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SPLIT FLOTATION OF LVMC COAL TO GENERATE MULTIPLE PRODUCTS FOR COMPLETE UTILIZATION

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ABSTRACT

A low volatile medium coking coal from Jharia coal field, India was used for this investigation. The proximate analysis of the sample shows that it contains about 25% ash, 21.4% volatile matter and 52.4% fixed carbon. The sizewise ash analysis of -0.5 mm coal indicates that -0.5+0.15 mm fraction contains lower ash (21.9%) than -0.15 mm fraction (29.7%). The flotation characteristics of the -0.5 mm coal were determined by release analysis. The study reveals that recovery of combustible at 15% ash is about 27% and 43% at 17% ash level. The low recovery is due to the presence of high ash in finer fraction. In order to improve the recovery, the -0.5 mm feed was classified into -0.5+0.15 mm and -0.15 mm fractions, and subjected to flotation separately. The recoverable combustible obtained from the release analysis of -0.5+0.15 mm at 15% ash level is 46%. The effect of collector dosage, frother dosage and aeration rate on flotation was studied. The responses of these variables in collectorless flotation of the -0.5+0.15 mm fraction containing low ash were also studied. A lower aeration and frother dosage favored the generation of clean coal with low ash. The ash content in the tailing stream from -0.5+0.15 mm flotation circuit is close to that of the original -0.15 mm fraction. The former is ground to -0.15 mm and the two fractions are processed together. As -0.15 mm fraction contains relatively higher ash, collector aided flotation using sodium silicate was performed to recover the clean coal with 17% ash. The products of the overall flotation circuit having different ash levels were recommended for use in different applications. The reject from -0.15 mm flotation circuit contained 56.4% ash which can be used for fluidized bed combustion (FBC). This eventually leads to complete utilization of coal.

Keywords: flotation, air flow rate, reagent dosage, bubble size, stability of froth

INTRODUCTION

Froth flotation is one of the effective techniques widely used in the coal processing industry for fine particle processing. It utilizes the differences in physicochemical surface properties of various minerals to achieve specific separation. Reagent dosage, rate of flotation and froth stability affect the flotation performance. For effective suspension and distribution of particles, rate of aeration is also a critical parameter. Gorain *et al* (1995 a, b) investigated the effect of impeller speed, impeller type and aeration rate on bubble size distribution, gas holdup and superficial gas velocity in industrial flotation cell. Air flow rate and impeller speed have a significant effect on flotation of coarse particles. This can be related to the stability of the particles-bubble aggregates with respect to the turbulence and also the effectiveness of the particles suspension. Particle suspension is favored by higher impeller speed and lower airflow. However, particle-bubble stability reduces by turbulence created due to higher impeller speeds. On the other hand, lower impeller speed and higher airflow favor reduced turbulence and stability of bubble-particle aggregates, and thus creates the optimum conditions. However, further increase in airflow may cause less effective suspension due to reduced pulp flow and excessive turbulence, and these conditions may not favor the recovery of coarser particles. The volume of air-bubbles in the pulp is directly

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proportional to the volume of air entering the flotation cell and inversely proportional to the speed of air passing through the pulp (Jain, 1986) i.e.

$$V = 100.t.Qa/Qb \text{ percent} \quad (1)$$

Where, V= total volume of bubbles in an unit of pulp volume as a percentage of the total effective machine capacity,

t = average time in seconds spent by bubbles in the pulp,

Q_a = air flow rate in cubic meter per second,

Q_b = effective capacity of the chamber in cubic meter

The dosage of collector and frother has a significant effect on flotation performance. Collectors impart hydrophobicity on the mineral particles. Frothers are added to stabilize the bubble formation in the pulp phase and to create a stable froth at the top of the froth layer. It also enhances the generation of fine bubbles and aids particle–bubble attachment. In terms of froth stability, an effective frother should allow sufficient thinning to the liquid film between the bubble and the colliding particle so that the attachment can occur within the time frame of the collision. It should also provide sufficient froth stability so that the adhering or mechanically entrained particles can escape with the draining liquid. If the froth is too stable, non-selective entrainment of gangue particles would reduce the product quality. If the froth phase is not sufficiently stable, mineralized bubble in the froth layer would rupture, and valuable particles drop back into the pulp (Klimpel and Hansen, 1988). Froth stability depends on the type and amount of the frother used as well as on the amount and nature of the suspended particles. This investigation highlights the effect of air flow rate and frother dosage, and the efficacy of split flotation for recovering the clean coal with low ash content. The objective of the present study is to produce multiple products at different ash levels including a low ash clean coal for total utilization with zero waste concept.

