K. M. K. SINHA
S. C. MAJHI
P. S. PRASAD
and
T. GOURI CHARAN

Beneficiation studies on high ash Indian coking coal using heavy medium cyclone test rig

Heavy medium coal processing technology has been widely used in coal preparation industries in the world since it is the most accurate and efficient coal preparation process to obtain clean coal with a highest possible yield. Separation of coal and impurities using this technology is based on density differences. Tests were carried out on a 100mm dia heavy medium cyclone test rig treating coal in the size range -6 + 0.5mm. A total of twenty seven experiments were carried out by varying the parameters like vortex finder diameter, spigot diameter and inlet feed pressure for each cyclone dia. The results indicate that for 100mm dia H. M. cyclone it is possible to achieve about 24% clean coal at an ash content of 17.3% from feed ash of 35% at a feed pressure of 0.35 kg/cm^2, vortex diameter of 42.5mm and spigot diameter of 28mm.

Introduction

The domestic availability of coking coal, a critical raw material required by steel industry is limited and therefore the Indian steel industry has to depend heavily on imported coking coal to meet its needs. Currently, domestic steel makers meet 80% of their coking coal requirement through imports. The quantum of imports may go up significantly in the near future as steel production in a large number of new projects is likely to be through the BF-BOF route and also to meet the requirement of existing steel plants.

The good quality coking coals of the upper seams are fast depleting leaving behind the inferior quality lower seam coal or low volatile coking (LVC) coals. The cleaning of the Indian coals requires crushing to a reasonable size for liberation of ash forming minerals and suitable technology adopted for washing this size fraction is processing them through heavy medium cyclone. Further for processing of the LVC (low volatile coking) coals or lower seam coal, the coal is to be first deshaled and crushed to 6 mm and for processing the coarser fractions (- 6 +0.5 mm), HM cyclones are the only efficient washers. It has been established worldwide that coal washing of intermediate sizes (- 6 +0.5 mm), HM cyclone is the best separator [1-4].

The most efficient gravity-based separator used for coal cleaning employs the use of dense medium, which is most commonly a suspension of ultrafine magnetite and water. As there is a general correlation between ash content and specific gravity, it is possible to achieve the required degree of removal of ash forming impurities from a raw coal by regulating the specific gravity of the separating fluid. The density of the suspension is adjusted to a value that is between the densities of coal and the associated mineral matter. Dense-media processes are capable of making sharp separations at any specific gravity within the range normally required even in the presence of high percentages of coal whose specific gravity is near to the specific gravity of separation, more commonly known as near-gravity material (NGM) [5]. The difficult washing characteristics due to the presence of high NGM in Indian coal makes dense-medium cyclones (DMCs) an obvious choice for most Indian washeries.

In a typical HMC, a mixture of medium and raw coal enters tangentially near the top of the cylindrical section, thus forming a strong vortex. The refuse moves along the wall of the cyclone and is discharged through the underflow orifice (spigot). The washed coal moves towards the longitudinal axis of the cyclone and passes through the overflow orifice, or vortex finder, and discharges through the central overflow chamber.

Around seventy per cent of the existing Indian coal washeries use heavy medium cyclones (HMC) as the main unit operation in the washing circuit. Most of these washeries are old and feed characteristics had drastically changed over the period, as a result it has become difficult to optimize the process which ultimately reduced efficiency. With this view, tests were carried out to study the performance of 100mm treating LVC coal in the size range of -6 + 0.5mm.

Experimentation

The LVC coal from operating coking coal mines of Jharia coalfields was taken for the study. For beneficiation by HMC scheme, the “as received” sample was crushed to below 75 mm in a double roll crusher and a representative portion of crushed coal was screened at 13 mm and 6mm. The screened fraction of -75 + 6 mm was deshaled at density of 1.80. The

Dr. KMK Sinha, Principal Scientist, Messrs. S.C. Majhi, Technical Officer, P.S. Prasad, Sr. Technical Officer and Dr. T. Gouricharan, Sr. Principal Scientist & Head of Research Group, Coal Preparation & Carbonization Dividsion, CSIR-Central Institute of Mining & Fuel Research, Dhanbad

deshaled product of -75 + 6 mm size fraction was crushed to below 6 mm and crushed product was then mixed with untreated minus 6 mm fraction to form the sample of -6mm.

The - 6 mm size fraction was screened at 0.5 mm. Thereafter, tests were carried out on a 100 mm dia HMC treating coal in the size range of -6 + 0.5 mm. Detailed washability studies were carried out for size -6 + 0.5mm and the Mayers curve is shown in Fig.1.

