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Enrichment of chalcopyrite using high-voltage pulse discharge

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ABSTRACT

In this study, high-voltage pulse was used for crushing copper ore. The effects of operational parameters on product size, yield and enrichment rate were studied. The influence of operational parameters on the yield of unit energy consumption (δ) for crushing was investigated using orthogonal experiments. The results showed that the variation trend in the content of completely broken product was opposite to that of the average grain size. The rate of enrichment (β) of chalcopyrite first increased, and then, decreased with the increase in voltage. However, the rate of enrichment decreased with the increase in the number of pulses, and was less affected by the spacing between the electrodes. With the continuous change in operational parameters, β for the chalcopyrite gradually stabilized within the range of 1.1–1.2. The high-voltage pulse can effectively enrich chalcopyrite, while the overall variation trend of β showed a decline with the increase in grain size. However, the value of β was higher than unity. Furthermore, the value of β for −0.3 mm broken product was relatively higher, and was about 1.46. Except for the 0.3 mm and 4 mm size fractions, there was no obvious turning point in the β curve of other size fractions. Additionally, the effect of size fraction on the value of β was weak. Under the conditions of breaking the mineral, the voltage had the greatest influence on δ value, which increased with the decrease of voltage and number of pulses. At 110 kV and 55 number of pulses, the maximum value of δ was up to 1.66, which gradually declined in the direction of increasing energy consumption.

1. Introduction

The process of crushing plays an important role in mineral processing, and consumes a large amount of energy. With the increasing demand of minerals, the high-grade mineral ore reserves are gradually depleting. Due to the shortage of high-grade ore, the demand for low-grade ore has increased. Fine grinding is needed for dissociation of useful components from low-grade ores, which increases the energy consumption and reduces the overall process efficiency [1]. A highly efficient crushing method is urgently needed for mineral processing. High-voltage pulse crushing has attracted significant research attention due to its unique selective crushing advantages [2].

Different from the selective mechanical crushing, the high-voltage selective crushing is based upon the electrical properties of various mineral components forming the ore (such as, permittivity and conductivity of various mineral components). After applying different electrode discharge, high electrical field is generated at the junction of different mineral components. As a result, the minerals dissociate along the grain boundary of these components [3]. For mechanical crushing, the main factors affact the crushing are the structure, hardness of ores and the characteristics of crushing equipment [4,5].

In the past years, high-voltage pulses have been used for crushing minerals. In 1980s, Beers guided the first high-voltage pulse to crush diamond minerals, and obtained undamaged diamond product [6]. U·Andres had done a lot of research on high-voltage pulse crushing minerals, conducted many high-voltage pulse crushing experiments, described the crushing mechanism using high-voltage pulses, and concluded that high-voltage pulse crusing is easily for the liberation of minerals [7,8]. Due to the discovery of advantages of high-voltage pulse crushing, many scholars have paid attention to the process. In 2007, the laboratory scale equipment using high-voltage pulse crushing was developed and commercialized [3], which greatly facilitated the laboratory scale research of high-voltage pulse crushing and promoted its rapid development.

Many scholars have studied the formation and development of electrical pulse channel in the process of crushing, and the results indicate the electrical pulse channel is formation and development near the high dielectric constant [6–10]. For exploring the advantage of high-voltage pulse crushing, many experiments were conducted to compare the difference between mechanical breakage and electrical breakage [11,12], Fengnian Shi conducted experimental and theoretical studies to explore selective crushing using high-voltage pulse, and showed that high electric field occurred between points/locations having different dielectric constants, induce the breakage of minerals [1]. And high-voltage pulse crushing can reach the higher degree of dissociation in

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coarse +53 μm, for mechanical crushing, the dissocaition is achieved in -53 μm [2]. In addition, the effects of various factors affecting high-voltage pulse crushing were also studied, the energy, particle size, dielectric characteristics and shape were included [13]. The pretreatment of ores can reduce the hardness of minerals, improve the crushing efficiency and reduce the energy consumption [14,15]. The study showed that high-voltage pulse have the effect of pre-weaking, reduce 9%–52% of the hardness and save 24% energy [16–18]. Except for pre-weaking, high-voltage pulse can be used to pre-concentration minerals, reduce the feeding of crushing and achieve the effect of save energy [19,20]. The further proessing of coal has good prospectsand it is realized by crushing to increase the degree of dissociation at present [21,22], Yan compared the coal treatment processes using mechanical and high-voltage pulse methods, and showed that the effect of high-voltage pulse on the dissociation of coal was much better than the mechanical crushing [23–25]. Duan studied the circuit board using high-voltage pulse crushing, the results showed that high-voltage pulse can achieve the liberation of metal and non-metal, and effective enrichment of copper could be realized in -2 mm [8,26–28]. The dissociation and surface chemical characteristics of porphyry copper was analyzed, indicating that high-voltage pulse can improve the degree of dissociation and influence the surface characteristics of the ore, improve the effect of flotation [29].

