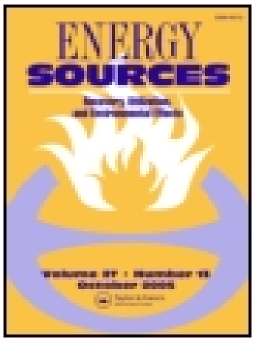

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Screening performance of coal of different size fractions with variation in design and operational flexibilities of the new screening machine

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ABSTRACT

Coal separation was usually carried out using the wet coal beneficiation technique. The waste generated by this technique pollutes the environment. So, in this work, a new mechanism of screening machine for dry coal beneficiation was developed. Dry coal screening removes ash impurities from the coal and improves its energy productivity. Hence, a new screening machine was developed with flexibility in changing the screen mesh, screen angle, and frequency of vibration. In this work, coal feed of less than 6 mm were divided into three groups of −6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm size fractions. Each size fraction was screened individually in the new screening machine by changing the screen mesh to the required perforation. The screening efficiency was determined for each size fraction by varying operational variables such as screen angle and frequency of vibration. This new screening machine provides maximum screening efficiency of 87.36%, 80.52%, and 66.42% for screening coal feed of 6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm size fractions, respectively. Highly efficient screening and higher removal of ash from coal were obtained due to the design and operational flexibilities of the screening machine.

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KEYWORDS
Coal screening; beneficiation; screening machine; screen angle; frequency of vibration

Introduction

Coal is a prime source of energy for the generation of electricity in the world (Çicek 2008; Houwelingen and de Jong 2004; Jiang et al. 2017c, 2017a, 2017b; Zhang et al. 2014). It is prominent in countries like India, China, Australia, South Africa, and some parts of the USA (Houwelingen and de Jong 2004; Zhang et al. 2014). As a result, an effective coal beneficiation technique is the most vital for environmental safety, and for energy resource security and saving (Zhang et al. 2014). The quality and quantity of coal beneficiation are increasing with the demand for environmental safety (Maoming et al. 2003).

Initially, wet coal beneficiation was utilized for the separation of coal (Zhovtiuk 2007). Wet coal beneficiation utilizes an enormous quantity of water and also requires water treatment circuit in the plant for treating the tailings (Houwelingen and de Jong 2004; Zhovtiuk et al. 2007; Sahu, Biswal, and Parida 2009). The pollution and waste produced during this process is a serious threat to the environment (Zhao et al. 2011). Larger coal is available in some areas of India, China, Australia, South Africa, and the USA where there is a scarcity of water (Zhao et al. 2011). Therefore, wet coal beneficiation is difficult to carry out in such countries. Hence, several such countries have given preference for the development of a highly efficient dry coal beneficiation technology.

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Dry coal beneficiation has numerous merits compared with wet coal beneficiation (Chalavadi et al. 2016; Çicek 2008). Some of the significant merits are prevention of consumption of water and elimination of waste and tailing water treatment. The availability of dry coal beneficiation technique for treating fine coals was limited (Chalavadi et al. 2016). So, the development of dry coal beneficiation technology will prove to be most beneficial for coal separation.

The screening process is a major technique used for coal beneficiation and transformation (Nag, Das, and Saxena 2016; Özer, Basha, and Morsi 2017; Zhao et al. 2011). Screening in one of the basic processes performed for size separation or sizing of powdered coal and mineral ore of different size fractions (Jiang et al. 2017c, 2017a, 2017b; Wang et al. 2019). Screening occurs due to the variation in screen vibration and density between the particles. Due to this variation, the fine particles will pass through the coarse particles and then through the screen aperture. Dry coal screening is one of the most difficult and important beneficiation techniques for size separation in India (Wang et al. 2019; Wodzinski 2003). With the increase in the need for dry coal screening, the development of a highly efficient screening machine is of prime necessity (Wang et al. 2019; Zhao et al. 2011). A screening machine with no variation in operational variables always results in low efficiency. An effective dry coal screening operation will not only reduce the cost of beneficiation but also produce good structured coal and improve energy productivity (Jiang et al. 2017b). The removal of ash from the coal is the major objective of numerous coal beneficiation techniques presently available (Osborne and Hughes-Narborough 1998). An efficient screening process will reduce ash impurities, which will provide efficient generation of electricity (Osborne and Hughes-Narborough 1998). So, a new screening machine for the screening of fine coal was developed and filed for patent by the present authors (Shanmugam et al. 2018). The new dry coal screening technology was developed with design flexibility in changing the screen mesh of different perforations and operational flexibility in changing the screen angle and frequency of vibration. In the present work, the study of the design and operational flexibilities of screening fine coal of different size fractions of less than 6 mm was carried out in the new screening machine.

