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Amenability to dry processing of high ash thermal coal using a pneumatic table

Dey Shobhana [a,*], Gangadhar B. [b], Gopalkrishna S.J. [b]

[a] Mineral Processing Division, CSIR-National Metallurgical Laboratory, Jamshedpur 831007, India
[b] Department of Mineral Processing, Vsku Pg Centre, Bellary 583119, India

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ABSTRACT

High ash thermal coal from India was used to conduct the dry processing of fine coal using a pneumatic table to evolve a techno-economically novel technique. The fine as-received sample having 55.2% ash was subjected to washability studies at variant densities from 1.4 to 2.2 to assess the amenability to separation. The experiments were conducted using a central composite design for assessing the interactive effects of the variable parameters of a pneumatic table on the product yield and ash content. The performance of the pneumatic table was analyzed in terms of clean coal yield, recovery of combustibles, separation efficiency (E_{sp}) and useful heat value of clean coal. The combustibles of clean coal obtained through a single stage operation at 35% and 38.7% ash were 40% and 63% respectively. However, the two stage processing was more effective in reducing the ash content in the clean coal. The rougher concentrate generated at higher ash level was subsequently processed in different conditions at 35% ash level, and 58% combustibles could be recovered. Hence, two stage processing increases the combustibles by 18 units and the useful heat value of clean coal increases from 1190 kcal/kg to 3750 kcal/kg.

1. Introduction

India has nearly 88 billion tons of proven reserves of thermal coal. There is an exponential demand of thermal coal by power, cement, paper, textiles and sponge iron units. The quantities of coal being beneficiated and the levels of beneficiation required are increasing while the quality of raw coals is decreasing. Presently, washing of thermal coal in India is typically targeted to yield less than 34% ash. Ministry of Environment and Forest promulgated new regulations in 2001, mandating coals must be cleaned to less than 34% ash content if transported more than 1000 km from pit-heads, or if burnt in urban areas, environmentally sensitive or critically polluted areas irrespective of their distance from the pit-head [1]. The quality of raw coals is on fast decline and hence the imminent requirement of processing is warranted to meet the demand and supply of clean coal. Coal is currently cleaned by size reduction. Wet cleaning adds 15–20% moisture in clean coal in the form of surface moisture, which significantly reduces the calorific values. Only the coarse size fractions are cleaned and the un-cleaned fine coal is added back to the clean coarse coal. Part of the moisture is drained off during transportation, particularly when the coal is transported over a long distance greater than thousand kilometers. Therefore, the processing of fine coals for the recovery of carbonaceous matter by wet processing and disposal of tailings are the major issues. Consequently, the wet-cleaning processes are difficult to justify for pit-head plants. Further, water is a scarce resource in most of the coal mining regions of India.

Indian coals are poor in quality with high ash content and near gravity material. These coals are difficult to wash/clean due to the fine dissemination of the ash-forming minerals in the coal matrices. The power plants were originally designed to handle 25–35% ash coal. On the contrary most of the coals burnt for power generation are raw coals containing 35–50% ash thereby causing low thermal efficiencies, high operating and maintenance costs, erosion, difficulty in pulverization and excessive amount of fly ash with large amount of unburnt carbons. Further, the transportation of high-ash coals is energy intensive, causing shortages of rail cars and trucks. The use of dry beneficiated thermal coal fines can increase the thermal efficiencies by 2–3% on existing pulverized coal boilers [2] and also reduce the emission of CO_2 significantly.

1.1. Need for dry processing

The pneumatic density separation of coal was widely accepted between 1930 and 1960. The reasons of its downfall in 1960s were the inefficiencies of the separators, deterioration in the quality of

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* Corresponding author. Tel.: +91 657 2349020.
E-mail address: sd@nmlindia.org (S. Dey).

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the mined coal, environmental problems and higher percentage of fines and moisture in coal. Undoubtedly the wet processes are more efficient, however the problems associated there on prompting to evolve an alternate techno-environmentally friendly technique like dry methods in recent years [3]. Dry processing requires less energy and no chemical pretreatment. Dry cleaning processes capture the advantages of the differential specific gravity of coal and shale to affect their separation. The principle of operation of dry coal cleaning is identical to conventional wet processes, except that the difference in specific gravity between the air and water has a significant effect upon the size ranges of particles that can be treated in particular separator. The concepts of equal settling and hindered settling ratios are most important in determining the feed preparation requirements, although the role of the latter plays in air separation is far less significant than with the water separation. Differential acceleration is one of the most important phenomena. The time available for effective separation to occur before the critical settling ratios are reached is much less than in wet separation.

