Characterisation and beneficiation of some Indian coal fines

* K. K. Bhattacharyya, P. S. R. Reddy, S. G. Kumar
S. R. S. Sastri and K. S. Narasimhan

INTRODUCTION :

India's total coal reserves are estimated 1,12,000 MT which is around one per cent of world's total reserves. Out of these, coking coal deposits are about 23,400 MT, of which 10,800 MT are proved reserves. Due to the deficiency in coking coal and to meet the increasing requirement of actual industry about 1.5 MT of prime coking coal was imported during 1983.

Demand for specific quality coal has increased with the development and modernisations in the field of iron and steel making. At the same time the known reserves of good quality coking coal are also being depleted. This has forced the mining system a shift from selective to bulk mechanised mining. In the interest of conservation of coking coal and in view of deteriorating quality of raw coal due to bulk mining, coal washing in India has of late assumed greater importance. There are at present 15 coking coal washeries operating in India with a total installed capacity of 28 MT per annum (1).

As the ash content of R.O.M. coal and that of fines generated is steadily increasing, fine coal cleaning circuits are envisaged for incorporation in existing and as well as for the coming washeries in India. In the existing 15 washeries altogether about 15-20% of fines less than 0.5 mm size are produced. These fines are not utilised properly due to their high ash content ranging from 25-40%. In order to utilise these fines judiciously and in view of scarcity of coking coal, these fines are to be beneficiated to reduce their ash content. Flotation is only known method to beneficiate these fines commercially. The present paper deals with some of the coal fines generated at different washeries viz. Sudamdih, Patherdih, Kathara and West Bokaro. The coal fines generated at the above four washeries were characterised to see the possibility of reducing the ash content. The studies include size and ash distribution, sink and float studies at 1.5 specific gravity and beneficiation studies on both standard flotation cell and flotation column.

Samples :

About 200 to 300 kgs of fines generated at each of the coal washeries viz. Sudamdih, Patherdih, Kathara and West Bokaro were collected in the form of wet slurry. The associated water was decanted and the material was air dried and kept for feed stock for the studies. Representative sample from each fines was collected by standard cone and quartering method. The size distribution was found out by wet sieving method using standard test sieves. Ash in each sized fraction was found out according to standard procedures. The size distribution of all the samples are given in table 1 and their ash distribution is reported in table 2.

EXPERIMENTAL :

Characterisation by sink and float test :

Sink and float tests were carried out on each close sized fractions of different samples at 1.5 specific gravity to evaluate the extent of liberation. Each sieve fraction of different samples has

* *Regional Research Laboratory,*
(Council of Scientific and Industrial Research),
Bhubaneswar-751013, Orissa, India.

been separated to obtain a clean coal fraction as float and the gangue as sink. This clean coal is virtually the liberated coal and the unliberated coal remains with the gangue minerals. The below 45 microns fraction in each sample was not treated by the sink and float test as it is difficult to obtain a clear cut separtion at such a fine size. For calculation purposes this below 45 micron fraction is combined with the tailings because of its high ash content except for West Bokaro sample where it is combined with the clean coal due to its low ash content.

Batch flotation tests :

A few batch flotation tests were carried out to assess the flotation response. The effect of collector and frother were studied in each case. The experiments were conducted in a standard Denver D-12 sub-aeration flotation machine with a pulp of 10 % solids. Flotation was carried out using the combinations of pine oil and methyl isobutyl carbinol mixture (50 : 50 by volume) as frother which got better frothing efficiency than using either of them above (2) and diesel oil as collector. The results obtained were compared with the sink and float results.

Continuous column flotation tests :

A series of experiments were carried out employing 100 mm diameter glass column developed at the Regional Research Laboratory (3) (Fig-1). This flotation column is essentially a counter current pneumatic machine with vertical cylindrical space in which the reagent conditioned feed slurry introduced at the middle of the column travels downward against the rising air bubbles generated at the bottom of the column. The continuously rising froth above the feed point is collected at the top of the column. The tailings are being collected at the bottom of the column. The column was operated at the nominal capacity of 20 kg/hr.

