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Processing of coal fines using air fluidization in an air table

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ABSTRACT

Dry beneficiation of fine coal was investigated using air fluidization in a vibrating air table. A systematic study based on a response surface method of experimentation revealed the features of separation. The ash content of the −1.0 mm coal feed was reduced from 25.8% to 16.2% with 40.9% mass yield of the clean coal. Optimization was carried out for a target clean coal ash and process conditions were identified for maximum mass yield. A detailed statistical analysis revealed the complex nature of influence of the operating variables on the separation performance. Mathematical models for the mass yield and ash content of the clean coal were developed based on the statistical analysis. The operating regimes for any target product were identified. It was established that complex interaction of the process variables described the separation performance. The longitudinal and transverse velocities of the particles were estimated by considering the components of force due to side tilt, end tilt, vibration frequency and bulk flow. The experimental results were explained in the light of the findings from force balance analysis. A phenomenological description of the separation features of air table has also been given.

1. Introduction

Wet cleaning of fine coal has serious issues associated with it. Not only is the dewatering process a daunting task, but the waste disposal is also equally challenging from an environmental perspective. Yet, wet beneficiation is the established practice for fine coal cleaning primarily because of the absence of any proven, commercially viable technology employing dry operations. A number of studies have been reported in literature for dry processing of coal though. An excellent review of dry beneficiation technology was given by Dwari and Rao (2007). Dry beneficiation of coal starts at the deshaling stage. Deshaling units including sorters with improved design features and performance levels were reported to have significant economic benefits (Salter and Wyatt, 1991; King, 1978; Honaker et al., 2006). Coal processing in the coarse size range using modern air jig is claimed to have achieved a quantum jump in terms of performance efficiency (Weinstein and Snoby, 2007). FGX dry separation technology for coarse coal processing has a large number of commercial installations (Lu et al., 2003; Li and Yang, 2006). Air dense medium fluidized bed separation of coarse coal is also reported to achieve significant performance efficiency levels (Zhenfu et al., 2007; Luo and Chen, 2001; Sahu et al., 2005).

However, in the fine coal segment literature has been limited. A fast fluidized bed for dry separation of iron ore and coal is reported for relatively finer size coal (Das et al., 2007). Dwari and Rao (2006) have reported electrostatic separation of mineral matter from the combustible fraction of ROM coal. Another investigation on triboelectric separation of coal was also reported by the same authors (Dwari and Rao, 2008). In the fine size range of coal cleaning, magnetic separation is limited to coals having significant pyrite content only. Such studies were performed using rare earth magnetic separation (REMS) and a good degree of separation was achieved for high-sulfur coals (Donnelly et al., 1994). It was shown that REMS can be used for the removal of iron containing minerals such as siderite and pyrite. The device offered promising results with 3–0.5 mm coal and may be suitable for pre-concentration of high-sulfur coals. The progress of segregation by air fluidization of coal particles over an inclined deck was studied by Chalavadi et al. (2015). The authors identified the separation pattern with reference to a high ash coal in this work. The applicability of an air table for fine coal cleaning was established by Chalavadi et al., 2016. The authors developed flow sheets for treating coals with different characteristics and ash contents using air table in multiple stages.

However, literature on fundamental and applied aspects of coal cleaning using air table has been very scanty. Air fluidization for separating the heavy mineral matter from the light combustibles is a prospective technique for dry beneficiation of coal. Air tables are used for separation of dry uniformly sized solid particles having different specific gravity in a shallow bed with controlled fluidization. Along with fluidization, the tilted and inclined deck of the air table is also subjected to vibration to achieve vertical as well as horizontal stratification. The air table is well suited to process −1.0 + 0.1 mm size coal particles. The ultrafine fraction (−0.1 mm) should preferably be removed from the feed. However, removal of this fraction under dry condition in an industrial scale for continuous operation could be a difficult additional task.

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Thus, keeping the practical application in view, efforts were made to investigate the separation features of the entire − 1.0 mm coal in the present study.

2. Working principle of the air table

Air table works on shallow bed fluidization principle in combination with the principles of stratification in wet shaking table separating the particles on the basis of specific gravity. The air entering from below the deck screen provides an upward thrust and supports the weight of the particles in variable degrees depending upon the size and density of the particle. In fact, the minimum fluidization velocity even for the fine, light particle is also barely reached. Vertical stratification of the particles takes place and the bed forms. Thus, all particles remain in effective contact with the surface of the deck screen. The deck is inclined in both transverse (side tilt) and longitudinal (end tilt) directions. The deck oscillation results in the heavier particles being pushed sideways towards the higher end of the deck on account of moment of inertia combined with traction offered by the deck. This operation results in the separation of particles with different densities and is the essence of fine coal cleaning in air table.