Material used

Fine particles of coal of size fractions between −6 + 0.5 mm were obtained from JSW Steels Ltd., Ballari. The chemical analysis of the coal is presented in Table 1.

The presence of 10.11% ash is the impurity present in the coal, and it is one of the major objectives of numerous coal beneficiation processes (Osborne and Hughes-Narborough 1998). This will improve the energy productivity of the coal (Osborne and Hughes-Narborough 1998). So, in this work, the coal was grouped into three size fractions and was subjected for screening using new screening machine. The size reduction of coal particles during screening will disintegrate the impurities such as ash and improves liberation of coal (Özer, Basha, and Morsi 2017). Therefore, chemical analysis was carried out on each size fractions after screening to determine its ash content.

Preparation of coal feed

The screening of coal of less than 6 mm was difficult and does not meet industrial standards (Maoming et al. 2003). The new screening machine, proposed in the present work, will be utilized for screening such fine coal. Coal feed of size fraction −6 + 0.5 mm was utilized for the present work. It was divided into three groups of −6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm size fractions by

Table 1. Chemical analysis of coal feed.

Chemical	Volatile matter	Ash	Fixed carbon
Percentage	22.42%	10.11%	67.47%

manual sieving, and further, fine particles and coarse particles of the coal feed of size fractions −6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm were further divided by manual sieving.

The fine particles and coarse particles of the −6 + 4 mm size fraction coal feed was of −6 + 5 mm and −5 + 4 mm, respectively. The fine particles and coarse particles of the −4 + 2 mm size fraction coal feed was of −4 + 3 mm and −3 + 2 mm, respectively. The fine particles and coarse particles of the −2 + 0.5 mm size fraction coal feed was of −2 + 1 mm and −1 + 0.5 mm, respectively. A proportion of 30% fine particles and 70% coarse particles were mixed to prepare the coal feed samples. The −6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm coal feeds were screened individually in the screening machine by changing the screen mesh of perforation to 5 mm, 3 mm, and 1 mm, respectively. Thus, the coal screening of size fractions −6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm will produce the final products of −5 mm, −3 mm, and −1 mm, respectively.

Machine used

Figure 1 shows the pictorial representation of new screening machine (Shanmugam et al. 2018). It mainly includes two eccentric shafts, which provides vibration to the screen. The shafts were driven by motors. As the eccentricity provided was 5 mm, the circular mode of vibration provided to the screen was also 5 mm. The eccentric shafts carry the load of the screen and the coal feed poured on to the mesh. The screen is mainly composed of a screen frame attached to the screen mesh, which provides the screening area. The length and width of the screen are 1.2 mm and 0.6 mm, respectively. The screening machine is provided with flexibilities in screen angle and the frequency of vibration.

The screen angle is the angle between the screen and the horizontal plane (Jiang et al. 2017a). It can be controlled in the upward and downward sloping direction by angle-adjusting bolts provided at the ends (feed end and discharge end) of the screening machine. The frequency can be varied by the variable frequency drive. The screening machine has design flexibility of varying the screen mesh. Three screen meshes were used for screening the coal depending on the size fraction. The screen mesh utilized in the present work was of 5 mm, 3 mm, and 1 mm for screening the coal of size

