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Tribo-electrostatic separation of high ash coking coal washery rejects: Effect of moisture on separation efficiency

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ABSTRACT

The present study illustrates the influence of relative humidity (RH) and applied voltage on the tribo-electrostatic separation of ash from Indian coking coal washery rejects. A prototype system was designed, fabricated, and installed to carry out the separation studies. The rejects on an average contained 51% ash; 33% fixed carbon and 16% volatile matter. The contact electrification of carbon and ash forming minerals was carried out using a rotary drum tribo-charger. The results indicate that the absolute charge magnitude of these particles is different and dependent on the operating variables. The charge magnitude of the particles decreases with an increase in humidity and a higher differential charge between carbon and mineral matter can be struck at lower RH. The results also show that the charge magnitude increases with an increase in the tribo-charging time.

The influence of environmental moisture on the tribo-electrostatic separation of coking coal was analysed. The results show that the yield and quality of the clean coal decreases with an increase in humidity but increases with an increase in applied voltage. The optimum separation efficiency is achieved at 10% RH, and 15 kV applied DC voltage. The overall results reflect that it is possible to produce clean coal with 35% ash at 35% yield from the feed sample (rejects) with 53% ash.

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1. Introduction

Coal is the principal source of fuel for thermal power generation and steel production. About 70% of total steel production in the world is based on coal as the source of energy The World Coal Association (WCA) has estimated that 41% of global power is produced by coal as a fuel [1]. In addition to power and steel, there is a huge demand of coal by other industries such as cement, paper, and textile. The sponge iron production through Direct Reduction of Iron (DRI) route has opened up another front for non-coking coal market. At present, India has coal deposits of around 293 billion tonne. Out of this, only 15% is coking coal while the rest is non-coking coal with a higher percentage of ash. In 2011, total coal production in India was 540 million tonne [1]. The present practice is to wash the coking coal using a wet processing technique to produce clean coal with low ash content for coke production. There are 18 coal washeries operating in India for washing coking coal at the rate of 30 million tonne per year. Furthermore, there are 34 non-coking coal washeries running at the moment to treat 131 million tonne of non-coking coal per year. Most of the coal washeries work on the wet processing technique except a few that follow both dry and wet processing technologies. These washeries use pneumatic jigs for coarse coal preparation.

Dry processing is more attractive than wet processing due to its inherent advantages such as no water requirement, no dewatering, and lower energy needs. In general, dry processes require less capital investment in comparison to wet processes. Dry coal preparation is based on the differences in physical properties of the maceral and ash forming inorganic matters. These properties are density, size, shape, lustre, magnetic susceptibility, electrical conductivity, frictional coefficient, friability, etc. [2,3]. Several types of equipment have been developed using gravity-based techniques for dry and coarse coal preparation such as air dense medium fluidized bed separator [4–6], air jig [7,8], and FGX separator [9–12]. Among these, air jig and FGX separators are in commercial use in various coal preparation plants across the globe. It is possible to reduce 6 to 8% ash content from feed coal in the size range of −80 to +6 mm with these separators [8]. However, due to bed instability, the efficiency decreases as the particle size decreases to below 6 mm size. The fine particulates cause instability by generating large gas bubbles and eddies inside the fluidized bed [3,6]. At present, several washeries in India are using air jigs of a 50 tonne h^{-1} capacity for coarse coal separation [8]. The gravity-based techniques are inefficient in processing fine coals while the response to the tribo-electrostatic separator is highly encouraging [13–15].

In a tribo-electrostatic separation process, particles are tribo-electrically charged by contact with other particles or a third material and then separated by an electric field. During contact electrification, there is an exchange of electron from the surface of one particle to the other until the energy of each material equalizes at the interface. The

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polarity and magnitude of charge obtained by the particles depend on the work function difference between the two surfaces in contact. The standard practice is to charge the particles by friction using a rotary drum, cyclone, vibratory feeder, pneumatic conveyor or fluidized bed system, to attain higher differential charge between them during contact electrification [14–21]. The differentially charged particulates are then allowed to fall between two high voltage electrode plates and get separated by deflection. The tribo-electrostatic phenomena have been explained by several researchers [22–28]. Many investigations have been carried out to understand the tribo-charging characteristics in pneumatic conveying [29–40] and gas–solid fluidized bed systems [41–44]. Many researchers have reported that carbon particles charge positively and minerals such as kaolinite, illite, and quartz charge negatively by frictional contact with the copper tribo-charging medium [14,15,45–47].

Several factors affect the efficiency of the tribo-electrostatic separator which may be broadly classified into three groups [48]: (1) physical properties such as particle size, density, surface state and purity; (2) operating variables such as tribo-charging time, applied electrode plate voltage, gap and angle between electrode plates, temperature of feed particle; and (3) relative humidity. Recent studies have shown that humidity is one of the most important factors that influence the electrostatic phenomena and tribo-electrostatic separation [49–51]. Therefore, for efficient separation in an electric field, it is important to understand the environmental moisture effect on the separation of gangue from coal. The maceral and mineral tribo-charging characteristics and their separation in an electric field are carefully studied and reported by several researchers [52–56].

