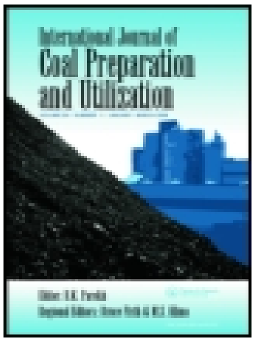

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Evaluation of a new vibrating screen for dry screening fine coal with different moisture contents

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ABSTRACT

A new vibrating screen was developed with a circular mode of vibration for dry screening of moist coal of size fraction −3 + 1 mm. Screen mesh of 2 mm aperture size will be used to separate the finer coal particles of size fraction −2 + 1 mm. The new vibrating screen has the flexibility in changing the operational parameters such as the angle of the screen in upward or downward sloping direction and frequency of vibration of the screen deck. The circular mode of vibration provided to the screen deck will incorporate the inertial force on the particle in the screen deck, reducing screen clogging. The present study involves the analysis of the screening performance of the new vibrating screen with the coal feed of varying moisture content of 4%, 6% and 8%. The maximum screening efficiencies obtained for screening the coal feed with the moisture contents of 4%, 6% and 8% were 85.96%, 77.84%, and 68.27%, respectively. The higher screening performance of new vibrating screen was obtained due to good exposure time, particle mixing, particle segregation and particle stratification of coal on the screen deck. The results of the new vibrating screen will be a breakthrough in dry screening technology and accelerate the pilot-scale development.

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Coal beneficiation; dry screening; vibrating screen; circular mode of vibration; angle of the screen; frequency of vibration

Introduction

The total consumption of coal in India was 845.19 million tonnes in 2017 (Energy Statistics 2018). Coal has to undergo various beneficiation process, which is the basic requirement for obtaining clean coal for utilization (Jiang et al. 2017b). Wet beneficiation has been utilized, but has numerous problems such as requiring large amounts of water during separation, losing water during tailings disposal, and problems related to the treatment of tailings water (Houwelingen and de Jong 2004; Sahu, Biswal, and Parida 2009; Zhao et al. 2011; Zhovtiuk 1988).

Screening is a key process for classification of coal into different size fractions (Jiang et al. 2017a; Jiang et al. 2017b; Wang et al. 2019). Over the past fifty years, wet coal screening has been more important compared to dry coal screening, mainly because of good screening efficiency (Sahu, Biswal, and Parida 2009).

Dry coal screening is the most difficult method of screening (Wodzinski 2003), which requires a lot of development. Some work on dry coal screening has been carried out in

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India, China, South Africa, Australia, and the USA (Houwelingen and de Jong 2004; Sahu, Biswal, and Parida 2009; Zhang et al. 2014). Dry coal screening prevents excess water consumption, which has provided motivation in the development of new dry screening technology. An efficient dry vibrating screen will produce clean coal that can reduce the production cost and increase financial benefits (Jiang et al. 2017c).

The dry separation of moist coal for size fractions below 6 mm is difficult (Maoming et al. 2003). So, a new vibrating screen was developed with the circular mode of vibration to screen deck for screening the difficult to screen moist coal of size fraction −3 + 1 mm (Bharath et al. 2018). The new vibrating screen also provides the flexibility in varying the operational parameters such as the angle of the screen in upward or downward sloping direction and frequency of vibration.

The paper presents the investigation on the screening performance of the new vibrating screen for dry separation of difficult to screen moist coal of size fraction −3 + 1 mm. A comparative study was carried out to determine the influence of operational parameters such as the angle of screen and frequency of vibration.

Experimental Details

Material Used

The bituminous coal used for this study was obtained from South African coal mine by JSW Steels Ltd, Ballari in India. Proximate analysis indicated that the coal had 22.42% volatile matter, 10.11% ash and 67.47% fixed carbon on a dry basis. The ash value needs to be reduced to less than 10% for use in the blast furnace during the production of iron ore. The screened product i.e., finer particles of −2 + 1 mm has reduced the ash content from 10.11% to 8.72% which was obtained by proximate analysis.