EXPERIMENTAL WORK

Material

The medium coking coal fines sample was obtained from the eastern part of India. The proximate analysis data for the coal are given in Table 1.

Table 1. Proximate analysis of composite coal and its size distribution

Size, mm	Wt%	Moisture (%)	Ash%	V.M. (%)	F.C. (%)
-0.5	100	1.38	24.82	21.41	52.37
-0.5+0.15	62.1	1.36	21.92	21.93	54.79
-0.15	37.9	1.57	29.67	23.48	45.28

The ash content of the raw coal is 24.8% with 21.4% volatile matter and 52.4% fixed carbon. The coal was split into two size classes. The -0.5+0.15 mm fraction contained 21.9% ash while the -0.15 mm fraction had 29.7% ash. The later contributes significantly to the total ash of the coal since nearly 38% of the -0.5 mm feed is less than 0.15 mm. The flotation characteristic of the as-received sample was determined by release analysis.

Methods

The flotation tests were carried out with the composite feed and split fractions. The release analysis of the composite sample was carried out following BS 7530 (1994). The composite sample (unclassified) was subjected to collector aided flotation in a 2.5 liter Denver flotation cell. The process variables considered for the present investigation were collector dosage, frother dosage and aeration rate. The kinetics of flotation was also studied. High speed diesel oil was used as collector, and its dosage was varied from 0.5 to 1.0 kg/t. Polyglycol type of synthetic frother was used. The experimental conditions are summarized in Table 2.

Table 2. Experimental conditions for collector aided flotation

Parameters	Values
Feed size	-0.5mm
Pulp density	10 % solids by weight
Wetting time	1 hour
Impeller speed	900 rpm
pH of Pulp	Ambient (6.6-7)
Collector dosage (High speed diesel oil)	0.5 kg/t, 1.0 kg/t
Conditioning time with collector	2 minutes
Polyglycol frother	400 g/t, 700 g/t
Conditioning time with frother	1 minute
Air flow rate	10 L/min, 20 L/min, 40 L/min

The responses to flotation studies were measured in terms of recovery of combustibles, ash of the clean coal and flotation rate. Based on the results obtained with composite coal, the conditions required for the flotation of split feed were decided. The aim of the work was to produce a clean coal at 15% ash and 17% ash with maximum yield while generating other products having different ash levels for different other applications.

RESULTS AND DISCUSSIONS

Data for the release analysis of the -0.5 mm coal in terms of the recovery of combustibles in the clean coal at various ash levels are plotted in Figure 1.