At present, M/s. Bharat Coking Coal Ltd., India have a large deposit of coking coal washery reject with more than 50% ash content. It is a valuable resource as there is a scarcity of coking coal in India. In the present work, the response of Indian coking coal *rejects* to tribo-electrostatic separation at different relative humidity is studied and its potential for dry coking coal preparation is discussed. Contact electrification studies on carbon and mineral matter are carried out at various relative humidity conditions. The effect of applied voltage on the separation of coal and gangue is also reported. Experiments are conducted using a rotary drum tribo-charger and free fall separator with a vibratory feeder dispensing system. The present investigation is the first of its kind to report the response of Indian coking coal to tribo-electrostatic separator at different environmental moisture conditions.

2. Experimental

2.1. Materials

In this study quartz, kaolinite, and carbon particles were used to assess their charging characteristics. High purity quartz was collected from Mayurbhanj, Odisha, India. It was crushed, ground, and classified into different size fractions and the $-300+210$ μm size fraction was used for charging studies. Pure kaolinite powder (finer than 70 μm) was procured from M/s. Ashapura Minechem Ltd., Trivandrum, India. XRD data confirmed the purity of kaolinite. The carbon powder (97% pure and finer than 175 μm) was procured from M/s. Thermo Fisher Scientific India, Pvt. Ltd., Mumbai, India. The mineral and carbon particles were dried in an oven for 1 h at 105 °C and kept in a desiccator for charge measurement studies. The particle size analysis and surface area measurements were carried out using a Malvern particle size analyzer (Mastersizer 2000) and a Smart BET surface area analyzer (SORB 92/93) respectively. The density of quartz, kaolinite, and carbon particles was measured using a true density meter Smart Pycno 30.

One ton of coal washery reject was collected from Dugda II washery (BCCL), Dugda, Jharkhand, India for characterization and tribo-electrostatic separation studies. The reject sample was crushed to -25 mm by a jaw crusher. A representative sample of the reject coal was prepared by coning and quartering techniques. The sample was classified into different size fractions using standard sieves such as $-25+18$, $-18+10$, $-10+6$, $-6+1$, $-1+0.850$, $-0.850+0.300$, $-0.300+0.210$, $-0.210+0.150$, $-0.150+0.075$, $-0.075+0.045$ and 0.045 mm. The bulk reject coal was also crushed by a jaw crusher followed by a roll crusher to a -1 mm size. The particles were classified into $-1+0.850$, $-0.850+0.300$, $-0.300+0.210$, $-0.210+0.150$, $-0.150+0.075$, $-0.075+0.045$ and 0.045 mm. The fractions retained on each screen were weighed to get the weight distribution. The classified size fractions were subjected to a sink and float test to assess the liberation and washability characteristics of the coal. A mixture of analytical grade acetone and bromoform was used for sink and float studies. The ultimate analysis of coal was carried out by using a LECO CHNS analyser (Truspec). The detail chemical composition of ash analysis was conducted using Shimadzu AAS 6300, Perkin Elmer Optima ICP OES 2100 DV, and an ELICO Flame Photometer CL22D. The calorific value of the coal was measured by a LECO Bomb Calorie Meter.

2.2. Sink and float test

The sink and float studies were carried out on the classified coal of different size fractions using a medium of specific gravity in the range of 1.3 to 2.0 at an increment of 0.1. The sink-float media of different specific gravities were prepared by mixing acetone (specific gravity, 0.99) and bromoform (specific gravity 2.99) in various proportions. These tests were carried out by the sequential method. After the sink and float tests, the float and sink products were cleaned thoroughly with acetone and dried in an oven at 105 °C. The proximate analysis of different size fractions, sink and float products, was carried out using the ASTM-D-3174 method using LECO TGA 601. The data generated were used for calculation of the characteristic washability curve.

2.3. Particle tribo-charging

The charge measurement of quartz, kaolinite, and carbon were carried out in a rotary cylindrical drum made up of copper. The detailed frictional charging and analysis procedure were described elsewhere [48]. The inside length and diameter of the tribo-charging drum were 0.196 m and 0.108 m, respectively. The drum was rotated at a speed of 35 rpm. About 5 g of sample was weighed and subjected to tribo-charging for a fixed interval of time such as 15, 30, 45, 60 and 90 s. After tribo-charging, the charge acquired by particulate was measured using a Faraday cup connected to a Keithley electrometer 6517 E [48]. The Faraday cup consisted of two stainless steel cups. The base of the outer cup was made up of PTFE to isolate the cups from each other. The copper drum was removed from the driving roll machine and charged particles were poured into the inner cup. The instantaneous charge was measured with the electrometer. The sample in the cup was weighed to calculate the charge to mass ratio of the particles. Each charge measurement was repeated five times to verify the repeatability and consistency of the measurement process. The mean value of the charge was considered, and the associated errors were estimated. All the charge measurements were carried out at different relative humidity (RH) in the range of 10–50% at an increment of 10% of RH. The tribo-electrostatic charge measurement, separation system and its accessories were kept in a closed room to maintain humidity level using a Bry-Air FFB 2000 dehumidifier. Samples for analyses were also prepared in the same environment. The humidity set point was digitally controlled with a variation of ±2%. The humidity at the experiment set-up location was also verified regarding the set point using a 6517-RH humidity probe connected to the electrometer. The observations matched the set humidity value.

2.4. Tribo-electrostatic separation

The tribo-electrostatic separation studies were carried out using in-house designed and fabricated free fall tribo-electrostatic separator. A schematic diagram of the separator is shown in Fig. 1. The details of

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