Preparation of Coal Feed

The raw coal was crushed with the help of jaw crusher before screening. The coal was manually sieved into size fractions of −2 + 1 mm and −3 + 2 mm. After sieving of mixture containing 70% −3 + 2 mm and 30% −2 + 1 mm was prepared. The initial moisture content of the coal feed was 2.45%. The water was added to the −3 + 1 mm mixture to obtained the desired moisture content. The moisture content was measured by Moisture Analyser – MX 50. Three different coal feeds of varying moisture content of 4%, 6% and 8% were prepared individually.

Machine Used

A vibrating screen with no flexibility in operational parameters will usually result in low screening performance. From the literature, it was found that a limited number of publications and patents on vibrating screens with flexibilities in operational parameters was available. Therefore, a new vibrating screen with operational flexibility and a circular mode of vibration was developed for the screening of moist coal, resulting in a patent application by the authors (Bharath et al. 2018). A schematic of the new vibrating screen is shown in Figure 1.

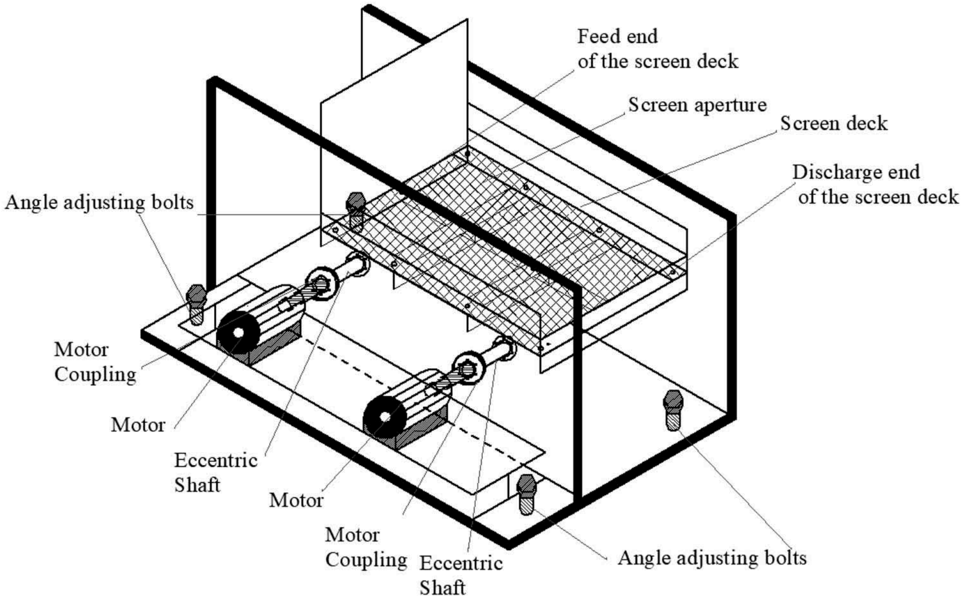

Figure 1. Schematic of the new vibrating screen with the circular mode of vibration.

The new vibrating screen consists of a screen deck, two shafts with 5 mm eccentricity connected to the respective motors near the feed end and the discharge end of the screen deck. The vibrating screen has a rectangular screen deck of width 0.6 m and length 1.2 m, which provides the area for screening. A screen mesh of 2 mm aperture size will be used for separating the finer coal particles of size fraction −2 + 1 mm from the coal feed of size fraction −3 + 1 mm. The two eccentric shafts are connected to the screen deck at the bottom surface. The eccentric shafts will provide the circular mode of vibration to the screen deck and also carry the weight of the coal feed and screen deck. The circular mode of vibration to the screen deck was provided by the 5 mm eccentricity of the shafts connected to the respective motors. The feed end and discharge end have the same amplitude and stroke length of 5 mm. The coal feed will enter the screen at the feed end, and the circular mode of vibration will carry the coal particles to the discharge end of the screen deck. The circular mode of vibration provided to the screen deck, together with variation in the angle of the screen (in upward or downward sloping direction) and frequency of vibration can provide good screening performance.