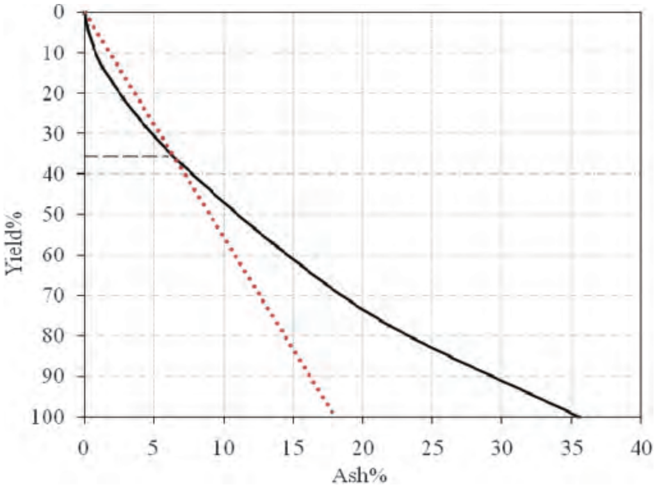

Fig.1 Mayer curve

The experimental set up of H M cyclone test rig is shown in Fig.2. The medium of desired specific gravity is prepared in the slurry tank. Finely ground magnetite (95 per cent passing through 44 micron) was used to prepare the heavy medium. The medium is fed to the cylindrical vessel and coal is fed from the top at the rate of desired quantity to maintain pulp density and suitable media to coal ratio. The media and the coal particles are mixed in the slurry tank and the mixture is fed to cyclone. There is a by-pass arrangement also to find out the specific gravity as well as ratio of media and coal fed to the cyclone. The by-pass line in the slurry tank is adjusted to feed the cyclone at definite pressure. The products of the cyclone are passed over launder divided into two parts for cleans and sinks. The coal particles (cleans and sinks) coated with magnetite are water sprayed, cleaned and collected. The dilute media is collected in a separate tank where the media settles and is reused. The cleans and rejects weights were recorded and analyzed for its ash content and also to study the efficiency of the cyclone float and sink tests on the products were carried out.

Experimental design

Twenty seven experiments were carried out to study the effects of vortex finder diameter (VFD), spigot diameter (SPD) and feed pressure (P) on the quality and quantity of the cyclone products. The level of the parameters studied is shown in Table 1 for 100mm dia cyclone, while Table 2 shows the ash content of the cleans and rejects and Table 3 shows the efficiency data with respect to organic efficiency, d50 and Ep.

Fig.2 H. M. cyclone test rig

Dense-medium efficiency

The two main measures of dense-medium plant efficiency are the organic efficiency and the Ecart Probable Moyen (EPM) that is derived from the partition curve. Organic efficiency measures the overall performance of the washing process whilst the EPM reflects the performance of the separating unit only [6,7].

Organic efficiency

The organic efficiency is a measure of the actual yield obtained from a washing process compared to the theoretical yield obtainable from the specific coal at the same ash content. It is defined as follows:

Organic efficiency =

$$\frac{\textit{Actual yield \% of clean coal}}{\textit{Theoretical yield \% of product of the same ash content}} \times 100 \quad \ldots \quad (1)$$

The theoretical yield is obtained from the washability of the feed coal. Organic efficiency is a function of the

Table 1: Parameters for operating the cyclone

	Feed pressure, lb/in^2	Vortex finder diameter, mm	Spigot diameter, mm
1	5	35	21
2	7	42.5	28
3	10	50	35

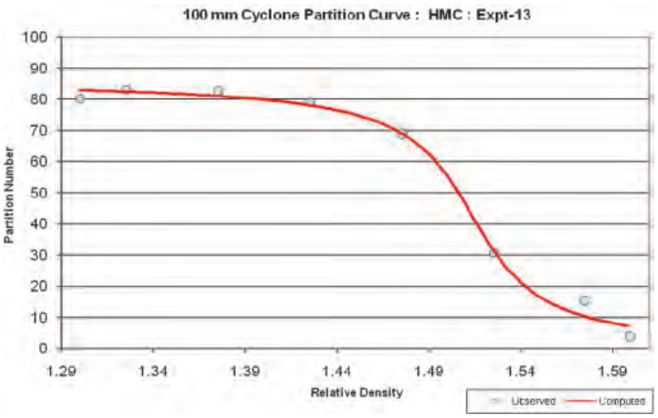

Fig.3 Partition curve

separating unit efficiency as well as the washing characteristics of the coal. A more efficient process, such as dense-medium, will always result in a higher organic efficiency than a less efficient process, like a jig for example, when both are processing the same coal. Organic efficiency is the measurement used as the basis for comparing the economy of differing processing options.