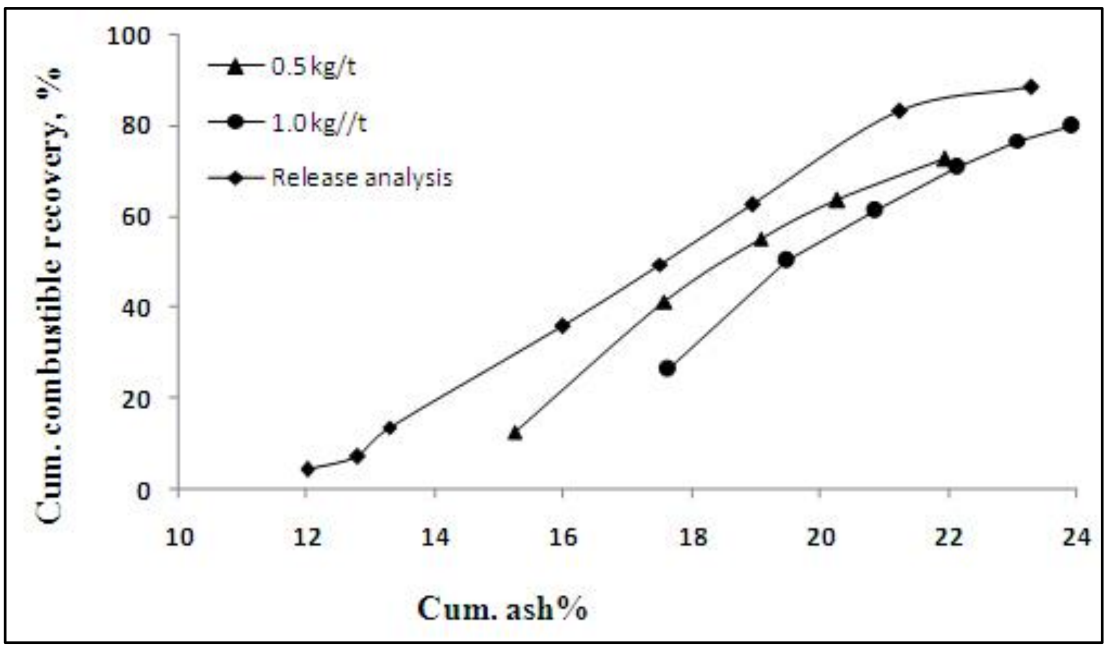

Figure 1. Release analysis and effect of collector dosage on composite coal

It reveals that at 15% target ash level, the maximum possible yield of clean coal and the recovery of combustible is about 23% and 27%, respectively. The yield for low ash in the clean coal is poor; however, 39% yield is obtainable at 17% target ash. The recovery of combustible at this level is about 43%. This indicates that this coal has reasonable floatability.

Effect of collector dosage on recovery of combustibles

The results of composite coal (-0.5 mm) flotation obtained from single stage addition of high speed diesel oil at two different levels are also shown in Figure 1. The floats were collected at different time intervals, and the products were analyzed**.** It is evident from Figure 1. that with 0.5 kg/t collector dosage, the curve is closer to the release curve at intermediate target ash. The recovery of combustibles is 12% at 15% ash, while at 17% target ash level, the recovery is 30.8%. At higher collector dosages, it was not possible to reduce the product ash level below 17.8%. Therefore, an attempt was made to reduce the ash content in the clean coal by varying frother dosage and air flow rate for maximizing the clean coal yield at 15% ash.

Effect of frother dosage

Flotation studies with the composite feed were carried out at different frother dosages and were decided based on the results of release analysis. It was varied between 400g/t to 700 g/t. The ash content and the recovery of combustibles obtained from float fractions collected at different flotation time are shown in Figure 2.

