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Selective drop breakage studies: a precursor for dry deshaling of Indian non-coking coals

The coal seams in India are mostly inter-banded, containing stone and hard shales, since such bands cannot be separated during the mining operations; these are mixed with the coal, thereby increasing the ash per cent of the run-of-mine (ROM) coal. In majority of the coalfields, it was found that the nature/character of the coal and stone is such that the stone is harder than the coal. Hence, it may be possible to remove the hard stone by incorporating a rotary breaker at the pithead or coal handling plant. However, before installing a rotary breaker, it is very much essential to understand the breakage characteristics of the coal and stone.

The present investigation includes selective drop breakage tests of coals and stones from variable heights. The differential breakage patterns of this material have been quantified in terms of Selective Crushing Index and its dependence on number of drops and heights. Attempts have been made to find a breakage constant with the assumption of drop breakage as a first-order process dominated by volume breakage. Results of the selective drop breakage tests on coal and stone from non-coking coalfields showed that there is a good potential of installing a rotary breaker at the pithead.

Introduction

Amongst other natural resources, coal occupies the key position as a major resource of commercial energy. As of today, the total reserves of coal in India are 265 billion tonnes. The coking coal reserves are very much limited, which constitute about 15% of the total coal reserves (GSI, 2010).

The majority of Indian coal reserves are of inferior quality with ash content between 24 and 45% and as high as 55% in some areas. The ash content in coal as delivered to some power plants is around 45%, which leads to various problems both at the supplier and user ends. The high ash content of coal generates various problems like an increase in erosion of heat exchange surfaces of the boiler, increased maintenance, higher transportation cost, increase of particulate emissions, and requirement of large area for fly ash disposal etc. (Saradana 2002).

Most of the coal seams are inter-banded, and the bands within the same seam or between the seams are sometimes thin containing stone and hard shales and such seams are found in most of the coalfields of India. Since, such bands cannot be separated during the mining operations; these get mixed with the coal, increasing the ash per cent of the ROM coal. Weak and soft roof and floor of the coal seams are also a contributory factor to deterioration in the quality of the ROM coal. Some dirts are disseminated in all the size fractions of coal as well as in the coal matrix. These factors are responsible for inconsistency in the ROM coal quality, particularly with regard to ash and moisture content. (Sen 1999).

A cost-effective technique for deshaling of these non-coking coals which are inferior in nature and contain high amounts of stone and hard shales is needed. This necessitates proper investigations on the properties of the non-coking coals with regard to breakage characteristics etc. (Biswas 1995). It is also desirable to identify a suitable size reduction unit to produce products with the appropriate size distribution akin to industrial scale and explore the possibility of dry deshaling devices like rotary breakers. Studies on the application of single particle breakage data to the modelling of the breakage processes in a rotary breaker for Australian coals, showed that rotary breaker may be used for size reduction to reduce the fines generation (Esterle, 1996). These devices remove the hard stone and shale, which reduces the ROM ash content and facilitates uniform feed supply and also reduce the fines generation. The scope exists to design a suitable rotary breaker for a particular coal/stone combination.

Experimental

Samples of discrete coal and stone pieces of size + 500 mm were collected from opencast coal mine where the total thickness of the working seam is about 28 m. The individual pieces were marked properly and the three dimension sides were measured for carrying out the detailed drop breakage tests.

Fig.1 shows the variable height belt conveyor wherein the following specifications were used for dropping the individual lumps of coal and stone pieces from various heights:

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Belt speed	:	1.36 m/sec
Conveyor length	:	9 m
Capacity	:	10 tph
Inclination	:	18^o (max) and 12^o (min)
Lift	:	3.290 m (max) and 2.045 m (min)

A thick manganese steel plate (25 mm thick) with perforations of desired size was placed in a wooden box of size 1800 × 1800 × 600 mm, so that the plate was at least 300 mm above the ground to cause resilient effect. This wooden box which had wheels was placed exactly below the belt conveyor.

Fig.1 Selective drop breakage experimental set-up

Individual lumps of coal and stone (free from visible cracks or fissures) were chosen, and they were individually measured in three dimensions and weighed. These lumps of coal/stone were dropped from heights of 2.0, 2.5, 3.0 m on to a manganese steel plate of dimension 1800 × 1800 × 600 mm. Usually when these lumps were dropped, some broke while some remained unbroken. The oversize material (i.e. + 200 mm) was screened in 250, 200 mm square hole screens and weighed separately the undersize material was also screened at 150, 125, 100 ,75, 50, 25, 13, 6 and 3 mm and weighed. The data generated for each drop was recorded and used for mathematical interpretations. This procedure was repeated until most of the coal/stone samples (95%) passed through the nominal top size.