Experiment

The new vibrating screen was utilized for screening the difficult to screen raw moist coal of size fraction −3 + 1 mm. In the current investigation, experiments were carried out with the difference in angle of the screen in the upward or downward sloping direction, frequency of vibration and the moisture content. The angle of the screen can be controlled by the angle adjusting bolt provided at the base near the feed end and discharge end. Frequency of vibration can be controlled by a variable frequency drive. Three different samples of coal feed with varying moisture contents were prepared.

The following settings were selected: Angle of screen: −1,-3,-5 degrees (downward sloping direction) and +1,+3,+5 degrees (upward sloping direction), frequency of vibration of the screen deck: 4, 5, 6, 7, 8, 9, 10, 11 and 12 Hz and moisture content of 4%, 6% and 8%.

During the screening, the angle of the screen was set in the upward or downward sloping direction at one angular inclination. The coal feed of one group of moisture content was fed at the feed rate of 500 Kg/hr i.e., 8.33 Kg/min to the screen deck by vibrating feeder. The feed rate was kept constant for all the experiments. The variable frequency drive was switched on, and frequency of vibration of the screen deck was set. As the screen deck vibrates, the circular mode of vibration of the screen deck is transmitted to the coal feed on the screen deck. The screening will take place and the particle stratification occurs on the screen. After screening, the finer particles are collected below the screen deck and the coarser particles are collected at the discharge end of the screen deck. After screening, the weight of the finer particles collected was measured and screening efficiency was determined. The screening efficiency was defined as the ratio of the amount of finer mass product that was recovered in the fine product to the amount of finer mass product that was contained in the raw material (Wodzinski 2003).

Results and Discussion

Figure 2 shows the variation in screening efficiency with variation of screen angle and frequency of vibration for the 4% moisture content coal. For screen angles of +1, +3 and +5 degrees in the upward sloping direction, the highest screening efficiency obtained for each angle was 85.96%, 78.43%, and 71.37%, respectively. For screen angles of −1, −3 and

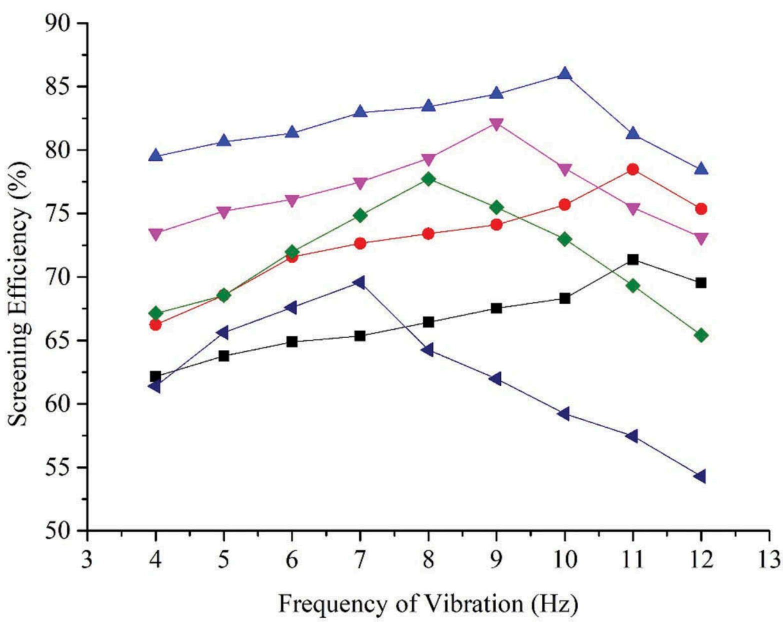

Figure 2. Screening efficiency of the coal feed of 4% moisture content for the different screen angles (—■—+ 5 degrees,—●—+ 3 degrees,—▲—+ 1 degree,—▼—-1 degree,—◆—-3 degrees,—◄—-5 degrees) and frequencies of vibration.