In present study, the mechanism of high-voltage crushing and selective breakage advantage were studied. And experiment results showed that high-voltage pulse can improve the dissociation and realize the selective breakage of minerals [30,31]. In this paper, the crushing and enrichment of copper ore is studied using high-voltage pulse method. In this work, high voltage pulse technology is used to break copper iron ore to separate specific mineral components under different operating conditions, and the mechanism affecting the yield of copper per unit energy consumption has been explored.

2. Experimental

2.1. Methodology

In this work, the SELFRAG LAB high-voltage pulse crusher (manufactured by SELFRAG AG, Switzerland) was used, and is shown in Fig. 1. The high-voltage pulse crusher consisted of a pulse energy provider, pulse discharge generator, reactor tank and the control panel [32]. The instruments were controlled using the control panel. The values for the parameters of pulse voltage, pulse frequency, pulse number (number of pulses), electrode spacing and energy consumption were displayed on the control panel.

The copper ore was completely immersed in deionized water. One of the conditions for crushing solid minerals is that the internal fragmentation occurs during the high-voltage pulse. The condition for internal breakdown or fragmentation means that the internal field strength approaches the internal material breakdown (or fragmentation) condition, though the strength of external field would not reach the external material's breakdown (fragmentation) condition [33]. The changes in the strength of breakdown field of the rock, transformer oil, water and air with the time rate of increase in voltage are shown in Fig. 2. When the time taken to increase the voltage was relatively short (<500 ns), the breakdown field of water was greater than that of the rock. In water, the rock minerals could reach the internal breakdown conditions [33,34].

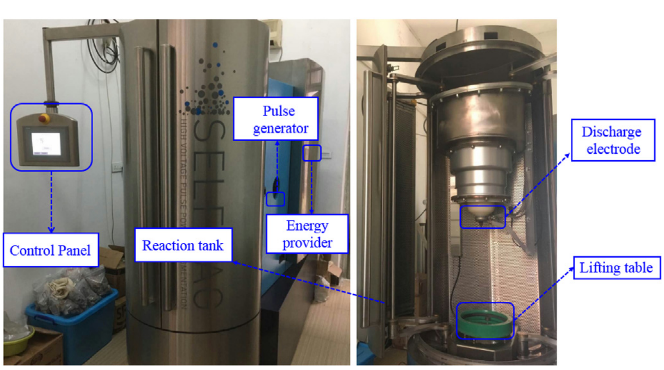

Fig. 1. The schematic diagram of high voltage pulse equipment.

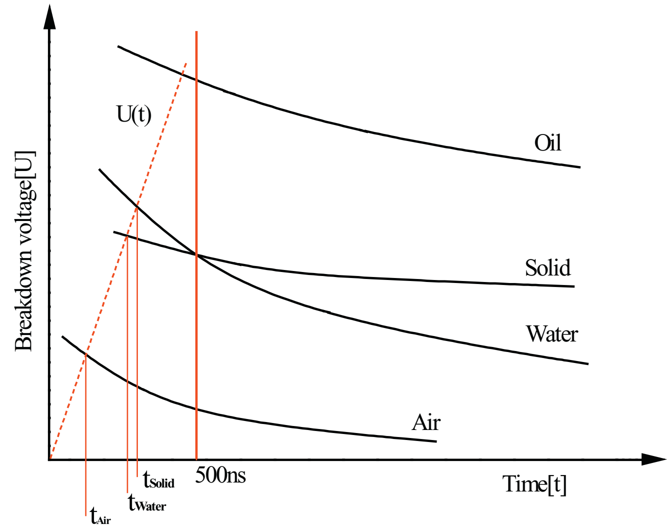

Fig. 2. Breakdown voltage of various materials as a function of the voltage rise time.

In order to ensure the same amount of pulse samples per unit time, a sieve-free reaction tank was used. After fragmenting each sample, the liquid medium was replaced to avoid any effect of the ionization of iron electrode in the liquid medium on the results of the experiments. After this, the size distribution and the grade of the fragmented products were further analyzed.

2.2. Material characteristics

The copper ore sample was taken from Fushun, Liaoning, China. The mineral was analyzed using X-ray fluorescence (XRF). The chemical composition of the mineral is provided in Table 1. The main component of the mineral was SiO_2 which accounted for 72.21% of the total mass of the mineral sample.

The X-ray powder diffraction (XRD) analysis of the minerals provided information about the contents of main mineral components of the copper ore quartz. The corresponding XRD results are shown in Fig. 3. Quartz and feldspar were the main gangue materials in the mineral, whereas small amounts of chalcopyrite, pyrite, mica and other minerals also existed in the sample.

2.3. Enrichment mechanism

For high-voltage pulse fragmentation, the current entered the reactor through electrode discharge. The mineral is fragmented based upon the dielectric properties of different mineral components. The location of the fragmentation is mainly the edge of the mineral components where the dielectric constants have different values [35,36]. In copper ore, chalcopyrite content was low, while that of the gangue having low permittivity was high. Chalcopyrite was dispersed in gangue,

Table 1
Chemical compositions of studied copper iron ore(mass fraction,%).

SiO_2	Al_2O_3	Fe_2O_3	MgO	S	K_2O	Cu	CaO	Zn	TiO_2
72.21	8.61	8.08	4.9	3.14	1.13	0.95	0.79	0.38	0.20