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Original research article

BENEFICIATION OF MINERAL ORES USING TRIBO-ELECTROSTATIC SEPARATOR

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ABSTRACT – ST Equipment & Technology (STET) has developed a tribo-electrostatic belt separator for mineral ore beneficiation, eliminating the need for water or chemical additives. This technology has been successfully scaled for diverse industrial applications, including the removal of unburnt carbon from fly ash, separation of silicates from calcite, magnesite from talc, and silicates from barite. STET's electrostatic separation technology offers an efficient and environmentally sustainable alternative to conventional minerals processing methods. The paper presents pilot-scale test results highlighting the technology's effectiveness in upgrading ultrafine iron ore, which is typically discarded as tailings, as well as a coarser air-classified iron ore sample.

Keywords: Electrostatic Separation, Tailings, Dry Beneficiation.

INTRODUCTION

Iron ore processing

Iron ore is one of the most important raw materials in the world and iron ore processing is one of the essential industrial processes. As the high-grade (>60% Fe content) iron ore deposits degrade, beneficiation of low-grade (<60% Fe content) deposits becomes essential to meet the quality requirements of the steel industry and maximizing ore utilization [1].

Wet magnetic separation is typically used in beneficiation of iron ores, utilizing the differences in magnetic properties of the ore components for separation of iron bearing minerals from gangue minerals. Wet low-intensity magnetic separators (LIMS) are widely used to process ores with strong magnetic susceptibility such as magnetite, whereas wet high-intensity magnetic separation (WHIMS) is used for ores with relatively weak magnetic susceptibilities such as hematite and goethite [2]. One of the challenges in magnetic separation is lower separation efficiency of fines particles, especially <20 micron because in this size range the liquid drag forces tend to be greater than the magnetic forces [3]. Flotation is another widely used process to beneficiate iron ores using either direct anionic flotation of iron oxides and reverse anionic or cationic flotation of quartz. However, the presence of fines poses a challenge, and de-sliming is conducted to remove fines (< 20 micron) to increase the effectiveness of flotation [4].

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Both magnetic and flotation processes face challenges in processing fine iron ore, and typically these fines are rejected as wet tailings. Proper disposal of these tailings has become an environmental concern [5]. In addition, both processes demand large amounts of water and require wastewater processing.

STET tribo-electrostatic separator

A notable advancement in dry mineral separation is the STET tribo-electrostatic belt separator (Figure 1), which has extended the effective particle size range to finer particles. Tribo-electrostatic separation leverages electrical charge differences generated by surface contact, or triboelectric charging, between two materials. In this process, the material with a higher electron affinity acquires electrons, becoming negatively charged, while the material with lower electron affinity becomes positively charged. This differential charging enables efficient separation of mixed particles using an electric field.

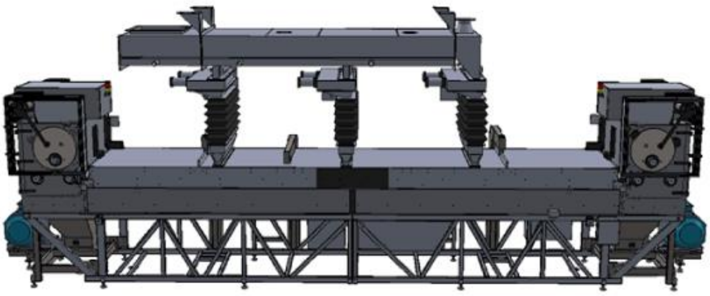

Figure 1 Model of STET separator

Material is fed into a thin gap (0.9–1.5 cm) between two parallel planar electrodes (Figure 2) charged up to +/- 10 kV, where particles acquire opposite charges through interparticle collisions. These charged particles are carried by a high-speed, continuous-loop, open-mesh belt toward opposite ends of the separator, guided by their attraction to electrodes of the opposite charge. The counter-current flow of particles and continual triboelectric charging enable multi-stage separation, achieving high purity and recovery.