Organic efficiency cannot be used to compare the efficiencies of different plants as it is a dependent criterion and is much influenced by the washability of coal. It is possible to obtain a high organic efficiency even when the separating efficiency as measured by partition data is quite poor.

Partition curve

The EPM is derived from the "Tromp curve" or "partition curve." The partition curve is obtained by plotting the distribution of clean coal that has reported to the product or "floats" fraction of the dense-medium process unit against the expected or theoretical distribution of clean coal. The data required to construct a partition curve are obtained by taking samples of the coal feed into a dense-medium unit and simultaneous samples of the product (floats) and rejects (sinks) material from the unit. The product and reject samples are subjected to float-and-sink analysis, using a range of closely spaced density intervals. The ash content of the feed sample, as well as the float-and-sink fractions of the product and reject samples, is determined as part of the analysis. The yield of clean coal is determined, by direct mass

TABLE 2: EXPERIMENTAL DATA FOR 150 MM DIAMETER H. M. CYCLONE TREATING COAL OF SIZE – 6+0.5 MM

Test no.	Pressure lb/in^2	Vortex mm	Spigot mm	Cleans		Rejects		Feed ash %
				Wt %	Ash %	Wt %	Ash %	
1	5	35	21	86.6	33.9	13.4	41.6	34.9
2	7	35	21	91.8	33.2	8.2	51.9	34.7
3	10	35	21	92.2	34.6	7.8	51.9	35.9
4	5	35	28	10.7	11.6	89.3	37.5	34.7
5	7	35	28	10.2	11.3	89.8	36.7	34.1
6	10	35	28	6.6	10.6	93.4	36.3	34.6
7	5	35	35	7.4	11.4	92.6	36.9	35.0
8	7	35	35	6.9	11.1	93.1	36.3	34.5
9	10	35	35	5.9	11.2	94.1	35.9	34.5
10	5	42.5	21	90.8	34.0	9.2	35.5	34.1
11	7	42.5	21	88.4	31.7	11.6	52.4	34.1
12	10	42.5	21	58.1	30.6	41.9	37.6	33.5
13	5	42.5	28	24.0	17.3	76.0	40.1	34.6
14	7	42.5	28	19.2	15.8	80.8	39.0	34.5
15	10	42.5	28	23.4	16.6	76.6	39.6	34.2
16	5	42.5	35	13.0	13.5	87.0	37.6	34.4
17	7	42.5	35	10.6	13.9	89.4	37.7	35.2
18	10	42.5	35	11.0	12.5	89.0	36.4	33.8
19	5	50	21	38.1	24.7	61.9	41.0	34.8
20	7	50	21	30.1	23.3	69.9	40.7	35.5
21	10	50	21	42.4	24.6	57.6	41.5	34.3
22	5	50	28	12.6	20.9	87.4	35.8	34.0
23	7	50	28	17.6	21.4	82.4	37.3	34.5
24	10	50	28	16.7	21.6	83.3	37.4	34.7
25	5	50	35	17.5	20.6	82.5	37.2	34.3
26	7	50	35	15.4	23.9	84.6	36.0	34.2
27	10	50	35	16.5	25.0	83.5	35.0	33.4

TABLE 3: EFFICIENCY DATA TREATING COAL IN 100MM DIA H. M. CYCLONE

Test no.	Pressure lb/in^2	Vortex mm	Spigot mm	Organic efficiency	d50	Ep
1	5	35	21	88.60	1.96	0.010
2	7	35	21	95.20	1.96	0.030
3	10	35	21	95.10	1.97	0.010
4	5	35	28	57.60	1.41	0.050
5	7	35	28	53.40	1.39	0.040
6	10	35	28	41.60	1.36	0.030
7	5	35	35	46.70	1.39	0.110
8	7	35	35	41.50	1.36	0.070
9	10	35	35	35.50	1.35	0.050
10	5	42.5	21	94.60	1.96	0.012
11	7	42.5	21	95.30	1.97	0.018
12	10	42.5	21	65.20	1.70	0.250
13	5	42.5	28	72.70	1.51	0.040
14	7	42.5	28	69.30	1.48	0.050
15	10	42.5	28	72.30	1.50	0.060
16	5	42.5	35	57.30	1.43	0.060
17	7	42.5	35	49.30	1.41	0.100
18	10	42.5	35	49.00	1.41	0.060
19	5	50	21	67.00	1.57	0.090
20	7	50	21	63.20	1.53	0.090
21	10	50	21	68.20	1.60	0.110
22	5	50	28	28.80	1.36	0.060
23	7	50	28	38.60	1.40	0.040
24	10	50	28	37.30	1.39	0.060
25	5	50	35	39.80	1.42	0.060
26	7	50	35	27.10	1.35	0.150
27	10	50	35	26.50	1.35	0.050

TABLE 4: STANDARDIZATION OF H. M. CYCLONE PARAMETERS

Cyclone diameter	Pressure, lb/in^2 (g)	Vortex diameter, mm	Spigot diameter, mm	Cleans wt. %	Cleans ash %	Rejects wt. %	Rejects ash %
100 mm	5	42.5	28	24.0	17.3	76.0	40.1

measurements if possible, but more often by using the “ash-balance” method.