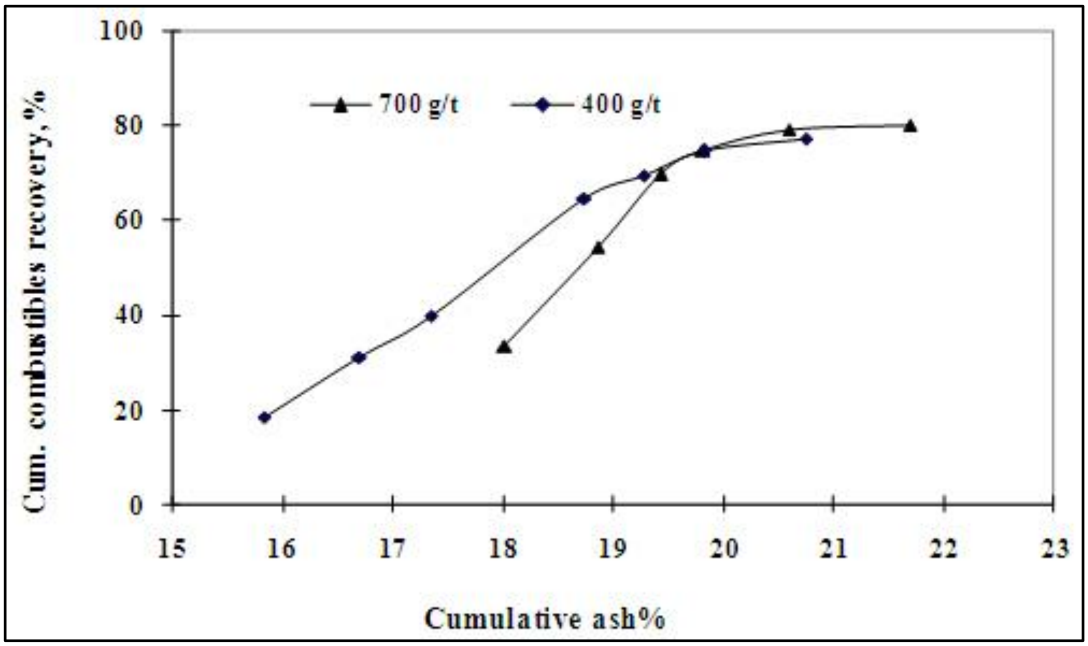

Figure 2. Effect of frother dosage on clean coal ash

The ash content in the first float at higher frother dosage (700 g/t) is about 18.0% and the combustible recovery is about 33%. The ash level achieved at a lower frother dosage (400 g/t) is 15.8% with 19.4% recovery of combustibles. Coal flotation follows the first order kinetics and rate constant was calculated using the following Eq. 2 (Agar *et al*, 1980):

$$k = [-\ln(1-R_{comb} / 100)]/t \qquad (2)$$

Where, k is the flotation rate constant, R_{comb} is the recovery of combustibles at time t.

The flotation kinetics at different frother dosage is shown in Figure 3. It appears that at higher frother dosage, the flotation rate is faster than at lower dosage. At the end of 60 seconds, the two graphs become asymptotic signifying completion of flotation albeit at different recovery levels. However, the increased frother concentration assists in the coalescence of bubbles which is undesirable. The low frother concentration leads to more effective dispersion of bubbles. The bubble size is also dependent on the concentration of frother, and it is the major factor determining the extent of entrainment in the froth phase. Smaller bubbles are formed due to the lowering of surface tension by the frother concentration, and that produces a thick froth. Miller and Ye (1989) observed that the bigger sized bubbles increase entrainment and also increase the drop back of particles from the froth phase subsequently (Goodwall and O'Connor, 1991). Rubinstein and Samygin (1998) noted that the entrainment of nonfloating gangue increases from 49% to 85% as the bubble size increases in the froth phase. In the present study also, the entrainment at higher frother dosage is evident from the higher yield and higher ash levels in the float fractions in comparison to those with lower frother dosage.