Results and Discussions :

The results of the sink and float tests are given in Table-3. The results indicate that at 1.5 sp. gr. a clean coal of 11.5% ash with 45.9% yield could be possible from Sudamdih fines of 40.3% ash. In case of Kathara fines a product of 9.3% ash with an yield of 61.3% could be obtained from a feed of 25.1% ash. The results of Patherdih washery indicate a product of 9.5% ash with an yield of 52.6% from a feed of 29.5% ash. The West Bokaro sample tests indicate a product of 11.8% ash with an yield of 75.1%.

These studies indicate that it is possible to get clean coal with 8—9% ash in all the cases. The flotation results obtained in standard cell are given in Table-4. In each case the effect of collector and frother were studied and dosages were optimised. It is clear from the results that all the coal fines are well responding to flotation. It is possible to recover 80 to 90% of the carbon by simple flotation. When compared to the results of sink and float tests, it is found that the grade of the clean coal differs possibly due to the presence of minus 45 microns fractions in the product as clearly indicated by the size and ash distribution of typical products presented in Table—5.

The results obtained in flotation column are shown in Table—6. In general, the performance of the column with respect to fines is according to expectations with high recoveries. When compared to the results of batch flotation tests it is found to have distinct advantages with respect to quality and grade. Column flotation can give better product at same recoveries or high recoveries at same grade of product as obtained in cell. When compared to the results of sink and float tests, it is found that the difference in quality is much negligible and at the same time recoveries are higher as some portion of minus 45 microns combines with the product. This is amply proved from the results of size and ash distribution of typical products in Table—7.

Table 1 : Size distribution of different coal fines

Size microns	Cumulative per cent passing (weight)			
	Sudamdih	Patherdih	Kathara	West Bokaro
500	80.3	88.2	96.1	81.9
420	64.5	59.4	85.3	66.5
210	38.1	41.3	57.0	39.4
125	23.7	35.5	43.3	30.2
75	15.0	25.5	33.1	24.7
45	10.8	19.2	26·7	12.4

Table 2 : Ash distribution of different coal fines

Size microns	Ash per cent			
	Sudamdih	Patherdih	Kathara	West Bokaro
+500	33.7	19.8	21.3	21.2
−500+420	42.5	22.4	24.1	19.8
−420+210	42.9	26.8	22.0	23.7
−210+125	38.5	23.5	31.6	30.7
−125+ 75	37.9	20.0	27.6	27.6
−75 + 45	45.8	30.9	36.8	24.0
−45	44.6	31.9	38.7	13.9
Head	40.3	25.1	29.5	22.3

Table 3 : Results of sink and float tests size and ash distribution in feed, float and sink

SUDAMDIH

Size in microns	Weight %			Ash %		
	Feed	Float	Sink	Feed	Float	Sink
+500	19.7	9.8	9.9	33.7	11.0	56.2
−500+420	15.8	7.1	8.7	42.5	10.5	72.1
−420+210	20.4	13.6	12.8	42.9	12.0	74.1
−210+125	14.4	7.6	6.8	38.5	9.8	72.2
−125+ 75	8.7	5.3	3.4	37.9	12.8	79.9
− 75+ 45	4.2	2.5	1.7	45.8	17.7	87.0
− 45	10.8	—	10.8	44.6	—	44.6
Head	100.0	45.9	54.1	40.3	11.5	65.1

Table 3 (Contd.) :

PATHERDIH

Size in microns	Weight, % Feed	Weight, % Float	Weight, % Sink	Ash, % Feed	Ash, % Float	Ash, % Sink
+500	11.8	9.2	2.6	19.8	8.6	60.0
—500+420	28.8	22.6	6.2	22.4	9.2	68.0
—420+210	18.1	12.0	6.1	26.8	8.1	66.0
—210+125	5.8	4.3	1.5	23.5	9.5	69.1
—125+ 75	10.0	8.3	1.7	20.0	9.2	71.0
—75+ 45	6.3	4.9	1.4	30.9	13.5	87.4
—45	19.2	—	19.2	31.9	—	31.9
Head	100.0	61.3	38.7	25.1	9.3	50.1