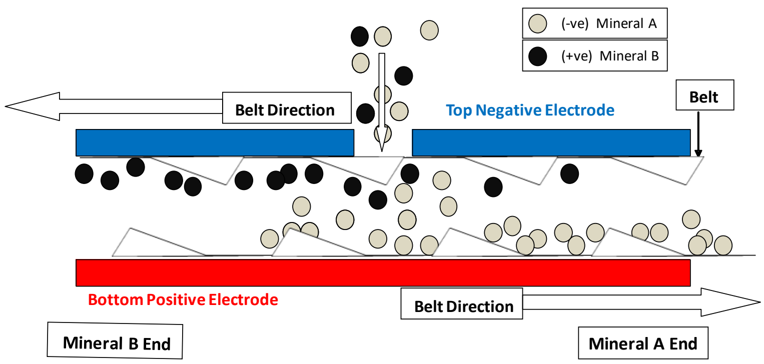

Figure 2 Schematic of separaton zone within the electrodes

Capable of processing up to 40 tons per hour, the compact STET separator measures 9.1 m long, 1.7 m wide, and 3.2 m high, with a power consumption of approximately 1 kWh per ton of material processed. This innovative technology has broadened the applicability of dry separation methods, offering a promising alternative for fine particle beneficiation. In this paper, STET tribo-electrostatic belt separation is presented as a possible beneficiation technology to upgrade iron ore.

EXPERIMENTAL

Materials

Two samples of iron ore were collected from iron ore processing plants in Brazil, and tested using a pilot-scale STET separator.

1. Ultrafine sample: This sample was the reject stream from a magnetic separation process, as the fines pose challenges in efficiency of magnetic separation.
2. Air-classified sample: This sample was collected from an air-classification step as fines.

The elemental composition was analyzed using a wavelength dispersive X-ray Fluorescence (WD-XRF) instrument and mineralogy was studied with the XRD (X-ray diffraction) technique. The loss on ignition (LOI) was determined by igniting a sample in a 1000 ºC furnace for 60 minutes and reporting the weight loss. Particle size distribution analysis (PSD) was conducted using a laser diffraction particle size analyzer - Malvern Mastersizer 3000 E.

The mineralogy of the samples is provided in Table 1. Hematite is the primary iron-bearing mineral in both samples, quartz and kaolinite being the primary gangue minerals. The elemental composition of the samples is shown in Table 2. Particle size distribution and moisture content of the samples is shown in Table 3. Samples were dried at 90 C prior to testing in the separator.

Table 1 Mineralogy of iron ore samples

Sample	Hematite	Goethite	Quartz	Kaolinite
Ultrafines	50.8%	17.9%	12.5%	18.5%
Air-classified	50.6%	3.4%	40.9%	3.5%

Table 2 Elemental composition (major elements) for iron ore samples

Sample	Al_2O_3	Fe_2O_3	Fe*	SiO_2	LOI
Ultrafines	7.7	66.0	46.2	20.8	4.3
Air-classified	2.2	59.7	41.8	*36.6*	1.0

*Calculated using stoichiometric relationship between Fe_2O_3 and Fe

Table 3 Particle size distribution for iron ore samples

Sample	Particle size distribution				Moisture content
	D_{10}	D_{50}	D_{90}	D_{98}	
Ultrafines	1 µm	4 µm	11 µm	16 µm	<0.2%
Air-classified	7 µm	32 µm	105 µm	215 µm	<0.2%

Method

Testing was conducted with the goals of enhancing concentration and minimizing the presence of gangue minerals, and to study effect of separator variables (Table 4) on product grade and mass yields. Pilot-scale testing is essential for evaluating separation performance at commercially viable feed rates and optimizing separator and feed variables for processing.

Table 4 Separator variables

Variables	Levels			Units
Belt speed	5		20	meter per second
Electrode gap	10		13	mm
Electrode voltage	6		10	kV
Feed port	1	2	3	
Top electrode polarity	Positive		Negative	

Tests were performed on the separators under batch conditions. Prior to each test, a small sub-sample of the feed material (referred to as "Feed") was collected. At the conclusion of each experiment, samples were collected, and the weights of the two product streams - designated as "Product E1" and "Product E2" were measured. In this setup, "Product E1" represents the gangue-rich product, while "Product E2" corresponds to the mineral-rich product. For each set of sub-samples (Feed, Product E1, Product E2), major elemental composition was analyzed using X-ray fluorescence (XRF).