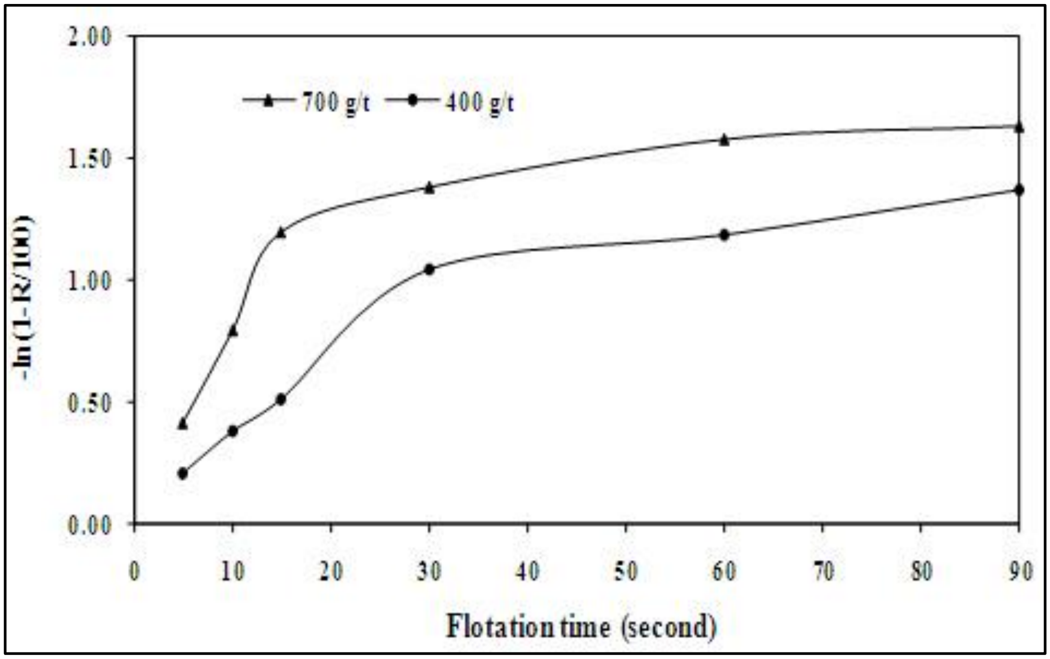

Figure 3. Flotation kinetics at different frother concentrations

Effect of aeration rate

The air flow rate has a direct bearing on the stability of the froth. The extent of aeration and the size of air bubbles generated play an important role in flotation. It determines the size, number and distribution of the air bubbles in the pulp. The collector aided flotation tests were performed at different air flow rates, i.e. at 10 L/min, 20 L/min and 40 L/min using 500 g/t of collector and 400 g/t of frother keeping other variables constant. The combustibles recovered at different air flow rates along with the ash contents in them are shown in Figure 4. It is observed that the combustibles recovered at 10 L/min air flow rate in 10 second flotation time is only 17.8% having 15% ash content. As the aeration rate increases the ash content in the clean coal also increases. At air flow rates of 20 L/min and 40 L/min, the yield of clean coal is high. However, in these two cases, the minimum ash level obtained in the concentrate at 10 second flotation time is above 17%. At low air flow rate, smaller size bubbles are generated, and the froths carry less entrained gangue. It indicates that at a low air flow rate only the highly hydrophobic particles, i.e. fast floating particles, float. Thus, the lower aeration rate favors to achieve the cleaner coal with lower ash. However, as the aeration rate increases, the bubble size increases, which assist to float the gangue minerals. Consequently, the yield of clean coal increases and the ash content in the product also increases. This is attributed to the entrainment of the gangue minerals at high aeration rate. The high yield at 40 L/min air flow rate is due to the entrainment of the nonfloating particles into the froth phase.

It may be concluded from the above collector aided flotation studies that at low air flow rate and low frother concentration decreases the ash content of the clean coal by reducing the entrainment. The same observation was made by Goodwall and O'Connor (1991). The product obtained by collector aided flotation of the composite feed does not produce reasonable yield at the target of 15% ash in the clean coal. Therefore, the split flotation of the composite feed at two different size classes, i.e. -0.5+0.15 mm and -0.15 mm were performed separately.