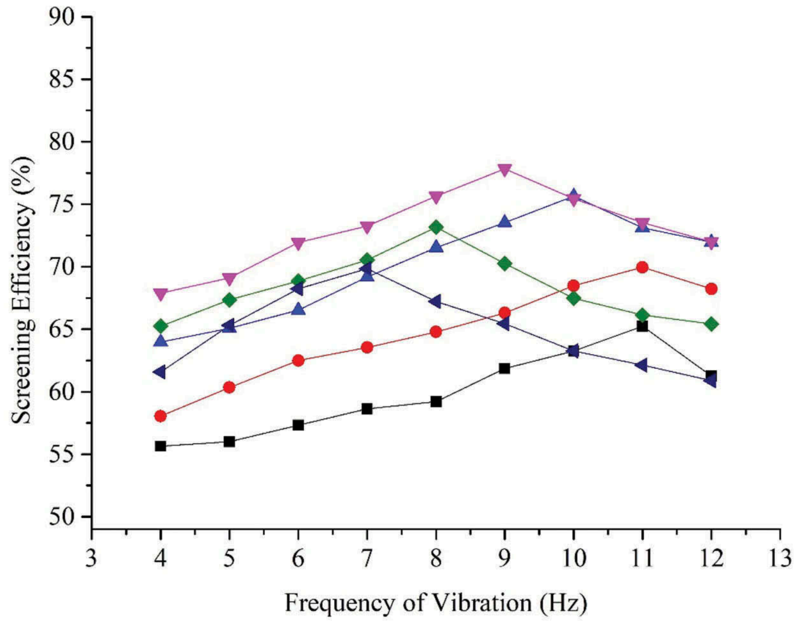

Figure 3. Screening efficiency of the coal feed of 6% moisture content for the different screen angles (—■—+ 5 degrees,—●—+ 3 degrees,—▲—+ 1 degree,—▼—-1 degree,—◆—-3 degrees,—◄—-5 degrees) and frequencies of vibration.

−5 degrees in the downward sloping direction, the highest screening efficiency obtained for each angle was 82.14%, 77.72%, and 69.57%, respectively. The maximum screening efficiency of 85.96% was obtained at 10 Hz and +1 degree.

Figure 3 shows the variation in screening efficiency with variation of screen angle and frequency of vibration for the 6% moisture content coal. For screen angles of +1, +3 and +5 degrees in the upward sloping direction, the highest screening efficiency obtained for each angle was 75.64%, 69.96%, and 65.23%, respectively. For screen angles of −1, −3 and −5 degrees in the downward sloping direction, the highest screening efficiency obtained for each angle was 77.84%, 73.17%, and 69.85%, respectively. The maximum screening efficiency of 77.84% was obtained at 9 Hz and −1 degree.

Figure 4 shows the variation in screening efficiency with variation of screen angle and frequency of vibration for the 8% moisture content coal. For screen angles of +1, +3 and +5 degrees in the upward sloping direction, the highest screening efficiency obtained for each angle was 63.11%, 59.21%, and 56.63%, respectively. For screen angles of −1, −3 and −5 degrees in the downward sloping direction, the highest screening efficiency obtained for each angle was 65.14%, 68.27%, and 63.58%, respectively. The maximum screening efficiency of 68.27% was obtained at 7 Hz and −3 degrees.

Influence of Angle of the Screen on Screening

The maximum screening efficiencies obtained for moisture contents of 4%, 6% and 8% were 85.96%, 77.84%, and 68.27%, respectively. These corresponded to screen angles of +1 degree, −1 degree and −3 degrees, respectively.