The dry processing of fine coal using an air table was commercially introduced in early 1916 in the United States and was quite popular for the next 50 years. Dry processing of coarse coal carried out by several researchers is found to be effective [4–6]. Haibin et al. [5] studied on low ash (25%), coarse coal (−25 mm) from South Africa using a compound dry cleaning apparatus. The application of air table concentrators for fine coal processing has been reported [7–9]. The segregation characteristic of fine lignite in a vibrated gas-fluidized bed was studied by Pengfei et al. [10]. Pneumatic tables are found to be more useable than any other dry gravity concentrator particularly in the food industry as they are originally developed for seed separation [11,12]. However, air tables have major application in the treatment of heavy mineral sand deposit [13,14], cleaning of coal fines [15–17], upgrading of tungsten values [18] and in other applications where water is at a premium [19,20]. A theoretical consideration shows that effective separation in a pneumatic table could be achieved when the time of free fall is minimized.

1.2. Working principle

In a pneumatic table, the feed is introduced from a corner of the deck through a vibrating feeder. The eccentric drive vibrates the deck in a side wise using a slow forward with a rapid return stroke, and the heavier particles move along the deck. Subsequently, the heavier particles are flowed off the deck through the higher side, which channels them downward to the discharge end and are dropped into the right-hand compartment of collecting bin (Fig. 1). On the other hand, the lighter particles which remain fluidized, drift downhill in the direction of the inclination of deck due to gravitational pull and are discharged at the lower end of the deck, and collected into the left-hand compartment of the collecting bin. The lighter material moves down the slope along the shorter route. Heavier particles move upslope due to the movement of the table. The fan blows air upward through the porous deck. The combined effect of the mechanical vibration and airflow dilates and stratifies the bed material on the surface of the deck.

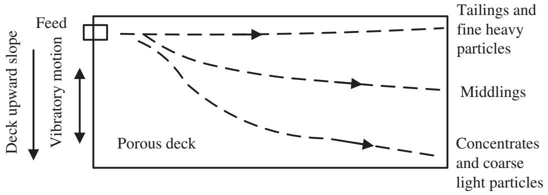

Fig. 1. Separation in a pneumatic table.

Table 1
Characterization of size fractions of feed sample.

Size (μm)	Avg. Sp. Gr	Wt (%)	Ash (%)	UHV (kcal/kg)
−1000 + 710	1.87	42.5	56.2	882.2
−710 + 500	1.86	20.2	56.27	1130.6
−500 + 250	1.84	25.5	55.93	1103.0
−250 + 180	1.75	7.1	55.76	1241.0
−180 + 140	1.72	4.7	55.72	1075.4

The mobility of the material increases with the deck eccentric speed or the increase of air velocity. According to the second law of thermodynamics, any system will show a tendency to achieve minimum i.e. reduction in free energy. The potential energy of the bed decreases when the bed is loosened. The stratification is a free energy reduction process completed through the redistribution and rearrangement of the particles. The particle start falling in accordance with their differential densities and undergoes stratification causing the heavier particles to settle on the deck and contact its surface, while the lighter particles float on the top of the heavier particles. Splitters allow an adjustable middlings fraction to be collected.

Literature studies reveal that a very limited work is being carried out on dry processing of coals/coking coals with high ash content using air table. Interactive effects between the variable parameters were not indicated, however; the effect of single parameter cannot be studied in isolation. The present investigation was carried out on high ash thermal coal which covers two primary objectives.

- Analysis of process variables of a pneumatic table and their interactive effects on responses in beneficiating the high ash thermal coal.
- Reduction of ash in a high ash thermal coal for subsequent enhancement of calorific value.

2. Materials and method

2.1. Materials

In the present investigation the high ash thermal coal sample from Vasundhara coalfield of Odisha, India was taken. The average ash content of the sample is 55.24% indicating that coal belongs to E-category [21]. The fixed carbon in the feed coal is about 22% and the useful heat value is 1190 kcal/kg only. The sample was stage crushed to 1.78 mm (−10 mesh) and −150 μm fraction was discarded. The characterization studies of coal fines were carried out in terms of size distribution and specific gravity of each size fraction (Table 1). The high specific gravity of each fraction reflects the poor quality of feed. It signifies to carry out the washability study of the sample up to very high density of the medium, varying from 1.4 to 2.2. The heat value of each density product was determined.

The minimum fluidizing velocity (u_{mf}) and terminal velocity (u_t) of each size fraction were calculated using Eqs. (1) and (2) [22,23]. The response of air velocity was studied keeping the range between the minimum fluidizing velocity and terminal velocity of the particles. The minimum fluidizing velocity (u_{mf}) is expressed as follows,

$$u_{mf}=\left(\frac{\mu}{D\cdot\rho_g}\right)\times\left\{\left[823.69+0.0494\cdot\left(\frac{D^3\cdot\rho_g\cdot\left(\rho_s-\rho_g\right)\cdot g}{\mu^2}\right)\right]^{1/2}-28.7\right\} \qquad (1)$$