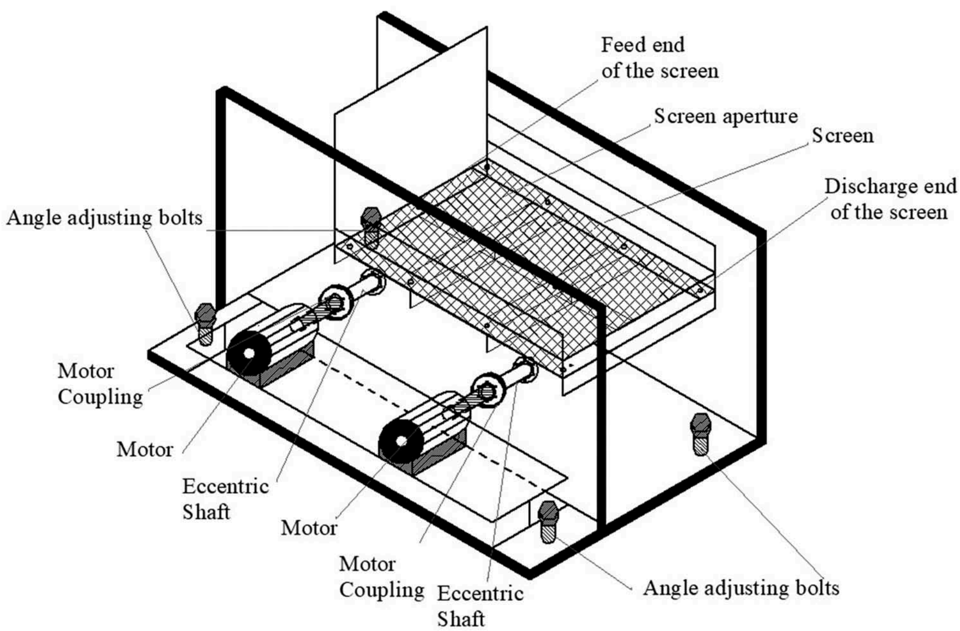

Figure 1. Pictorial representation of the new screening machine.

fractions −6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm, respectively. So, each size fraction of the coal was screened individually in the screening machine by changing the respective screen mesh, screen angle, and frequency of vibration.

Experiment

In the present work, experiments were conducted with variations in the screen mesh, screen angle, and frequency of vibration. All other parameters such as the dimension of the machine, coal material, and moisture content were kept constant. The initial moisture content of the coal was 4.72% and the density of the coal was 1346 Kg/m^3. The settings selected for the present work were: coal feed of size fractions −6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm, screen angle of +1,+2, and +3 degree (upward sloping) and −1,-2, and −3 degree (downward sloping), and the frequency of vibration was 4, 5, 6, 7, 8, 9, 10, 11, and 12 Hz. The perforation of the screen mesh selected was 5 mm, 3 mm, and 1 mm for screening size fractions −6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm, respectively. For each size fraction of the coal feed, experiments were conducted with different screen angles and frequencies.

During experimentation, the screen angle was fixed and one group of coal feed was fed into the screening machine through the feed end using the vibratory feeder as shown in Figure 2. The vibratory feeder was set at 0.5 TPH (Tonnage per hour), i.e., 8.333 Kg/min (Shanmugam et al. 2019). The coal feed consisted of fine and coarse particles. The frequency was set by the variable frequency drive. The fine particles were collected in the collection bag placed under the screen. The remaining particles were collected at the discharge. The variable frequency drive was turned off once all the coal feed was discharged from the screen. The fine particles were weighed and its corresponding screening efficiency was calculated. The screening efficiency is defined as the quantity of fine particles recovered to the fine particles contained in the coal feed (Shanmugam et al. 2019) (Wodzinski 2003). In the present work, the screening efficiency of −6 + 4 mm, −4 + 2mm, and −2 + 0.5 mm coal were discussed.