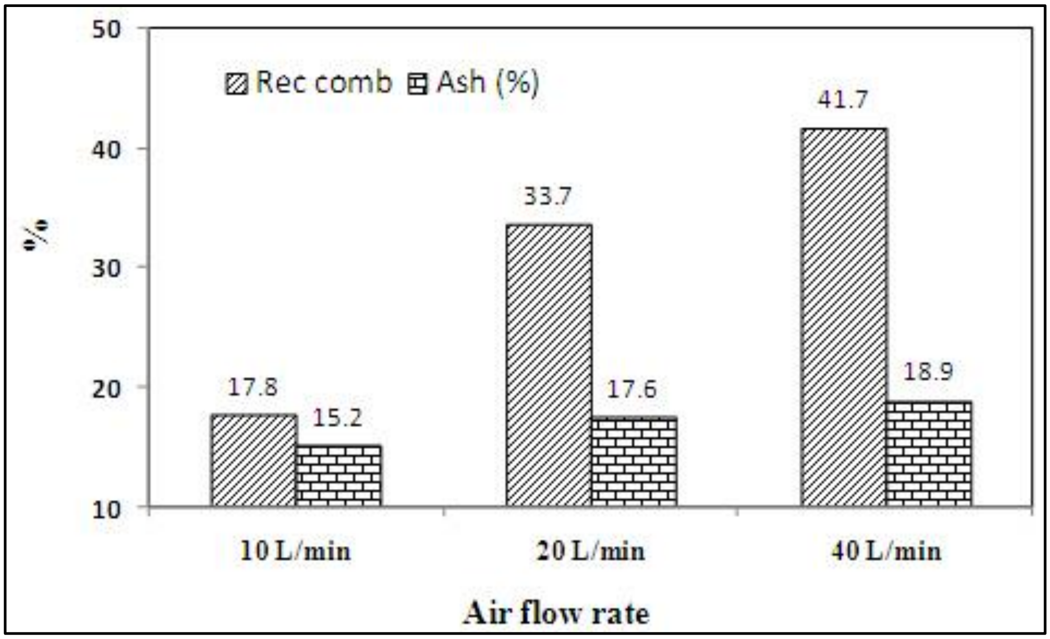

Figure 4. Recovery of combustible at different air flow rate

Flotation of -0.5 + 0.15 mm size fraction without collector

Release analysis of the -0.5+0.15 mm feed (refer Figure 5) indicate that the achievable recovery of combustibles at 15% and 17% ash levels are 46.6% and 63.5%, respectively (refer Table 3). The combustibles recovered at these ash levels are substantially improved when compared to the release analysis data of the composite coal (-0.5 mm). As the ash content of the -0.5+0.15 mm fraction was found to be low (21.9%), flotation studies were carried out without collector at different air flow rates. At a low aeration rate (10 L/min) 34% combustibles could be recovered at 15% ash although the yield was relatively low (refer Figure 5). When the air flow rate is increased to 40 L/min, the minimum ash in the clean coal increased to 16.2% and the recovery of combustibles increased to 36.7%. Release analysis data indicated that further improvement in the recovery can be achievable by optimizing the experimental conditions. A comparison of single-stage flotation without collector addition at different aeration rates vis-à-vis the release analysis data for this size fraction is given in Table 3.

To improve the clean coal yield at 15% target ash, two-stage collectorless flotation was carried out with -0.5+0.15 mm feed. In the first stage, airflow rate was maintained at 40 L/min using 400 g/t frother dosage to minimize the loss of combustibles in the primary tailing. In the second stage, the frother dosage was reduced and the aeration rate was kept at 10 L/min to obtain a low ash concentrate. The rougher concentrate achieved in the first stage was at 79.2% yield (49.2% with respect to original feed) with 19.3% ash. Subsequent cleaning of this product in the second stage at low air flow rate produced a clean coal with 15% ash at 40.4% yield (25% with respect to original feed) and with 17% ash at 54.8% yield (34% with respect to original feed). These results are closer to the results obtained in release analysis and are shown in Table 4. Split flotation of -0.5+0.15 mm fraction enhanced the yield by more than 15% for both the target ash levels. Split flotation of -0.5+0.15 mm fraction enhanced the yield by more than 15% for both the target ash levels.

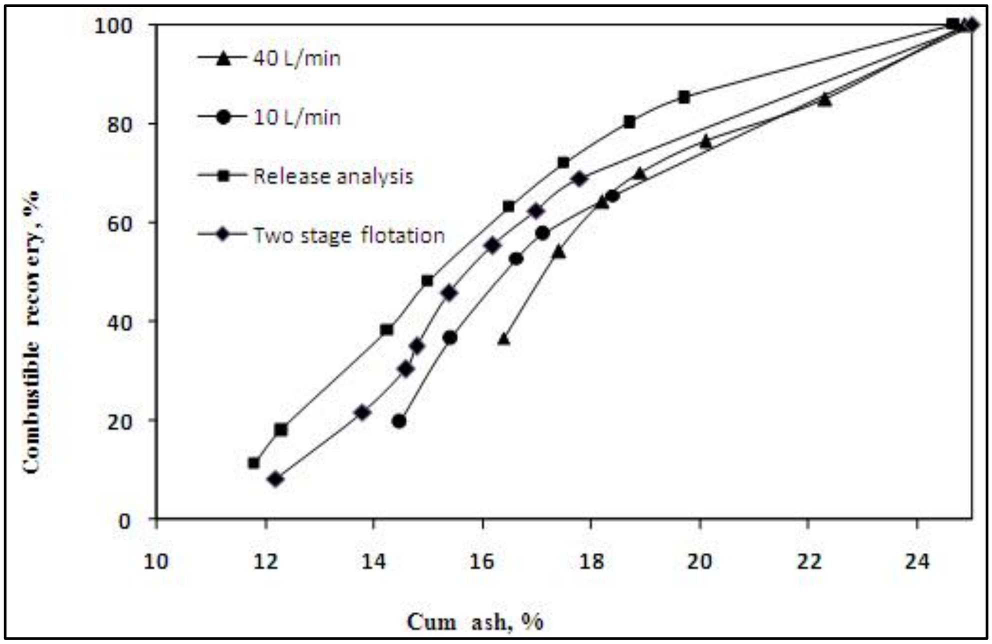

Figure 5. Flotation behavior of -0.5+0.15 mm feed in single-stage and two-stage flotation

