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A new method to produce high voltage static electric load for electrostatic separation – Triboelectric charging

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ABSTRACT

Numerous methods for generating electric charge on material surfaces through friction and contact have been applied in many industries. Triboelectric charging is one of these methods that achieve this phenomenon by frictional charging. The resulting electric field can be manipulated to control the directional path of falling particles. In a triboelectrostatic separator, particles are charged by the triboelectric effect before electrostatic separation.
The purpose of this work is to develop a new system to provide the required electric potential to the electrodes of a separator by triboelectric charging, and to use the resulting charge for mineral separation. Experimental studies mainly covered the investigation of the effect of varying belt/roller combinations, belt speeds, brush lengths, and electrode surface areas on triboelectric charge generation. Belts were selected from wool, polyester, polyethylene/acrylic, PVC, nylon woven, nylon, and fiber/nylon materials. Additionally; teflon, polyamide, aluminum, polyoxymethylene and polyethylene rollers had been used. Following the investigation of operational parameters, mineral separation tests were performed with artificially prepared samples by using the designed setup.
The results showed that static electric charge can be increased to a maximum of ± 35 kV on an electrode by tribocharging. Investigation of the operational parameters proved that increasing the belt speed causes an increase in surface charge, and the measured surface charge increases with an increase in the width of harvesting brushes. Furthermore, the separation test results revealed that non-conductive and conductive particles can be separated in an electrostatic separator using the high voltage directly produced by tribocharging.

1. Introduction

Electrostatic separation, which covers electrostatic, electrodynamic, and triboelectric separation, utilizes electrical conductivity differences between the mineral particles for separation. This method is defined as the sorting of charged or polarized particles by using the combination of attractive/repulsive forces of electricity, gravity, and centrifugal forces in an electric field [1]. The particles can be charged by contact between dissimilar particles (triboelectric), ion bombardment, and induction [2]. The electrostatic separators mainly use a pure electrostatic field or a convection field for separation. The particle feeding systems are roughly classified as stationary chutes, plates or shelves, rotary rollers, free falling stream, and vibrating tables [3]. In these systems, the particles are attracted or repulsed depending on their surface charge by a single or double electrode that possesses high tension. This action changes the orbits of moving particles in order to collect these particles in separate trays [4–7]. This method has been used commercially to beneficiate many minerals such as zircon, rutile, ilmenite (mainly beach and stream placers), and coal since the 1960s [8,9]. This is also an effective method in recycling minerals [10–12].

Triboelectric charging of solids has been a well-known process for a very long time. The triboelectric effect (also known as triboelectric charging) is a type of contact electrification in which certain materials become electrically charged after they come into contact with a different material [13]. If two dissimilar solids (at least one of the surfaces has a high resistance to electric current) are separated after they come into contact, an exchange of electrical charges are often observed on the contact surface. Then, the solids are left with an equal but opposite net charge. This phenomenon, known as tribo- or contact electrification, has been used to charge the mineral grains in mineral separation processes for several years [2,14].

Electrical charging of materials by the tribocharging effect is mainly dependent on the molecular structure of these two different materials. The molecules of different materials have varying amounts of positively charged protons and negatively charged electrons, while a molecule with an equal number of electrons and protons yields a neutral state, implying that it is neither positively nor negatively charged. When two dissimilar materials come close enough, an electrical bond forms between their molecules. When the bond is formed, electrons move from one molecule to another according to their structures. This action deteriorates the electrical balance in both types of molecules. After the two materials separate, electrons do not return to their original positions. The material that accepts electrons becomes negatively charged

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while the material that gives the electrons becomes positively charged. The theory of triboelectric charging has been presented in detail previously [15–18]. This can be used for both the charging of particles and producing static electric charge on the electrodes of the electrostatic separator. Most of the research investigated charging the particles by tribocharging before electrostatic separation [19–21]. However, there are no studies concerning the use of this static electric charge as a main power source in an electrostatic separator.

In this study, a new system for triboelectrostatic separation to provide the required electric potential to the electrodes of a separator by triboelectric charging was introduced. Experimental studies covered the tests for determining the operational limits of the equipment along with the actual separation tests of artificially prepared samples.

2. Experimental setup overview

There are two main types of electrostatic separators which are used in the mineral processing industry, and the working principles of both are immensely similar. These are electrodynamic separators (also known as high-tension rollers) and electrostatic separators [22,23]. In the electrodynamic separators, different mineral particles are charged by a corona discharge. There are two electrodes in this separator: the first to create the corona discharge and the second for mineral separation. A rotating conductive drum gently carries the particles into an electric field. While the conducting particles lose their charge, non-conductive particles keep their charge. Electrical attractive and repulsive forces between the electrodes and the particles change the orbits of these moving particles. There are no moving parts in an electrostatic plate-type separator. The charged particles slide down through an inclined plate and are separated by electrical attractive and repulsive forces on reaching the electric field.

