheels. When the wheels were released the weights impact simultaneously on opposite sides of the measured smallest dimension of the rock. The height of fall was progressively increased until the rock broke. The work index was obtained from the average of at least ten breaks and is calculated as [29]:

$$W_i = 53.49\frac{ICS}{SG} \tag{1}$$

where *ICS* is the impact crushing strength in Joules per mm of rock thickness, *SG* is the specific gravity of the rock, and W_i is the work index in kWh/t.

2.3. Abrasion index measurement

The Bond Abrasion test determines the Abrasion index, which is used to determine steel media and liner wear in crushers, rod mills and ball mills [30]. The Abrasion index is determined from the weight loss of the standard alloy steel paddle hardened to 500 Brinell under standard operating conditions. 1.6 kg of ore sample in size class of (−19 + 12.5 mm) was used to perform the test. From plant data, empirical equations correcting with Abrasion index were developed to estimate rod, ball, mill liner and crusher liner wear rates. These equations are shown in Table 2 [31]. Abrasion index tests were carried out on both high voltage pulses and conventional crusher products to assess the pre-weakening effect on media and liners wear consumption rate.

2.4. High Voltage Electric Pulse Crusher (HVEPC)

The pulse generator as a standard electrical device which was capable of generating high voltage pulses and comparable with that of natural lightning came into the existence at the end of 19th century [32]. Nicolas Tesla used a coils resonant transformer circuit for the wireless transfer of electrical energy and created the electrical "super weapon". His coils circuit included a transformer, several high voltage capacitors, and a spark gap for generating high voltage pulses. Nevertheless, the contemporary pulse generators were developed in 1927 by Edwin Marx in the Braunschweig University in the form of a network of high voltage capacitors connected in parallel and interspersed with resistors to produce an additive capacitance of the network. The capacitors were connected together in series and were charged in parallel through the resistors but a gap was left in this circuitry [32].

Several research studies have used the SELFRAG lab machine to investigate the effect of high voltage electrical pulses on comminution circuits [1,24–27]. However, the effect and role of the instrumental parameters on the final product quality has not comprehensively been studied. Therefore, it was aimed in this study to design and fabricate a new High Voltage Electric Pulse Crusher (HVEPC) consisted of three main parts to further consider the effect of design and process parameters on the comminution circuits. The first part of the HVEPC contains the electrical pulse generation circuit with required specifications as pulse generator.

A schematic of the HVEPC developed in this study is shown in Fig. 1. Three main parameters including voltage, Capacitance and voltage rise time affect the operation of the instrument. Using an HV Transformer, urban 220 volt AC circuit was converted to a maximum of 100 kV AC. Then, the voltage was increased to a maximum value of 140 kV DC V. The same voltage could also be used as the pulse. Another parameter was the capacitance of the capacitor