KATHARA

Size in microns	Weight, % Feed	Weight, % Float	Weight, % Sink	Ash, % Feed	Ash, % Float	Ash, % Sink
+500	3.9	2.9	1.0	21.3	9.7	53.3
—500+420	10.8	7.4	3.4	24.1	8.7	56.2
—420+210	28.3	22.2	6.1	22.0	9.6	66.3
—210+125	13.7	8.7	5.0	31.6	9.7	70.0
—125+ 75	10.2	7.4	2.8	27.6	10.1	74.5
— 75+ 45	6.4	4.0	2.4	36.8	8.6	83.3
— 45	26.7	—	26.7	38.7	—	38.7
Head	100.0	52.6	47.4	20.5	9.5	51.5

WEST BOKARO

Size in microns	Weight, % Feed	Weight, % Float	Weight, % Sink	Ash, % Feed	Ash, % Float	Ash, % Sink
+500	18.1	13.8	4.3	21.2	11.6	51.5
—500+420	15.4	12.2	3.2	19.8	13.0	46.0
—420+210	27.1	18.1	9.0	23.7	13.0	51.2
—210+125	9.2	6.0	3.2	30.5	10.6	64.0
—125+ 75	5.5	3.5	2.0	27.6	8.9	62.4
— 75+ 45	12.3	9.1	3.2	24.0	7.1	72.4
— 45	12.4	12.4	—	13.9	13.9	—
Head	100.0	75.1	24.9	22.3	11.8	55.8

Table 4 : Results of batch flotation tests

SUDAMDIH

A. EFFECT OF COLLECTOR (Frother : 0.25 ml/kg coal)

Sl.	Collector	Weight per cent		Ash per cent		
No.	ml/kg	Product	Tails	Product	Tails	Feed
1.	1.25	56.8	43.2	20.9	69.7	41.9
2.	1.50	61.1	38.9	21.8	73.7	42.0
3.	1.80	60.4	39.6	20.0	74.5	41.6

B. EFFECT OF FROTHER (Collector : 1.80 ml/kg coal)

Sl.	Frother	Weight per cent		Ash per cent		
No.	ml/kg	Product	Tails	Product	Tails	Feed
1.	Below 0.1 ml/kg frother no froth.					
2.	0.10	33.3	66.6	14.4	55.9	42.1
3.	0.15	54.1	45.9	15.0	70.4	40.4
4.	0.20	58.2	41.8	19.6	69.4	40.4
5.	0.25	60.4	39.6	20.0	74.5	41.6

PATHERDIH

A. EFFECT OF COLLECTOR (Frother : 0.2 ml/kg coal)

Sl.	Collector	Weight, %		Ash, %		
No.	ml/kg	Product	Tails	Product	Tails	Feed
1.	0.25	57.6	42.4	11.7	42.0	24.5
2.	0.50	67.0	33.0	12.3	50.8	25.0
3.	1.00	75.1	24.9	13.6	58.8	24.9
4.	1.50	78.9	21.1	14.3	66.4	25.3
5	2.00	81.8	18.2	15.1	74.0	25.8

Table 4 (Contd.) :

B. EFFECT OF FROTHER (Collector : 1 ml/kg coal)

Sl. No.	Frother ml/kg	Weight, %		Ash, %		
		Product	Tails	Product	Tails	Feed
1.	0.025	30.5	69.5	9.6	32.8	25.7
2.	0.05	41.5	58.5	11.5	37.5	26.7
3.	0.10	74.9	25.1	14.0	58.9	25.3
4.	0.15	79.5	20.5	14.7	69.0	25.8
5.	0.20	75.1	24.9	13.6	58.8	24.9