Results and discussion

Screening performance of −6 + 4 mm size fraction coal

Figure 3 shows the screening performance for −6 + 4 mm coal feed obtained for different screen angles (+3, +2, +1, −1, −2, and −3 degrees) and frequency of vibration (4, 5, 6, 7, 8, 9, 10, 11 and 12 Hz). The highest

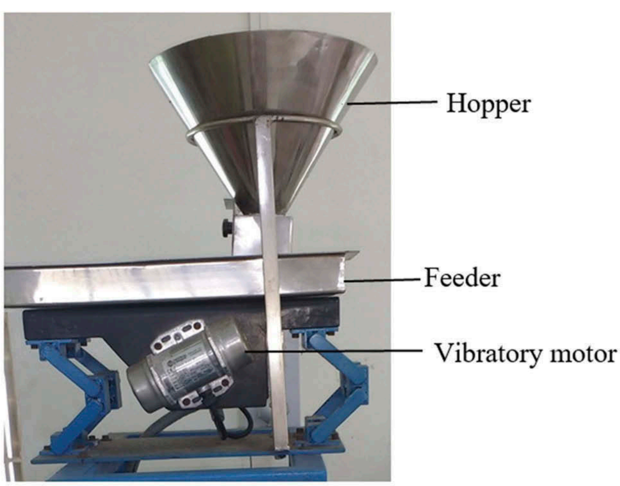

Figure 2. Vibratory feeder.

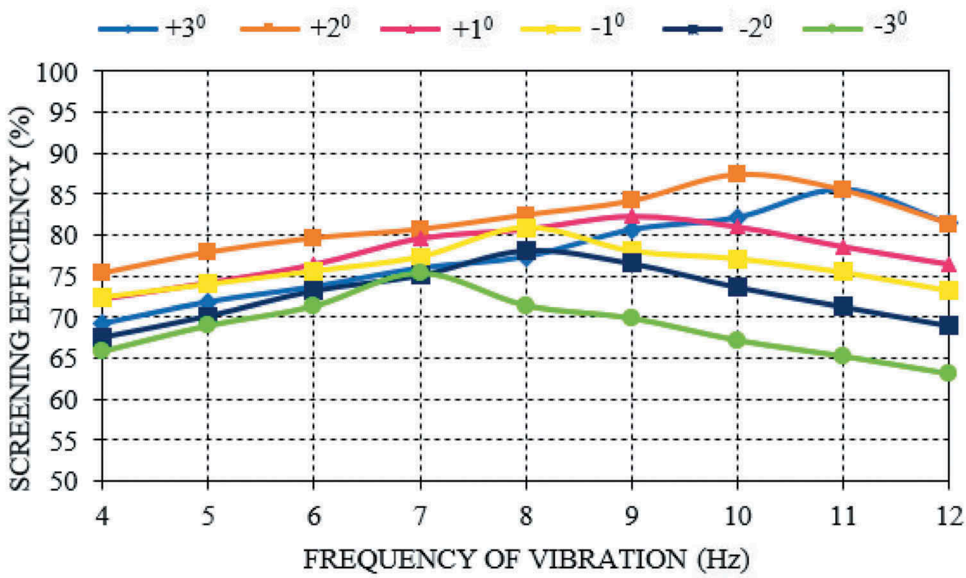

Figure 3. Screening efficiency of −6 + 4 mm coal for variation in screen angles and frequencies.

screening efficiency of 75.26%,78.14%, 80.90%, 82.24%, 87.36% and 85.58% was obtained at screen angles of −3, −2, −1, +1, +2, and +3 degrees, respectively. The screen angle at the upward sloping of +1, +2, and +3 degrees was against the gravity. The increase in screen angle from +1 degree to +2 degrees, and then to +3 degrees reduces the velocity, and also, the coal movement. The reduced velocity of the particles on the screen provides higher residence time for the coal and thereby, increases the opportunities for the fine particles to pass through the screen aperture, which increases its screening efficiency. The screen angle at the downward sloping of −1, −2, and −3 degrees was toward gravity, which increases the velocity of the feed on the screen. This increase in velocity reduces the residence time of the coal feed and thereby, reduces its corresponding efficiency. From Figure 2, it was clear that the −6 + 4 mm coal feed experiences more residence time at the screen angle of +2 degrees. Further increase in screen angle to +3 degrees increases particle vibration and the material retained on the screen leading to reduced efficiency of 85.58%. So, for screening −6 + 4 mm coal feed, maximum screening efficiency of 87.36% was obtained at +2 degrees.