RESULTS AND DISCUSSION

Air-classified iron ore

Optimization of separator variables was conducted, and three processing schemes were developed targeting a range of product grades. The feed grade was approx. 42% Fe content.

Scheme 1 involves a rougher stage followed by a cleaner stage, yielding a high-grade product with approximately 62% Fe content. The cleaner by-product is recycled and blended with the fresh feed. This scheme achieved an overall mass yield of 61% and a Fe recovery of 90%.

Scheme 2 involves only a rougher stage yielding a mid-grade product with approximately 57% Fe content. Additionally, a scavenger run was performed, with its product blended with the rougher stage output. This scheme achieved an overall mass yield of 67% and an Fe recovery of 91%.

Scheme 3 involves producing a high-grade product at the rougher stage and then a scavenger stage was used to increase overall recovery. The scavenger product was blended with the fresh feed. This scheme achieved an overall mass yield of 46% and a Fe recovery of 68%.

Table 5 summarizes the findings from air-classified iron ore testing, presenting the range of product grades achieved along with their corresponding mass yields and Fe recoveries.

Table 5 Summary of results from air-classified iron ore

Scheme	Product mass yield	Fe recovery	Product Fe content
1. High grade product (using rougher + cleaner)	60.9%	90.1%	61.8%
2. Mid grade product (using rougher + scavenger)	66.8%	90.8%	56.8%
3. High grade product (using rougher + scavenger)	46.1%	67.5%	61.1%

Air-classified iron ore

Similar optimization of separator variables was conducted, and processing schemes were developed targeting a range of product grades. The feed grade was approx. 46% Fe content.

Scheme 1 involves a rougher stage followed by a cleaner stage, yielding a high-grade product with approximately 59% Fe content. Additionally, a scavenger run was performed, with its product blended with the rougher stage output. The cleaner by-product is recycled and blended with the fresh feed. This scheme achieved an overall mass yield of 32% and a Fe recovery of 59%.

Scheme2 involves only a rougher stage, yielding a mid-grade product with approximately 55% Fe content. Additionally, a scavenger run was performed, with its product blended with the rougher stage output. This scheme achieved an overall mass yield of 55% and a Fe recovery of 66%.

Table 6 Summary of results from ultrafine iron ore

Scheme	Product mass yield	Fe recovery	Product Fe content
1. High grade product (using rougher + scavenger + cleaner)	31.9%	40.8%	59.2%
2. Mid grade product (using rougher + scavenger)	54.9%	65.9%	55.4%
3. Low grade product (using rougher + scavenger)	73.8%	82.3%	51.5%

By changing the belt speed and feed port of the separator, a low-grade product scheme was developed (Scheme 3) resulting in product grade of 51% Fe. Testing involved a rougher stage, and a scavenger run with its product blended with the rougher stage output. This scheme achieved an overall mass yield of 74% and a Fe recovery of 82%.

Table 6 summarizes the findings from air-classified iron ore testing, presenting the range of product grades achieved along with their corresponding mass yields and Fe recoveries.

CONCLUSION

The STET tribo-electrostatic belt separator provides an innovative, dry-processing alternative for mineral beneficiation, overcoming key challenges associated with conventional wet separation methods. Unlike traditional processes, this technology efficiently processes ultrafine particles while eliminating the need for excessive water consumption and mitigating environmental concerns related to wet tailings disposal.

This report presents pilot-scale results demonstrating the separator's effectiveness in upgrading iron ore. By adjusting separator variables, the system enabled the production of a range of product grades using difference processing schemes, while optimizing mass yield and Fe recovery.

These findings underscore the tribo-electrostatic separator's potential to enhance sustainable mineral processing by reducing waste, conserving critical resources, and promoting more efficient beneficiation practices.

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