Selective crushing index

The Selective Crushing Index (SCI) between coal and stone is given by:

$$SCI = i_{coal}/i_{stone} \quad \ldots \quad (1)$$

where,

i_{coal} = crushing degree for coal

i_{stone} = crushing degree for stone, under the same conditions

$$\text{Crushing degree } (i) = d_o/d_p \quad \ldots \quad (2)$$

where,

d_o = Average diameter of material before crushing

d_p = Average diameter of material after crushing

The process of selective crushing and removal of rejects as oversize are considered:

Low when	SCI = 1 to 1.5
Medium when	SCI = 1.5 to 2.5
Good when	SCI = more than 2.5

The data generated from the selective drop breakage tests were used for calculating the SCI values and depicted in Fig.2.

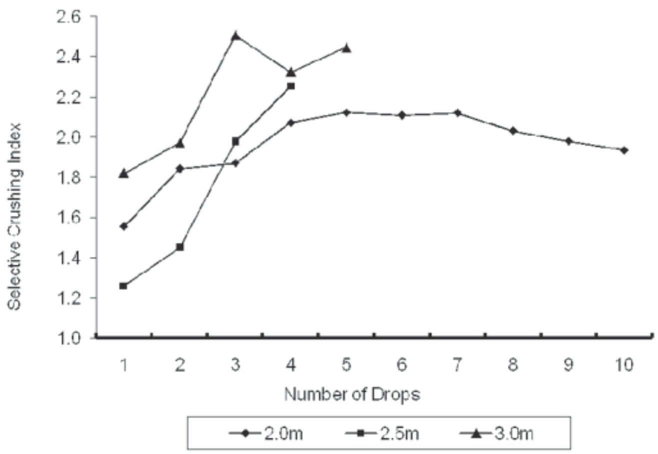

Fig.2 Selective crushing index of coal: Stone at different drop height

PARTICLE SIZING

The oversize retained on a particular screen after each subsequent drop of the individual samples of coal and stone when plotted as cum. wt.% vs. no. of drops indicates the extent of separation between coal and stone over that particular screen. These data are very useful in determining the extent of stone removal at a particular size, height and number of drops (Fig.3).

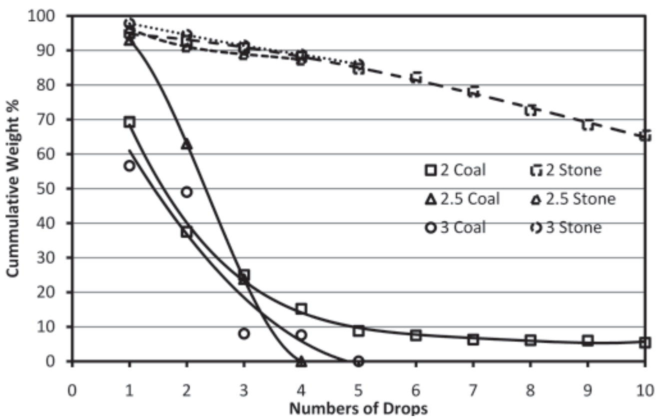

Fig.3 Cumulative wt% retained over 200 mm screen at 2.0 m, 2.5 m and 3.0 m drop height

An effective means of representing the particle size distribution data as suggested by Rosin-Rammler-Bennet (RRB) is to plot the log (log distribution of the cumulative weight per cent retained/100) against the log of the screen size. This graphical representation allows one to set the undersize/ oversize at any screen size and also helps to identify the characteristic particle size (material retained, 36.8%).

The Rosin-Rammler-Bennet (RRB) distribution curve is commonly used to describe a particle size distribution after size reduction. In the present case the RRB distribution was fitted to the products of a discrete sample of lump coal/stone after each drop. For each height the average of three samples was taken and the RRB plots were plotted for the different drop heights (Fig.4)

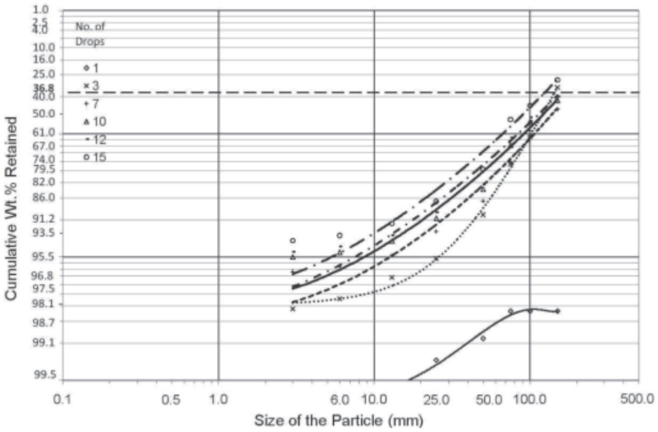

Fig.4 RRB plots for coal sample drop height 3.0 m

BREAKAGE PARAMETERS

To understand the breakage characteristics, mathematical treatment of size reduction data is of paramount importance. This ranges from a simple empirical relationship to more complicated treatments including the concept of selection function and breakage distribution function. The mathematical modelling of coal broken by Bradford breaker and drop shatter technique incorporating pendulum breakage function was developed for comparison of model predictions with actual observed values, using conventional modelling techniques for two Australian coals (Grouhel, 1988). In the present study an attempt was made to mathematically fit the data to standard Rosin Rammler distribution function and also to make a quantitative description of the process.