KATHARA

A. EFFECT OF COLLECTOR (Frother : 0.25 ml/kg coal)

Sl. No.	Collector ml/kg	Weight, %		Ash, %		
		Product	Tails	Product	Tails	Feed
1.	0.25	71.4	28.6	16.2	62.5	29.4
2.	0.50	71.9	28.1	19.0	65.6	32.1
3.	0.75	72.2	27.8	17.7	64.2	30.7
4.	1.00	74.0	26.0	18.4	63.1	30.0
5.	1.25	73.7	26.3	18.4	66.2	31.0
6.	1.50	79.6	20.4	20.6	76.8	32.1
7.	1.75	81.2	18.8	19.2	79.5	30.5
8.	2.00	76.3	23.7	21.0	72.5	33.2
9.	2.25	82.4	17.6	18.9	77.6	29.2

B. EFFECT OF FROTHER (Collecter : 0.25 ml/kg coal)

Sl. No.	Frother ml/kg	Weight, %		Ash, %		
		Product	Tails	Product	Tails	Feed
1.	0.025	9.2	90.8	10.1	33.3	31.2
2.	0.05	44.6	55.4	14.2	44.2	30.8
3.	0.10	64.1	35.9	16.5	55.4	30.5
4.	0.15	75.5	24.5	17.4	72.6	30.9
5.	0.20	74.7	25.3	17.9	72.9	31.8
6.	0.25	71.4	28.6	16.2	62.5	29.4

Table 4 (Contd.) :

WEST BOKARO

A. EFFECT OF COLLECTOR (Frother : 0.2 ml/kg coal)

Sl. No.	Collector ml/kg	Weight, %		Ash, %		
		Product	Tails	Product	Tails	Feed
1.	0.125	73.4	26.6	15.8	52.0	25.4
2.	0.25	79.2	20.8	17.3	44.7	23.0
3.	0.375	85.6	14.4	17.3	46.6	21.5
4.	0.50	86.8	13.2	18.0	50.6	22.3
5.	1.00	89.5	10.5	18.1	61.0	22.6

B. EFFECT OF FROTHER (Collector : 0.375 ml/kg coal)

Sl. No.	Frother ml/kg	Weight, %		Ash, %		
		Product	Tails	Product	Tails	Feed
1.	0.025	7.2	92.8	11.4	23.9	23.0
2.	0.05	19.1	80.9	13.2	25.8	23.4
3.	0.10	56.3	43.7	14.5	34.3	23.2
4.	0.15	67.5	32.5	15.8	37.8	23.0
5.	0.20	85.6	14.4	17.3	46.6	21.5

Table 5 : Size and ash distribution of typical batch flotation products

Size microns	Weight, %				Ash, %			
	Sudamdih	Patherdih	Kathara	West Bokaro	Sudamdih	Patherdih	Kathara	West Bokaro
+500	18.2	13.0	4.0	18.0	16.0	9.5	12.0	15.8
−500+420	13.9	28.7	12.0	16.0	17.0	10.7	11.7	19.6
−420+210	26.5	18.3	35.8	25.1	18.5	8.9	14.3	20.3
−210+125	14.4	8.4	14.3	9.1	19.5	10.2	15.3	17.2
−125+ 75	10.9	14.2	13.0	6.0	20.6	10.4	18.3	14.3
− 75+ 45	5.5	8.4	7.0	12.0	24.4	16.2	15.3	13.0
− 45	10.6	9.0	13.9	13.8	29.8	20.2	22.3	12.3
Head	100.0	100.0	100.0	100.0	19.7	12.4	15.7	16.7