The highest efficiency for screen angles of −3, −2, −1, +1, +2, and +3 degrees were obtained at a frequency of vibration 7 Hz, 8 Hz, 8 Hz, 9 Hz, 10 Hz, and 11 Hz, respectively. As the screen angle was increased from −3 degrees in the downward sloping to +3 degrees in the upward sloping, the frequency increased from 7 Hz to 11 Hz for obtaining highest screening efficiency. The screening in the downward sloping direction was toward gravity, which carries the coal particles due to the screen angle and also requires lower frequency for carrying the coal from the feed to the discharge. The screening in the upward sloping direction was against gravity and requires higher frequency to carry the coal on the screen. The higher frequency also provides higher throwing force of the coal feed, which improves the particle mixing on the screen. So, the maximum efficiency of 87.36% was obtained at 10 Hz. The further increase in frequency to 11 Hz increases the vibration of the coal causing excessive collision between the particles on the screen. This excessive collision reduces the opportunity of the fine particles to pass through the screen aperture, and thereby, reduces the screening efficiency to 85.58%. Maximum screening efficiency of 87.36% for screening −6 + 4 mm coal feed was obtained due to improved coal mixing and stratification on the screen. The improved coal stratification provides for faster fine particles movement between the gaps of the coarse particles to reach the screen aperture, thereby, providing more residence time for the fine particles to pass through the screen aperture.

Screening performance of −4 + 2 mm size fraction coal

Figure 4 shows the screening performance for −4 + 2 mm coal feed obtained for different screen angles (+3, +2, +1, −1, −2, and −3 degrees) and frequency of vibration (4, 5, 6, 7, 8, 9, 10, 11, and 12 Hz). The highest screening efficiency of 72.14%, 75.22%, 79.62%, 80.52%, 77.48%, and 73.62% was obtained at screen angles of −3, −2, −1, +1, +2, and +3 degrees, respectively. For screening −4 + 2 mm coal feed, maximum efficiency of 80.52% was obtained at +1 degree and at 10 Hz. Screening at a frequency of 10 Hz provides for good coal mixing on the screen. Screening at a screen angle in the upward sloping increases the residence time of the fine particles on the screen. So, screening the −4 + 2 mm coal feed at +1 degree and at 10 Hz provided good screening performance. But screening the −4 + 2 mm coal feed above +1 degree and 10 Hz resulted in higher particle vibration, which in turn resulted in the coal retained on the screen and reduced screening efficiency. The circular mode of vibration of the screening machine incorporates vertical force, which lifts the coal particles clogged on to the screen, and thereby, reduces screen clogging (Kumar et al. 2019). This reduction in screen clogging provides good screening efficiency of 80.52%.

Although the screening efficiency was good for screening −4 + 2 mm coal, there was a drop in the screening efficiency from 87.36% to 80.52% as the particle size fraction was reduced from −6 + 4 mm to −4 + 2 mm. This was due to the misplacement of fine particles with the coarse particles during discharge and also due to coal agglomeration on the screen. The coal agglomeration leads to increase in near size particles, which leads to higher screen clogging. Both the fine particles misplacement and coal agglomeration reduces the screening efficiency to 80.52%. Although there was a reduction in the screening efficiency, the results obtained for the screening of −4 + 2 mm coal was good compared with other dry separation techniques.

Screening performance of −2 + 0.5 mm size fraction coal

Figure 5 shows the screening performance for −2 + 0.5 mm coal feed obtained for different screen angles (+3, +2, +1, −1, −2, and −3 degrees) and frequency of vibration (4, 5, 6, 7, 8, 9, 10, 11, and 12 Hz). The highest screening efficiency of 65.16%, 66.42%, 63.08%, 62.93%, 61.76%, and 60.24% was obtained at