The float-and-sink data obtained from the clean coal and the reject samples are used to compute the so-called “reconstituted feed.” The reconstituted feed reflects the washability analysis of the coal fed into the dense-medium unit. The amount of the coal in each of the relative density intervals that reports to the clean coal, expressed as a percentage of the coal in each of the relative density intervals of the reconstituted feed, is determined. These percentages, expressed as dimensionless partition coefficients (or partition numbers), plotted against the mean density of each relative density interval, yield the partition curve.

PARTITION DENSITY

This is the relative density corresponding to a partition number of 50 on the Tromp curve. It is also referred to as the “cutpoint density” and is usually denoted as d50

ECART PROBABLE MOYEN

The Ecart Probable Moyen (EPM) or probable mean error is defined as follows:

$$EPM = (RD_{75} - RD_{25})/2$$

where RD_{75} is the relative density corresponding to a partition coefficient of 75 and RD_{25} is the relative density corresponding to a partition coefficient of 25.

The partition curve is shown in Fig.3.

Results and discussions

From the washability data of coal size of -6 + 0.5 mm the theoretical yield at 18% ash level is 35.6, while the corresponding rejects being 64.4% at ash of 45.2%. The cut density is 1.59 and the NGM at this gravity is 36%, which categorize the coal as difficult-to-wash coal..

When the ratio of vortex finder dia and spigot dia were kept 35 mm and 21 mm and the pressure were varied from 5lb/in^2 , 7lb/in^2 10lb/in^2, no substantial ash rejection in cleans could be achieved. Again for next set of experiments vortex finder dia and spigot dia were kept 35 mm and 28 mm respectively and the pressure was varied from 5lb/in^2, 7lb/in^2 10lb/in^2 ash% of cleans came down to 11.6% to 10.6% but the yield of cleans was as low as 10.7% to 6.6%.

In the next set of experiments the dia were kept 35m for both vortex finder and spigot and the pressure was varied from 5lb/in^2, 7lb/in^2 10lb/in^2 the ash% in the cleans reported nearly 11%. But again the yield was very low. Further for next set of experiments the dia of vortex finder and spigot were varied and kept 42.5 mm and 21 mm and as mentioned above pressure were varied. Though the yield was as high as 90.8% to 58.1% but the ash% was also very high (34% to 30.6%)

For the next set of experiments vortex finder dia was kept 42.5 mm and the spigot dia changed as kept 28 mm. The pressure of the feed were kept from 5lb/in^2, 7lb/in^2 10lb/in^2. The results were highly encouraging. The ash% of cleans reported 17.3%, 15.8%, 16.6% whereas yield were 24%, 19.2%, 23.4% which is highly appreciable. In next set of experiments i.e. from experiments no. 16 to 18 though the ash% of cleans showed slight low but the yield of cleans came down drastically. In next experiments from 19 to 27 not much encouraging results were observed. Hence, it may be concluded that among experiments 13 to 15, experiment 13 and 15 are highly appreciable.

Based on the above findings the cyclone parameters in terms of yield and ash content of the cyclone cleans and sinks at different operating conditions and also considering the efficiency parameters the H. M. cyclone was standardized and the final parameters which meet the required quality is shown in Table 4.

Conclusions

Hence, it may be concluded that for recovery of clean coal at desired ash level, the lower seam coal may be deshaled and the deshaled cleans may be crushed to 6 mm, followed by washing of 6 - 0.5mm fraction in 100 mm dia HM cyclone for optimum recovery. The effect of these variables on the performance of the 100 mm heavy medium cyclone (HMC or HM cyclone) was investigated. The results indicate that it is possible to achieve about 24% clean coal at an ash content of 18.517.3% at a feed pressure of 5 lb/in^2, vortex diameter of 42.5mm and spigot diameter of 28mm. The tromp curves obtained from operating the cyclone gave a probable error of 0.040, indicating good separation efficiency. Since, the NGM of the lower seam coal is very high, it is always beneficial to wash the coal in heavy medium cyclone. The rejects which is as high as 76% at 40.1% ash level may be used for power generation.

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