According to the Coulomb's law, an electric force between two charged objects is directly proportional to the amount of charge on the objects. In addition, it is inversely proportional to the square of the distance between the two objects. In its simplest form, Coulomb's law is given as [24];

$$F = \frac{kQ_1Q_2}{d^2} \tag{1}$$

where

- Q_1 the quantity of charge on object 1 (particle) [C],
- Q_2 the quantity of charge on object 2 (electrode) [C],
- d the distance between the two objects [m],
- k Coulomb's law constant. It is approximately 9.0×10^9 N·m²/C² for air.

Since Q_1 is smaller than Q_2, the force between the particle and electrode depends mainly on the charge of the electrode. Therefore, efficient and continuous charging of the electrode is important. In the conventional electrostatic separator, a transformer using industrial electric current controls the charge of the electrode. This provides sufficient static charge required for separation. Unlike the conventional separator, the capability of tribocharging as the main static electric source was investigated in electrostatic separation for this study.

In the triboelectrostatic separator purposed within this study, a belt running between two rollers produces continuous electrical charge on the contact surfaces by tribocharging. The conductive brushes harvest this charge and send it to a plane shaped metallic electrode. The specified materials were used to produce a static charge on the special electrodes similar to the Van de Graff [25] generators. It produces high voltage direct current (DC) electricity at low current levels. The charge collected on the electrodes can be positive or negative depending on the material used in the electrical production system. In the production system, two different materials from opposite sides of the triboelectric series [15,26] can be selected to adjust the amount and polarity of the charge produced. The electrical charge harvested may reach up to tens of thousands of volts on a metallic surface. With this voltage level, the required electric potential for the separator is provided. The level of this electric potential is similar to the potential on the electrodes of a conventional electrostatic separator. It is important to note that, in conventional electrostatic separators used for industrial purposes, high voltage (HV) required for the electric field is produced by large transformers. Transformers convert the industrial alternating current to direct current and raise the voltage up to thousands of volts. The goal is to provide a sufficient HV to charge the particles and separate them in these systems.

The main differences between conventional electrostatic separators and the proposed system is the method of HV production, which is required in order to produce an electric field. While the conventional systems use transformers, this system produces the required static electric charge by friction which is produced by a relatively small electric motor. HV power suppliers used in the industrial operations are known for the space required for installation, low efficiency resulting with high heat losses and high installation costs. When they are used in high power applications such as electrostatic separation, HV power suppliers require additional components like large transformers to handle the power. Therefore, overall size and complicity of the HVs increase resulting with a challenge when they used in combination with electrostatic separators. Using additional components eventually increases the overall operating cost considerably. Although the triboelectric charging may be an alternative for HV generation, it is also important to note that considering the scale of the separator presented in this study, a compact, solid-state HV supply is sufficient for generation of the required charge. That being underlined, the method discussed within this work has the potential to be used for the production of electric potential without transformers, unlike conventional electrostatic separators in the mineral separation and recycling industry.

The new design is composed of a tribo-electric production unit and a separation unit. The general layout of the tribo-electric production unit which was designed to produce, harvest, and collect the electrical charge is given in Fig. 1. The tribo-electric production unit includes a continuously moving belt, a copper brush that harvests charge from the belt, and two or more rollers, where one is for driving the belt and the other is free moving to provide support for the belt. The width of the belt is 19 cm and the diameter of the rollers is 1.9 cm. The brush is connected to a plate shaped metal electrode by a conductive wire. More than one brush can be placed at the nearest points of the contact between belt and each roller. Each brush can be connected to the same electrode in the separator. Measurements show that more brushes build more electric potential on the electrode. Moreover, the polarity of the electricity produced changes depending on the types of roller and belts used. Therefore, different electrical charges can be harvested and loaded to different metallic electrodes in the same system.

The second part of the experimental setup is the separator. This part is similar to the conventional drum-type electrostatic separator. It includes a conductive drum with an adjustable driving mechanism and a vibrating feeder. The electrode of the separator which is charged by the tribocharging unit is placed against the drum. The size and the material type of this electrode can be changed, and its position can also be adjusted during the separation process. The electricity production unit was connected to the separation unit with a conductive wire. This provides charge for the electrode with the harvested electricity. The amount and the polarity of the electric potential collected on the electrode were adjusted by adjusting the roller speed and the selection of roller and belt materials.

The feed material was heavily mixed for a pre-determined time interval in a plastic box, and particles were charged with tribo-electric. Then, this material is fed on to the turning drum via a vibrating feeder, and the drum directs the particles into the electrical field present in front of the electrode. Particles with a similar charge as that of the