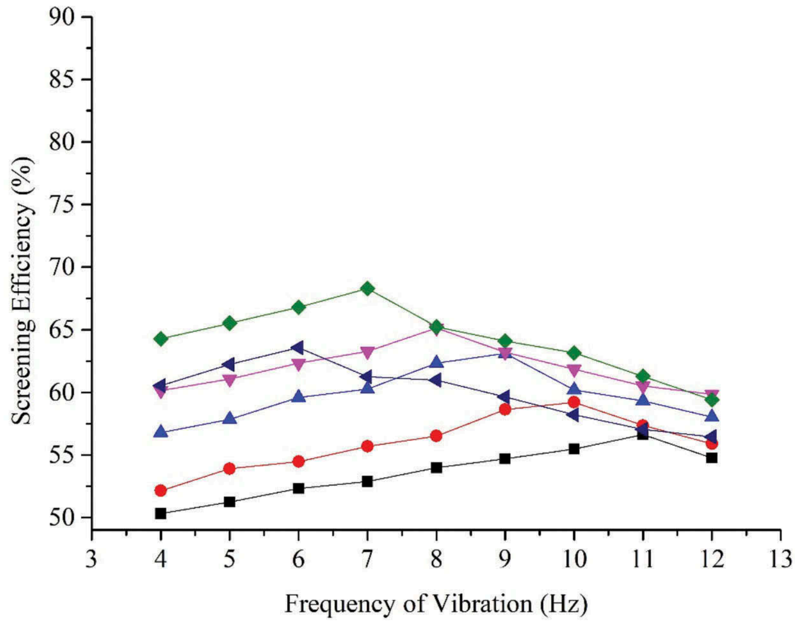

Figure 4. Screening efficiency of the coal feed of 8% moisture content for the different screen angles (—■—+ 5 degrees,—●—+ 3 degrees,—▲—+ 1 degree,—▼—-1 degree,—◆—-3 degrees,—◀—-5 degrees) and frequencies of vibration.

During screening, particle stratification leads to the formation of a layer of fine particles above the screen aperture. The angle of the screen will control the movement of the particles along the screen deck thereby increasing the retention time of particles on the screen deck. The increased retention time of the finer particles on the screen aperture increases the probability of finer particles passing the screen aperture. The screening efficiency is directly proportional to the probability of finer particles passing through the screen aperture (Zhovtiuk 1988).

Although the Steeper angle such as +3 degrees and +5 degrees gives longer retention time, the coal feed material movement was reduced from the feed end to discharge end of the screen deck with the steeper angle. Some portion of the coal feed was retained in the feed end of the screen deck which has reduced the screen exposure of such coal feed materials. So, the lesser screen exposure of some portion of coal feed has reduced screening efficiency for steeper angles.

Influence of Frequency of Vibration on Screening

The screen deck with the circular mode of vibration creates centrifugal force to throw the particles opposite to the direction of rotation of the eccentric shafts, for separating the finer particles from the coarser particles.

For the screening of 4% moisture coal feed, the maximum screening efficiency was obtained at a screen angle of +1 degree and a frequency of vibration of 10 Hz. The screening in the upward sloping direction with the higher frequency of vibration of 10 Hz increases the acceleration cycle of the coal on the screen deck. The acceleration cycle will carry the coal feed from feed end to the discharge end of the screen deck. The further increase in the frequency of vibration above the maximum screening efficiency condition creates an intense mixing of particles on the screen deck. The intense mixing reduces the movement of the coal particles on the screen deck. The reduced movement of the coal particles increases the retention of the coal particles on the screen deck, which will reduce screening efficiency.

For the screening of 6% and 8% moisture coal feed, the maximum screening efficiencies were obtained at screen angles of −1 degree and −3 degrees in downward sloping direction and at frequencies of vibration of 8 Hz and 7 Hz, respectively. As the angle of the screen is changed from an upward sloping direction to a downward sloping direction, a lower frequency of vibration was required to obtain good screening performance. If the frequency of vibration was reduced below the maximum screening efficiency condition, then the movement of the coal particles on the screen deck was difficult, which increased the retention of coal particles on the screen deck.

Both conditions of higher and lower frequency of vibration lead to higher retention of the coal particles, which reduces screening efficiency. So, optimum frequency of vibration has to be maintained. The optimum frequency of vibration will provide good mixing of the coal feed on the screen. The good mixing will provide good segregation of coal particles on the screen thereby increasing the screening efficiency. The circular mode of vibration provided with an optimum frequency of vibration to the screen deck will reduce the impact of the material on the screen mesh which will reduce the breakage of material to generate fines. This is referred as 'fines production'. The coal has high tendency of ignition. The reduction in the fine generation will reduce the risk of ignition which reduces the accident such as fire, explosion, etc., and also prevents dust production which provides safe and healthy conditions to the labour.