Table 6 : Results obtained on flotation column

Sl. No.	Collector ml/kg	Frother ml/kg	Product Wt. % Conc.	Tail	Ash % Conc.	Tail	Feed
A. SUDAMDIH							
1.	1.8	0.50	48.2	51.8	15.2	61.2	39.1
2.	1.8	0.75	56.3	43.7	12.5	61.9	34.1
3.	1.8	1.00	52.7	47.3	14.2	62.6	37.3
4.	1.8	0.25	50.0	50.0	13.6	60.8	37.2
B. PATHERDIH							
1.	1.0	0.30	85.0	15.0	14.4	59.3	21.6
2.	1.0	0.45	77.9	22.1	14.3	65.1	25.5
3.	1.0	0.60	80·0	20.0	13.6	76.2	25.3
4.	1.0	1.20	81.8	18.2	14.6	76.2	25.8
C. KATHARA							
1.	0.2	0.30	56.3	43.7	12.7	52.4	30.0
2.	0.2	0.45	75.8	24.2	15.9	67.9	28.5
3.	0.2	0.60	84.2	15.8	17.8	76.8	27.9
4.	1.0	0.30	82.1	17.9	17.2	79.6	28.9
D. WEST BOKARO							
1.	1.25	0.30	77.4	22.6	16.1	44.3	22.5
2.	1.25	0.30	35.3	14.7	17.1	56.5	22.9

Table 7 : Size and ash distribution of typical products of column flotation

Size microns	Weight % Sudamdih	Patherdih	Kathara	West Bokaro	Ash % Sudamdih	Patherdih	Kathara	West Bokaro
+500	16.5	11.0	4.1	16.0	11.5	9.4	10.3	12.3
−500+420	13.3	28.3	11.0	14.5	10.0	10.4	10.0	15.4
−420+210	27.6	17.4	34.5	24.0	13.2	9.3	11.0	16.2
−210+125	15.2	8.6	15.6	10.2	10.4	11.2	12.5	13.5
−125+ 75	11.3	14.8	13.2	7.1	13.0	10.8	10.4	14.3
−75 + 45	5.8	8.6	6.8	14.2	18.5	16.0	13.5	12.0
−45	10.3	11.3	14.8	14.0	20.2	19.3	18.4	13.1
Head	100.0	100.0	100.0	100.0	12.4	11.7	12.3	14.2

Conclusions :

Analysis of the above results lead to following conclusions :

1. Sink and float tests gives an idea of liberated coal present in the fines which can be recovered to yield a product of low ash content whereas the per cent yield is also considerably high.
2. Flotation in conventional cells gives a product at same or little higher per cent yield with relatively high ash content.
3. Flotation column gives a product at higher yield with comparatively low ash content.

It is known that at present only three washeries are having flotation circuit to treat the fines. As the results are very encouraging and in view of the ecology and conservation of coking coal it is worth to install flotation circuits in all the existing and future washeries to treat fines. While planning to install flotation circuit it is worth trying at least in some of the washeries this technique of column flotation as it has got some distinct advantages over the conventional flotation cell like (i) better product with higher recovery (ii) reduction in number of stages of operations (iii) simplicity in design and construction without any moving parts (iv) less capital cost (v) needs less floor space and (vi) less power consumption.

Acknowledgements :

The authors are thankful to Prof. P. K. Jena, Director, Regional Research Laboratory, Bhubaneswar for his kind encouragement and giving permission to present this paper. Analytical assistance of Shri L. N. Mishra and secretarial assistance of Shri A. B. Patra are acknowledged.

Authorities of Coal India Limited and Central Fuel Research Institute are acknowledged for providing the samples.

References :

1. B. P. S. Chawhan and T. C. Rao "Coal Washing Practice in India" — Journal of Mines, Metals and Fuels, Vol. 31, No. 3, March, 1983. PP. 75-80.
2. S. G. Kumar, K. K. Bhattacharyya, P. S. R. Reddy, S. R. S. Sastri and K. S. Narasimhan. "Synergestic Effect of Frother on Coal Flotation" — (to be published).
3. P. S. R. Reddy, S. G. Kumar, K. K. Bhattacharyya, S. R. S. Sastri and K. S. Narasimhan. "Flotation Column for Fine Coal Beneficiation" — (to be published).

DISCUSSION :

I. N. Bagchi,
Tisco, W. B. C.

Question 1 : What is the feed rate to the column ?

Author : The flotation column of 100 mm. diamater was operated at the nominal capacity of 20 kg/hr. feed rate.