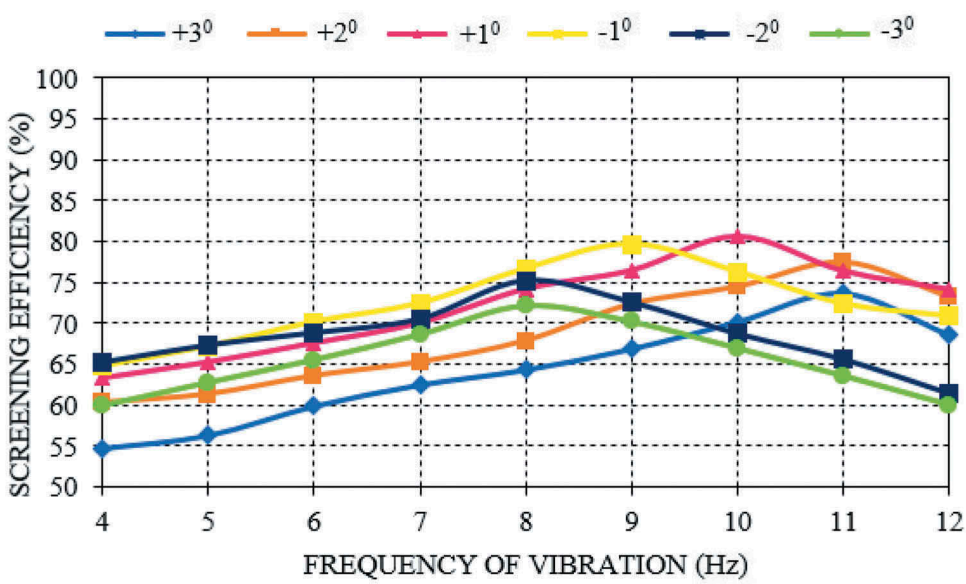

Figure 4. Screening efficiency of −4 + 2 mm coal for variation in screen angles and frequencies.

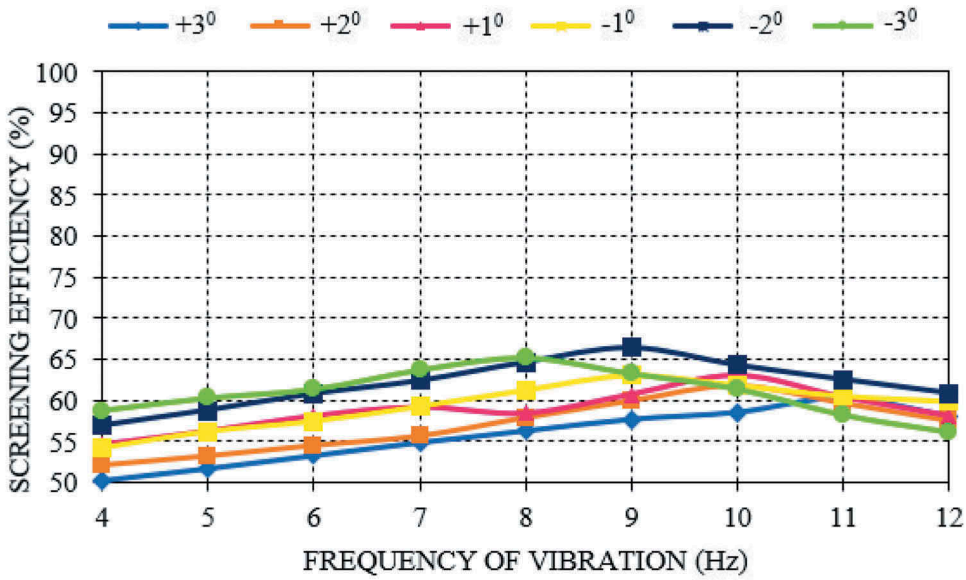

Figure 5. Screening efficiency of −2 + 0.5mm coal for variation in screen angles and frequencies.

screen angles of −3, −2, −1, +1, +2, and +3 degrees, respectively. For screening −4 + 2 mm coal feed, maximum efficiency of 66.42% was obtained at −2 degree and 9 Hz. The results for screening −2 + 0.5 mm coal feed was different compared with the results of −6 + 4 mm and −4 + 2 mm coal feeds. Maximum efficiency for screening −6 + 4 mm and −4 + 2 mm was obtained at the screen angle in the upward sloping at a frequency of 10 Hz. But maximum screening efficiency for screening −2 + 0.5 mm coal feed was obtained at the screen angle in the downward sloping at a comparatively lower frequency of vibration of 9 Hz.

