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Triboelectric properties of ilmenite and quartz minerals and investigation of triboelectric separation of ilmenite ore

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A B S T R A C T

Triboelectric separation, as an entirely dry technology, is a prospective method to process fine minerals. The aim of this paper is to investigate the performance of triboelectric separation of ilmenite and quartz minerals in a lab unit and to get ready for the separation of ilmenite ore. A tribocharge measurement system was used to test the triboelectric properties of ilmenite and quartz particles with tribochargers respectively made of PVC, PPR, PMMA, Teflon, copper, stainless steel and quartz glass. The results show that the ilmenite particles charged positively while quartz charged negatively when tribocharged with PVC tribocharger. The mixture of 12% ilmenite and 88% quartz was prepared for the triboelectric separation. The recovery of ilmenite increases with the increase of airflow rate, decreases with the increasing feed rate, and grows up firstly and then decreases with the increasing voltage. A maximum ilmenite recovery of 51.71% with ilmenite content 32.72% was obtained at 40 m^3/h airflow rate, 6 g/s feed rate and 20 kV voltage. According to the optimal parameters of the separation of ilmenite and quartz mixture, fine ilmenite ore with 7.55% Ti content was beneficiated using the unit and the Ti content increased to12.32% in concentrate product.

1. Introduction

Triboelectric separation provides a means to beneficiate fine minerals with an entirely dry technology. Compared with the wet separation, dry separation shows advantages of much lower energy consumption, avoid changing native properties of materials and the ability to be applied in areas where water resources are scarce [1,2]. As one of the major dry separations, triboelectric separation is becoming more and more important in mineral processing, waste plastics recycling and other industries [3–7]. Industrial productions have strongly proved the high-efficiency, small environmental pollution and high economic effectiveness of triboelectric separation, especially when it is adapted to recycle waste containing commonly polymers [8–9].

Triboelectrification is contributed by the inherent differences of electrical conductivity and dielectric constant properties belonging to different materials [10,11]. When particles rubbed with tribocharger or themselves, the material with higher work function negatively charged, while the others positively charged due to electron transfer [12,13]. Subsequently, when charged particles placed in an electric field, they will be separated under the influence of the external electric field [14]. Particles with different polarities and quantity of charge would have different trajectories under the competition between drag, electrostatic, and gravitational forces. Negatively and positively charged particles are going to move toward the positive and negative plate respectively [15]. For the charge transfer mechanism in tribocharging process, there are three main models: electron transfer, ion transfer and material transfer [12]. It has been reported that electron transfer can only occur in a maximal depth of 30 nm and ion and material transfers can influence the charge polarity and the charge density of materials [16,17]. The exchange of charge is strongly influenced by mechanical nature of the interaction between a particle and other solid surface [18]. Hower et al. found that when moisture content is too high, it may lead to a decrease in separation efficiency [19]. Some scholars compared charging behavior of a single material and a mixture, and found that the charging behavior of mixture is more

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complex because that interactions among particles play an important role in tribocharging [15,20–21]. Ferguson researched a basic triboelectric series for heavy minerals and provided theoretical basis for minerals' triboelectric separation [22]. Wang et al. indicated that combined parameters of lower feeding, higher gas flow rate and higher electric field strength were significant to reduce interactions among oppositely charged particles [15]. Tao et al. investigated the electrical properties and separation behavior of fine coal and fly ash of power plants in a rotary triboelectrostatic separator [23]. Experimental results indicated that the separator offered significant advantages in particle charging and separation efficiency. Electrical properties of fly ash and effects of feed rate, rotation speed of charger, applied charger voltage, injection flow rate, and charger material were also given [24–26]. Sobhy and Tao also detailedly introduced the principle of triboelectric separation and investigated the effects of major process parameters on particle charging and phosphate separation efficiency using rotary triboelectrostatic separator [27]. Steve conducted experiments of removing minerals from coal and factors affecting the separation results were studied [28]. Alexandru et al. separated muscovite mica from feldspathic pegmatites using electrostatic separation and the best results of 46.11% SiO_2, 33.64% Al_2O_3, and 11.1% (K_2O +Na_2O) were obtained by performing a three-stage separation [29]. Though electrostatic separation is widely used in pulverized coal processing, it is rarely applied to the enrichment of valuable elements in metallic mineral beneficiation. Triboelectric belt separator as one of the commercial separation machines has been successfully applied to the beneficiation of a variety of minerals including calcium carbonates, talc, and potash and recently has been used in beneficiation of phosphate ores [30].