Question 2 : What is the air flow rate and air pressure maintained ?

Author : Air rate of 5.5 lit/min was maintained during the testing of different coal fines at nominal pressure of 860 mm absolute pressure.

N. Chakravorty,
National Metallurgical Laboratory, Jamshedpur.

Question 3 : Collector for Kathara is very low 0.2—0.4 compared to 1.2—1.8 in other places. Why ? Ref. Table of results.

Author : The collector dosage was first optimised in conventional DENVER D 12 flotation cell of 10 liters capacity. The amount of collector required depends upon the surface properties of coal fines. The flotation response is very good in case of Kathara which is the main reason to consume less amount of collector.

Dr. S. Sivaiah,
National Metallurgical Laboratory, Jamshedpur.

Question 4 : What are the advantages in the design of column flotation unit developed in RRL over the already existing units elsewhere in the world ?

Author : The design details of Flotation column being developed and used elsewhere in the world are not available. At this stage it is not possible to compare the unit developed at Regional Research Laboratory with the other units. However, the advantages over the conventional cells are given in the paper.

L. Prasad,
Tata - Robins - Fraser Ltd., Jamshedpur.

Question 5 : Is there any industrial application of column flotation any where in the world ? Kindly furnish details, if possible.

Author : Details of industrial application of column flotation :

Location	Details
1. Mines Gaspi Qbec, Canada	Molybdenite from Cu-mo bulk concentrate. 950 mm × 450 mm column.
2. Brunsuick Mining & Smelting Co., USA.	As Zinc Cleaner 1830 mm diameter column.
3. Qeister Concentrator Co., Florida, USA	Phosphate beneficiation 0.13 to 19 m^3 capacity
4. USSR	Coal sludge 1400 mm dia, 4.6 m height Capacity 9.0 $l/hr./m^2$

Mr. R. Y. Sane,

Paramount Sinters Pvt. Ltd. Nagpur.

Question 6 : What is retention time in column flotation ?

Author : An average feed residence time of 30 sec. is sufficient in column flotation.

Question 7 : What is the throughput capacity of the column developed by you ?

Author : We have so far developed 220 mm diameter column which can treat 100 kg/hr of coal fines from Suadmdih Washery. A one meter diameter column was designed and it is to be set up at Sudamdih Washery which can treat 2.5 – 3.0 tonnes per hr.

Question 8 : How much total quantity of coal fines you have treated in this unit and what was the consistency of grade and recovery ?

Author : About 10 tonnes of coal fines generated at Sudamdih Washery were tested in 220 mm diameter column and the conditions were optimised to get product with required grade and recovery. The results are reproducible in duplicate tests.

V. Venkatachalam,

MMCL, Bombay.

Question 9 : Is the height of siphon adjustable to remove tailings ?

Author : The height of siphon system is adjustable.

Question 10 : How does the recovery compare with conventional flotation process ?

Author : The results obtained in Conventional cell and column are given in Tables 4 and 5 respectively. From these results it is clear that flotation column can give better product at same recoveries or high recoveries at same grade of product as obtained in cell.

Question 11 : Have you thought of a pilot plant ? If so what is the approximate cost ?

Author : Bench scale studies indicated several advantages over conventional cells. In view of encouraging results and in the interest of the country for the conservation of coking coal resources, it is proposed to set up a pilot plant of one metre diameter column at Sudamdih Washery for demonstration and research purposes, which can treat 2.5 to 3 tonnes per hour at the cost of around Rs. 36.0 lakh. The plant cost includes instrumentation and control which are required for research purpose.

Question 12 : Could you be able to maintain the constant pulp density in the column throughout experiment ? If so, please explain.

Author : Constant pulp density could be maintained in the column after reaching steady state.

Question 13 : While spraying water from top the froth will break, the particles will come down, and yield decrease. Please comment.

Author : Suitable wash water spray velocity was maintained in order to strip entrained gangue material which is not sufficient to break the froth in the column.