The breakage of coal, stone etc. follow a definite pattern depending upon its geological history, inherent properties and previous history of degradation. The nature of breakage can be surface breakage, volume breakage, etc (Teo 1990). In this study discrete pieces of coal and stone were dropped from different heights, and the size remaining above a selected top size was redropped and sieved. Assuming the breakage phenomenon is predominantly dominated by volume breakage, an attempt has been made to describe the breakage as a first-order process (Sahoo, 2005). This implies that the amount of material broken in a drop is proportional to the amount dropped.

The first-order process can be represented in the following mathematical form:

If M1, M2 are the mass remaining after first and second drop of original mass Mo then

$$M1 = Mo - Mo * K = Mo\,(1-K) \quad \ldots \quad (3)$$

$$M2 = M1 - M1 * K = M1(1-K) = Mo\,(1-K) * (1-K) \quad \ldots \quad (4)$$

The general formula after n drops can be expressed as:

$$Mn = Mo * (1-K)^n \quad \ldots \quad (5)$$

where Mo is the original mass dropped and Mn is the mass remaining within a sized interval after n drops and K is defined as the volume breakage constant. This value of K can be interpreted as an index of strength, where high value of K implies lower strength or increased breakage. If the process follows this first order process a plot of log (Mn/Mo) vs no. of drops will yield a straight line the slope of which will give the value of K. The slope values are shown in Table 1 and Fig.5 depicts the plot of log(Mn/Mo) vs no. of drops.

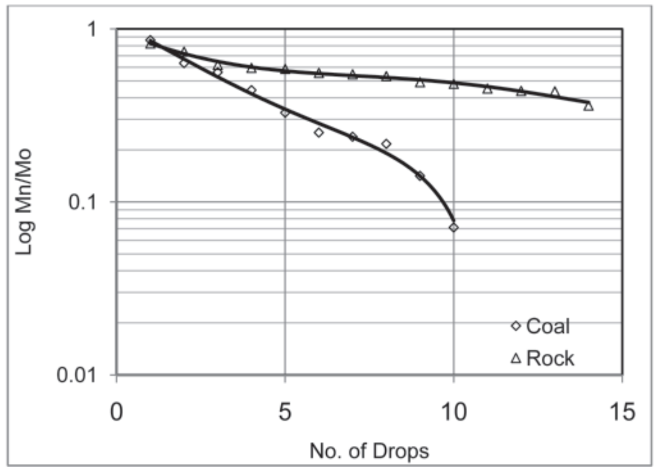

Fig.5 Plot of log (Mn/Mo) vs no. of drops

TABLE 1: BREAKAGE PARAMETER STUDIES WITH RESPECT TO SLOPE (K) AT DIFFERENT DROP HEIGHTS

	Drop ht: 2.0m slope (K)	Drop ht: 2.5 m slope (K)	Drop ht: 3.0 m slope (K)
Coal	0.0508	0.0405	0.0733
Stone	0.0099	0.0160	0.0135

Results and discussion

For each height the average of three samples was taken and SCI values were calculated for coal and stone. The different values of SCI were plotted against the number of drops graphically and shown in Fig.2. The SCI values were 2.1, 2.3 and 2.3 for drops heights of 2.0, 2.5 and 3.0 m respectively, when the experiments were carried out with 200 mm as the base size. This indicates that SCI values are high for separation of stone.

The oversize retained on the 200 mm screen after each subsequent drop of the individual samples of coal and stone is shown in Fig.3 for the drop heights of 2.0m, 2.5m and 3.0m. It seems that about 85.9% stone could be discarded as 200 mm oversize while dropping the individual lumps from a height of 3.0 m (5 drops) and under similar conditions almost no coal was found to be lost with the rejects.

It can be seen from the Fig.4, that after 3-4 drops the effective liberation of material is started and maintains the steady separation until and unless the curve becomes more or less a straight line. In the case of breakage parameter studies, the data obtained from the selective drop breakage tests of coal and stone at different heights were plotted in figure. The K values for coal and stone were calculated and are given in Table 1. It can be seen that coal at all drops shows high values of K, which indicate that the coal tested was having lower strength or increased breakage and in the similar conditions the stone shows lower K values indicating its higher strength. The graph between log (Mn/Mo) versus number of drops is straight line and follow the first order breakage rate and steeper is the gradient of the line in the graph, the higher is the value of Kv and weaker the coal sample.

Conclusions

The selective crushing index obtained from the drop breakage test on coal and stone suggest the use of rotary breaker as an effective means for removing the stone from this particular coal. The cumulative weight % retained on a 200 mm screen suggests that a substantial amount of stone can be discarded as oversize. The representation of screen analysis by RRB diagram is useful for obtaining directly the characteristic diameter (do) and also the nominal diameter (d20) which is helpful in predicting the result. The breakage parameter studies showed that the breakage phenomenon is volume breakage and it follows a first order process. However, to validate the laboratory findings and for obtaining an optimum design specification such as screen size, drum diameter and length, rpm etc., it is necessary to conduct pilot scale studies.

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