Influence of Moisture Content on Screening

The handling of the finer particles of coal feed with higher moisture content is difficult to screen due to the higher agglomeration of the coal particles (Özer, Basha, and Morsi 2017). The presence of finer particles will agglomerate with coarser particles, which increase the size of the agglomerates, leading to the production of near-size particles on the screen aperture (Özer, Basha, and Morsi 2017). The near-size particles can lead to blinding of the screen apertures (Özer, Basha, and Morsi 2017). This problem was solved by the circular mode of vibration of the new vibrating screen, which incorporates both horizontal and vertical forces on the coal particles on the screen deck. Both forces will loosen the agglomerated fine particles on the screen deck during screening. The loosening of the agglomerated particles will improve the particle segregation and particle stratification on the screen deck.

Figure 5 showing the near-sized particles clogged to the screen aperture. The circular mode of vibration in the new vibrating screen incorporates the vertical force, which provides an inertial force on the particles on the screen deck (Feller, Zion, and Pagi 1986). The inertial force lifts the near-sized particles clogged in the screen aperture (Feller, Zion, and Pagi 1986). This avoids blinding during screening and increases the screening efficiency (Feller, Zion, and Pagi 1986).

Figure 5. Screen clogging to the screen aperture.

The eccentricity of the circular mode of vibration of 5 mm provided to the screen deck provided sufficient inertial force for the 4% moisture coal feed to obtain good screening efficiency of 85.96%. As the moisture content of coal feed was increased to 6%, the screening efficiency was reduced to 77.84%. The further increase in the moisture content of coal feed to 8% reduced the screening efficiency to 68.27%. So, the sufficient increase in eccentricity more than 5 mm will increase the particle loosening, particle segregation, particle stratification and also reduces the screen clogging. Thus, the increase in eccentricity will increase the screening efficiency of the new vibrating screen for screening high moist coal particles. From the results, it is clear that the new vibrating screen with the circular mode of vibration can provide higher screening efficiency without consumption of water compared to wet screening. So, dry screening with the new vibrating screen can be a suitable replacement for wet screening.

Conclusions

A study on the performance of a new vibrating screen when screening coal with various moisture contents has been highlighted. A screen mesh of 2 mm aperture size will be used for separating the finer coal particles of size fraction −2 + 1 mm from the coal feed of size fraction −3 + 1 mm. The angle of the screen and frequency of vibration can be varied. The maximum screening efficiencies for coal moisture contents of 4%, 6% and 8% were obtained at screen angles of +1, −1 and −3 degrees and frequencies of vibration of 10 Hz, 9 Hz, and 7 Hz, respectively. The highest screening efficiency of 85.96% was obtained for screening the 4% moisture coal feed but also the lowest feed moisture is due to sufficient eccentricity for obtaining reduced screen clogging, good particle segregation and particle stratification of the coal particle on the screen deck. The lowest screening efficiency for the 8% moisture coal was due to the agglomeration of finer particles with the coarser particles. The agglomeration results in blinding, reducing particle segregation and particle stratification and less retention time of the coal particles on the screen deck.

The circular mode of vibration provided with an optimum frequency of vibration to the screen deck will reduce the impact of the material on the screen mesh which will reduce the breakage of material to generate fines. This is referred to as 'fines production'. The coal has a high tendency of ignition. The reduction in the fine generation will reduce the risk of ignition which reduces the accident such as fire, explosion, etc., and also prevents dust production which provides safe and healthy conditions to the labour. The new vibrating screen has advantages such as easy operation, easy maintenance, reduced moving parts also provides high screening efficiency. The results of the new laboratory-scale vibrating screen will accelerate the pilot-scale development of the vibrating screen.

Acknowledgments

NITK, Surathkal and JSW Steel, Ballari, have been in collaborative agreement during the course of this research work. A joint patent has been filled on the new type vibrating screen by NITK, Surathkal and JSW Steel, Ballari and the temporary patent application number is TEMP/E-1/53448/2018-MUM.

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