Table 3. Results of single stage collectorless flotation of -0.5+0.15 mm coal

Release analysis				**Collectorless flotation at 10 L/min**				**Collectorless flotation at 40 L/min**			
15% ash level		17% ash level		15% ash level		17% ash level		15% ash level		17% ash level	
Yield (%)	RC (%)	Yield (%)	RC (%)	Yield(%)	RC (%)	Yield (%)	RC (%)	Yield (%)	RC (%)	Yield (%)	RC (%)
42.8	46.6	59.8	63.5	30.0	34.0	52.0	55.3	33.0 (16.2% min ash)	36.7	48.5	51.5

Table 4. Results of two-stage collectorless flotation of -0.5+0.15 mm coal

Products	**Yield (%)**	**Overall Yield (%)**	**Ash (%)**	**RC (%)**
At 15% ash				
Concentrate	40.35	25.1	15.0	45.27
Cleaner tail	38.85	24.1	23.87	39.38
Primary tail	20.8	12.9	31.28	19.03
At 17% ash	**Yield (%)**	**Overall Yield (%)**	**Ash (%)**	**RC (%)**
Concentrate	54.8	34.1	17.0	60.56
Cleaner tail	24.4	15.0	24.63	24.49
Primary tail	20.8	12.9	31.28	19.03

Collector aided flotation of -0.15 mm fraction

The primary tailing obtained from collectorless flotation of -0.5+0.15 mm was ground to -0.15 mm and treated along with -0.15 mm fraction. The overall -0.15 mm feed was then 50.8% by weight with about 30% ash. Collectorless flotation did not respond favorably due to the high ash content (Dey, 1997). Thus, to impart hydrophobicity, two-stage collector-aided flotation tests were performed using 0.75 kg/t collector dosage, 0.3kg/t frother dosage and 1.0 kg/t sodium silicate for depressing the associated siliceous gangue. The clean coal obtained from this fraction at 17% ash was 18.8% of the original feed by weight which is a suitable product for coke making. Scavenging of the tailing using 1.5 kg/t sodium silicate and 1.0 kg/t collector produced an intermediate clean product with 24.2% ash at 16.7% overall yield. The combination of this intermediate stream with cleaner tailing generated from the flotation circuit of -0.5+0.15 mm gives a product with 24% ash at 40.8% overall yield. This product can be used for sponge iron or cement industries. The final tailing from -0.15 mm is 15.3% by weight containing 56.4% ash which can be utilized in fluidized bed combustion for power generation (www.bee-india.nic.in). The schematic of the developed flowsheet with the yield and ash values of the product streams are shown in Figure 6.