In titanium industry, TiO_2 pigment is one of the most important products and more than 90% of the titanium production is used for TiO_2 pigments [31]. For the beneficiation of ilmenite, several methods are used in industry and laboratory. Dry magnetic and wet gravity separation are used to separate the ilmenite from the zircon and rutile; electrostatic separation is used extensively in the beneficiation of heavy mineral sands for the recovery of rutile, zircon and ilmenite; flotation is used to separate fine ilmenite [32,33]. Compared with froth flotation and gravity separation, electrostatic separation has no requirement of dewatering for the production, and the native properties of materials will not be changed and energy consumption will be lower [34]. So the wide application of triboelectric separation and other dry separation methods is a trend in separation and purification industry, especially in water-scarce areas.

In this paper, based on the difference of triboelectric properties of ilmenite and quartz, the mixture of ilmenite and quartz were separated by applying triboelectric separation unit in lab. The triboelectric characteristics of ilmenite and quartz with several materials were tested to determine the optimal tribocharger material. The effect of operation parameters on separation was investigated, and the performance of triboelectric separation of ilmenite and quartz was evaluated. Each test was conducted for three times in identical experimental conditions and error bars of the results were also given. On the base of experiments of ilmenite and quartz mixtures, ilmenite ore was separated by using the lab triboelectric separation unit.

2. Materials and methods

2.1. Materials

2.1.1. Properties of ilmenite ore

The raw ilmenite was collected and pulverized. In order to investigate the performance of this triboelectric separator, 45–90 μm ilmenite ore sample was selected to separate in lab tests. The properties of ilmenite ore were analyzed by XRD and XRF. The X-ray diffraction pattern of ore is presented in Fig. 1 and elements and their contents in sample are shown in Fig. 2. It can be seen the content of Ti is 9.28% and minerals containing titanium are main ilmenite and kaersutite. Silicon aluminate and silicon magnesium are the main gangue minerals.

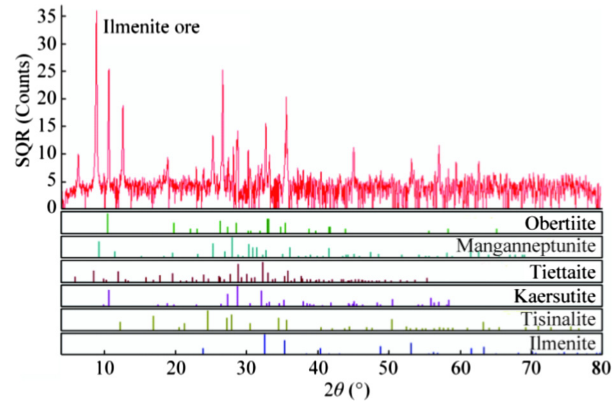

Fig. 1. X-ray diffraction pattern of ilmenite ore.

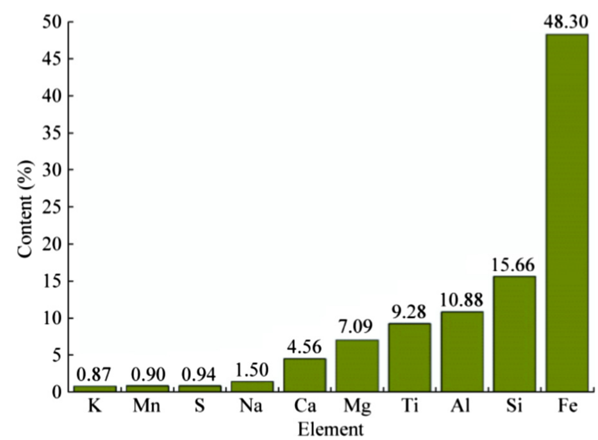

Fig. 2. Elements and their contents in ilmenite ore.

2.1.2. Ilmenite concentrate and quartz

In the experiment, to analyze the properties of ilmenite and quartz and investigate the parameters of triboelectric separation of ilmenite, pure ilmenite (ilmenite concentrate) and pure quartz fines were selected to test. The ilmenite concentrate tested in this study was produced by the process of "magnetic separation-flotation" from a primary rock deposit of titanomagnetite in Panzhihua, China. The 45–90 μm ilmenite sample was obtained by screening. The quartz mineral sample with a purity of 93.98% was purchased, crushed and screened for the test. The samples were shown in Fig. 3. The X-ray diffraction pattern of ilmenite sample and quartz were illustrated in Fig. 4 and it can be seen that the ilmenite sample contains some ecandrewsite and chamosite minerals. The elements and their content in ilmenite and quartz samples were shown in Fig. 5. It can be seen from the results of element analysis that the grade of ilmenite in sample is 87.29%.

In this paper the mixture of ilmenite and quartz was separated using the lab triboelectric separation unit and the mass percent of ilmenite in mixture was set at 12%.

To avoid the interference of fine particles and make electrostatic separation possible, ilmenite, quartz and ilmenite ore samples used

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