The experimental apparatus used for present study is shown in Fig. 1. It consists of a rectangular deck and the table chest. The deck is 131 cm long and 82 cm wide. It is connected to an eccentric mechanism driven by a variable speed drive motor. This mechanism triggers the desired oscillation in the deck imparting vibratory motion to the particles which leads to the segregation of the particles based on their densities. The oscillation is transmitted to the deck by the tie rods imparting vibration to the deck at an angle β as shown in Fig. 2. The deck is provided with mechanical arrangement (end tilt) for raising and lowering of the discharge end relative to the feed end. Another arrangement (side tilt) for tilting this raised deck to one side is also provided. The air is blown through the deck from blowers mounted below the deck inside the air table chest. The blower speed can be controlled by the variable speed drive motor. Thus, the air flow rate can be controlled as desired. The feed flow rate can be controlled by opening/closing the feed hopper discharge port. Thus, there are essentially five major process variables (degrees of freedom) that influence the separation, namely, the feed rate, deck eccentrics, side tilt, air flow rate and end raise. These are controlled by automatic control panel attached to the unit. The separation performance is actually affected by a strong inter-dependence of these process variables. The material fed into the receiver tank on top passes into the feed hopper. The material is then discharged from the feed hopper onto the deck through the discharge chute with an adjustable opening. The material drops and spreads over the deck continuously at a uniform flow rate.

Fig. 1. Air table set up used in the study.

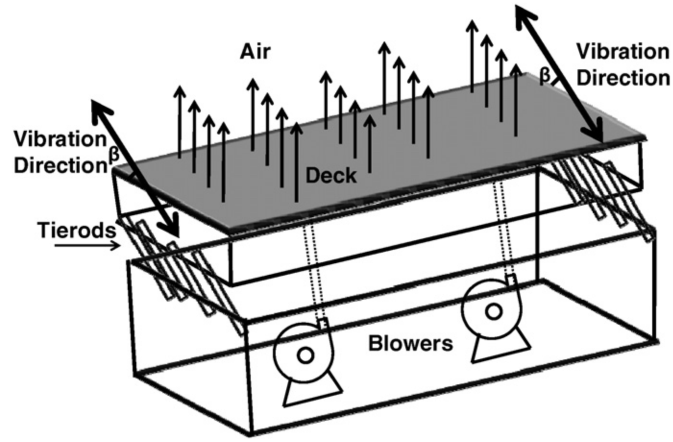

Fig. 2. Transmission of oscillation to the deck is done through the tie rods.

3. Mathematical formulations

The seemingly simple movement of the particles on the deck surface is extremely complex to describe from a fundamental perspective. Apart from gravity and the fluidization forces the particles are also acted upon by vibrating force, frictional force, drag force and the force due to bulk flow of solids down an inclined plane. Consideration of all these forces and interaction among them may be an extremely difficult task. An effort has been made to quantify some of these forces with some degree of simplification and explain the experimental observations from the fundamental understanding derived thereof.

The forces on a particle may be described with the help of Fig. 3. At one corner on the deck surface the feed is introduced from the hopper at controlled rate as shown in the figure. Fluidization helps in vertical stratification while the vibrating force helps in spreading the stratified layer on the deck surface. The deck has a side tilt of φ and an end tilt of θ. Due to the eccentric mechanism the vibrating force acting on the particle makes an angle β with the deck surface. In this direction the displacement S of the particle can be expressed as a simple harmonic motion. The displacement of a particle at any time t is given as.

$$S = A \sin \omega t \tag{1}$$

where ω is the angular velocity and A is the amplitude of vibration.

Therefore, the vibrating force acting on the particle having a mass m is given as

$$F_v = m\frac{d^2S}{dt^2} = -mA\omega^2 \sin \omega t. \tag{2}$$

The normal force on the particle perpendicular to the deck surface will be given by the resultant of the gravity force and the component of the vibration force as follows

$$N = mg\cos\varphi – (-mA\omega^2 \sin \omega t \sin \beta) = m(g\cos\varphi + A\omega^2 \sin \omega t \sin \beta). \tag{3}$$

The frictional force can be easily estimated as

$$F_f = \mu N = \mu m(g\cos\varphi + A\omega^2 \sin \omega t \sin \beta). \tag{4}$$