Screening the −2 + 0.5 mm coal feed in the upward sloping and higher frequency led to excessive fine particles misplacement and coal agglomeration on the screen. It was observed that fine particles misplacement and coal agglomeration was found to be very high during the screening of coal feed of size fraction −2 + 0.5 mm compared with the screening of coal feed of −6 + 4 mm and −2 + 4 mm size fractions. The higher fine particles got misplaced with the coarse particles, which reduced the opportunity of the fine particles to pass through the screen aperture, thereby, reducing screening efficiency. The higher coal agglomeration led to increase in screen clogging as shown in Figure 6.

It was also observed that in the screening of −2 + 0.5 mm coal feed, the eccentricity provided to the screen was not enough to increase coal mixing and stratification, which would reduce screening performance. It was also observed that for screening 2 + 0.5 mm coal feed, the screen required higher eccentricity of more than 5 mm for lifting the clogged material from the screen aperture and reducing the screen clogging. The excessive fine particles misplacement, coal agglomeration, screen clogging, and reduced particle stratification led to a higher reduction in the screening efficiency to 66.42%.

It was also found that for screening coal feed of size fractions −6 + 4 mm and −4 + 2 mm, the eccentricity provided was enough to increase coal mixing, stratification, and reduce screen clogging, which led to good screening efficiency. The results showed that the design and operational flexibilities ensured perfect conditions for screening. Reducing the size fraction of the coal reduced the ash content and increased the liberation of the coal (Özer, Basha, and Morsi 2017). The ash percentage in the coal need to be reduced less than 10% for utilization in the blast furnace. So, in the present work, the chemical analysis was carried out on the fine coal obtained after screening. The ash content of the fine coal obtained from screening coal feed of −6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm size fractions was 9.35%, 8.94%, and 8.46%, respectively. From the results, it was clear

Figure 6. Screen clogging of −2 + 0.5 mm coal.

that the ash content reduced with the reduction in the size fraction of the coal. So, the new screening machine is a very significant and efficient separation technique for removing ash impurities during screening coal of size fraction less than 6 mm. The development of the present screening machine will be a successful and suitable replacement for the existing wet and dry separation techniques.

Conclusions

A study on the coal screening relevant to a screening machine with design and operational flexibilities has been highlighted. An efficient screening machine with flexibility in design variable such as a change in screen mesh along with flexibility in operational variables such as the screen angle and frequency of vibration was developed. An attempt was made to test the performance of the screening machine with flexibility for the screening of coal less than 6 mm. So, in the present work, coal less than 6 mm was divided into three groups of −6 + 4 mm, −4 + 2 mm, −2 + 0.5 mm size fractions, which was screened individually in the screening machine by changing the screen mesh to 5 mm, 3 mm, and 1 mm perforation, respectively.

The maximum screening efficiency of −6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm size fractions was found to be 87.36%, 80.52%, and 66.42%, respectively. The optimum screen angle for obtaining maximum screening efficiency for coal feed of size fractions −6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm was +2 degrees, +1 degree, and −1 degree, respectively. The maximum screening efficiency for screening coal feed of size fractions −6 + 4 mm, −4 + 2 mm, and −2 + 0.5 mm were obtained at a frequency of vibration of 10 Hz, 10 Hz, and 9 Hz, respectively. As the particle size of the coal was reduced from −6 + 4 mm to −2 + 0.5 mm, the screening efficiency reduced from 87.36% to 66.42%. This reduction was due to excessive fine coal misplacement, coal agglomeration, screen clogging, and reduced particle stratification. The new screening machine offers higher screening performance and higher removal of ash impurities compared with the other types of screening machines. The results show that the proposed screening machine will be a breakthrough in the field of dry coal separation and also provide financial benefits.

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