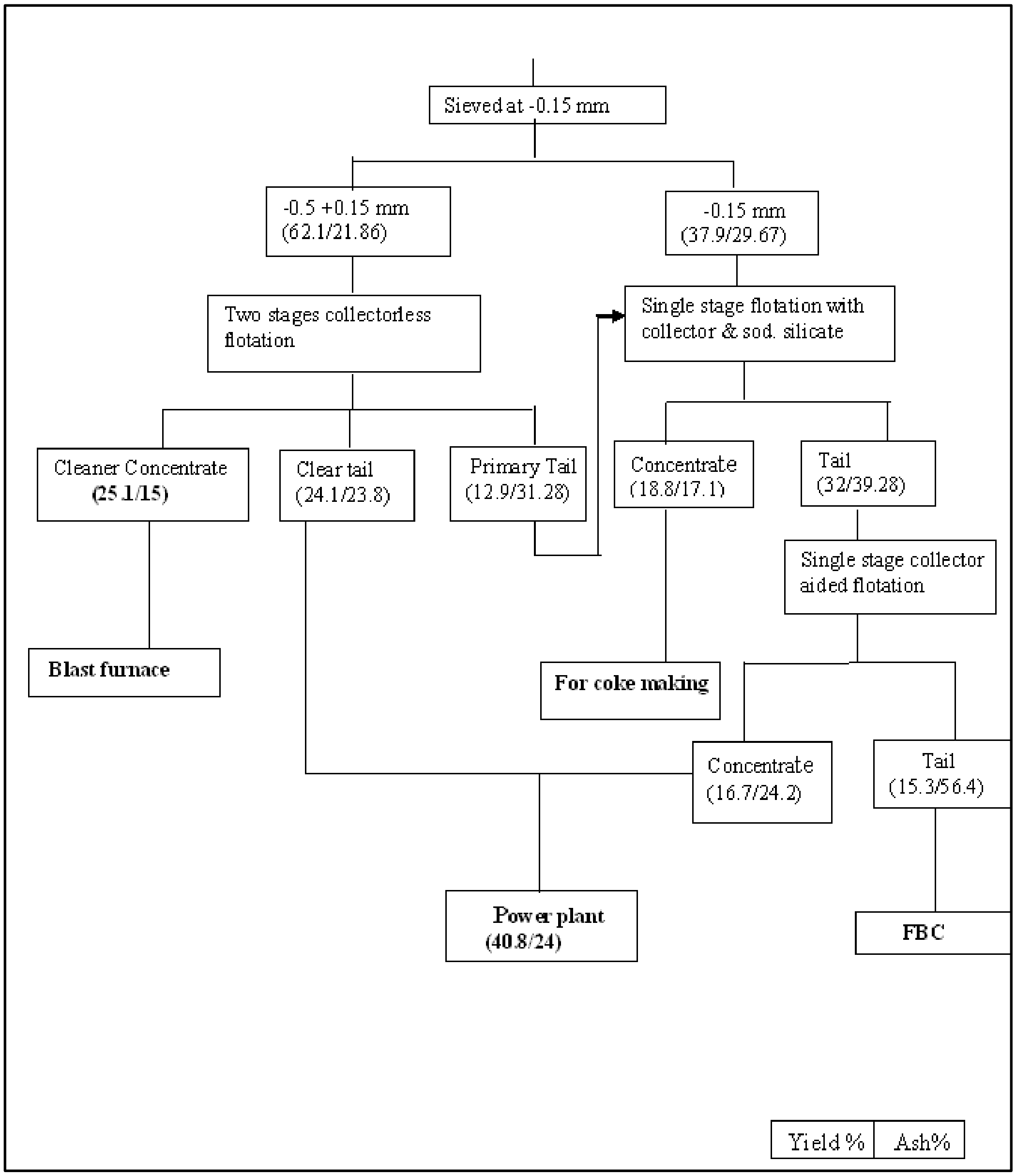

Figure 6. Schematic flowsheet of the process

CONCLUSIONS

The size-wise ash analysis of the -0.5 mm feed coal reflects that -0.5+0.15 mm fraction contains lower ash and the high ash bearing fraction is -0.15 mm. The release analysis of the -0.5+0.15 mm fraction indicates that the yield can be substantially improved at 15% and 17% target ash level. Thus, to achieve the clean coal with a low ash, split flotation of the composite coal (-0.5 mm) was performed. The conclusions of the study are summarized as follows:

- It was not possible to generate a low ash clean coal (15-17% ash) at reasonable yield from the composite -0.5 mm feed coal using flotation. Split flotation was found to meet these criteria.
- Clean coal from the -0.5+0.15 mm fraction by two-stage collectorless flotation at 25% yield with 15% ash could be produced which can be used in blast furnace. The cleaner tail is about 24% by weight with 23.8% ash. When this product is blended with the concentrate produced in the second stage flotation of -0.15 mm fraction, a combined product with 24% ash at 40.8% yield is obtained. This product can find application in sponge iron making or cement industries.
- The final tailing produced after two-stage flotation of -0.15 mm feed had 56.4% ash and a yield of 15.3%. This high-ash product can be used in fluidized bed combustion for the generation of power.
- In the case of two-stage collectorless flotation of -0.5+0.15mm, substantial increase in yield and recovery of combustibles can be achieved in the clean coal at 17% target ash level. The blending of this product with the concentrate obtained in the first stage of collector aided flotation of -0.15 mm produces overall clean coal of 53% yield at 17% ash level. This product can be used in coke making as sweetener.
- The findings highlight the application of split and collectorless flotation for developing a multiproduct zero waste processing scheme for the low volatile medium coking coal fines.

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