WASHABILITY AND FLOTATION CHARACTERISTICS OF TWO DIFFERENT COALS REPORTING AS FEED TO AN OPERATING COAL WASHERY

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ABSTRACT

Coal washeries source their coal from various seams. Two such coal samples of different origin and source, namely seam IX coal and a mixed seam coal, reporting as feed to an operating washery, were characterised for their washability and flotation response. The washability characteristics of these two coal samples were studied by heavy media separation. The wettability properties of these coals were evaluated by measuring the ratio of carbon to hydrogen in them and their contact angles. The ash content of seam IX coal and mixed seam coal were 34.10% and 24.90% respectively. Washability studies indicated that at equivalent ash content of 15% in clean coal, yield in the case of mixed seam coal was higher at 29% as compared to that in the case of seam IX coal at 24%. Improved yield at lower ash levels in clean coal warranted grinding the samples for liberating the coal macerals followed by separation by flotation. 72.88% of clean coal analyzing 12.60% ash could be obtained at 0.13 kg/t of frother and 0.605 kg/t of diesel after 3-stage cleaning of finely ground mixed seam coal (85% -100 μm) which was superior to clean coal obtained by flotation on coal fines (-0.5 mm) of the same sample. Similarly, 49.15% of clean coal analyzing 14.49% ash could be obtained at 0.0108 kg/t of frother and 0.605 kg/t of diesel after 4-stage cleaning of finely ground seam IX coal (87.5% - 100 μm) which was superior to clean coal obtained by flotation on coal fines (-0.5 mm) of the same sample. Better flotation in the case of mixed seam coal could be attributed to the higher hydrophobicity of mixed seam coal as borne out from the contact angle measurements and the higher carbon to hydrogen ratio (18.11) in its case as against that in the case of seam IX coal (16.91). Also, the flotation kinetics studies showed that the mixed seam coal floats faster ($k= 0.00439\ s^{-1}$) than seam IX coal ($k=0.00343\ s^{-1}$). Thus mixed seam coal is relatively easier to wash compared to seam IX coal and their yields and the ash content in clean coal could be predicted from these studies.

Key words: *coal washery; clean coal; washability studies; coal flotation; contact angle*

1. Introduction

Coal is a heterogeneous degradation product of vegetable and mineral matter [1], fossilized through oxidation. The appearance and properties of coal is determined by the nature of its origin and the physical and chemical changes occurred after deposition, leading to wide variation in their genesis and composition. Coal is susceptible to weathering and oxidation resulting in the increase in formation of oxygenated functional groups on the coal surface, thereby, altering the degree of natural hydrophobicity of the coal surface. This natural hydrophobicity influences the coal preparation processes that depend on surface properties of coal. The presence of mineral matter of shale bands within the coal seams [2] which on combustion transforms to ash is a major drawback in coal and coal cleaning process when compared to other forms of fuels [3]. Modern mechanized coal mining techniques generate large amount of fine particles that have to be recovered in coal washing plants [4]. Fine coal processing has always been a problematic and costlier than the cleaning of coarse coal [5]. Froth flotation technique is an effective and best available technique for cleaning fine coal with particle size less than approximately 0.5mm [6-8]. Flotation is a solid-solid separation process in aqueous solution based on the hydrophobicity differences between the substances to be separated [9]. In flotation, fine particles show lower flotation rate, resulting in low flotation recovery [10]. Flotation being a surface based separation, utilizes the differences in the surface properties mainly the hydrophobicity of coal which is one of the main factor in determining the separation efficiency by flotation [11]. However, because of the heterogeneity on surface composition, the hydrophobicity or contact angle of coal surface can vary in a wide range [12-14]. The separation efficiency depends on the wettability difference between the coal-rich and mineral-rich particles of the coal slurry in the flotation circuit. The high percentage of ash presence in the Indian coal is one of the setbacks for coal cleaning.

In coal preparation plants using flotation, approximately 5-15% of the mixed seam coal feed is processed through the flotation unit for recovery of fine coal particles. The basic difference between ore and coal flotation is that for ores the entire tonnage is ground to flotation size, whereas for coal

only the fine fraction (about 60 mesh x 0) not able to be processed by gravity concentration is treated by flotation.

Floatability is very much dependent on the rank of coal. Low volatile, mid volatile, high volatile, anthracite, or oxidized (weathered) coals all float differently. Oxidized coal causes problems with poor recoveries even when blended with higher rank coals.

The main aim of this study is to study the washability and flotation characteristics of mixed seam and seam IX coal. The surface properties such as wettability, contact angles and elemental analysis of the two coals were delineated to understand their differential separation behaviour.

2. Materials & Methods

Sampling was carried out to draw a representative sample of mixed seam and seam IX coals.

The heavy medium of desired density was obtained by using organic liquid mixtures of bromoform, tetrachloroethylene and benzene whose densities are 2.88g/cc, 1.62g/cc and 0.88g/cc respectively. The media ranging from density 1.80g/cc to 1.30g/cc with an increment of 0.1g/cc were prepared by mixing the above mentioned liquids in proper volume proportions.

Contact angle measurements of coal samples were carried out using 'sorption method' of Kruss tensiometer instrument (K100 model).

The mixed seam coal and seam IX coal were subjected to elemental analysis using Euro-vector Elemental (C, H, N, S) analyzer.

Bench scale conventional flotation tests were performed in a D12 Denver Flotation Machine.

High Speed Diesel (HSD) and Nalco 9840 frother were used as collector and frother respectively in flotation tests.

3. Results and discussion

3.1 Particle Size Analysis

Representative samples of seam IX and mixed seam coal were subjected to dry sieving and the weight percentage retained in each screen was recorded as tabulated in Table 1. Also ash analysis of the corresponding sieve fraction was carried out. Mixed seam coal was found to be relatively coarser (d_{80}: 421µm) than seam IX coal (d_{80}: 377µm). The ash content in the mixed seam coal (24.90%) is lower than that in seam IX coal (34.10%). Ash content in individual size fraction is found decreasing with decrease in particle size whereas ash distribution was found to increase with decrease in particle size.

Table 1 Sieve & Ash Analysis of two coal samples

S.No.	Size, µm	Seam IX Coal			Mixed seam Coal		
		Wt., %	Ash, %	Ash Dist., %	Wt., %	Ash ,%	Ash Dist., %
1	+500	4.74	38.34	5.26	16.61	32.16	20.26
2	-500+355	19.42	37.49	21.08	13.58	26.95	13.88
3	-355+212	24.89	33.69	24.28	18.46	25.67	17.97
4	-212+100	23.27	33.39	22.50	22.11	23.71	19.88
5	-100	27.68	33.52	26.88	29.24	25.27	28.01
Head Assay				34.10	Head Assay		24.90

3.2 Heavy Media Separation (HMS)

The data obtained from HMS tests were used to plot the washability curves as shown in Fig. 1. These curves are used to determine the maximum limit of separation that can be achieved by washing the coal. The +0.5mm size fraction of the two coals alone were subjected to heavy media separation.

Washability Curves:

Float Curve: It represents the relationship between the cumulative wt % float Vs specific ash % in float.

Sink Curve: It represents the relationship between cumulative wt % sink Vs cumulative ash % in sink.

Instantaneous Curve: It depicts the relationship between the weight fractions of float and its ash content.

Specific Gravity curve: It's a relationship between the cumulative float Vs Specific gravity at which the material is floating.

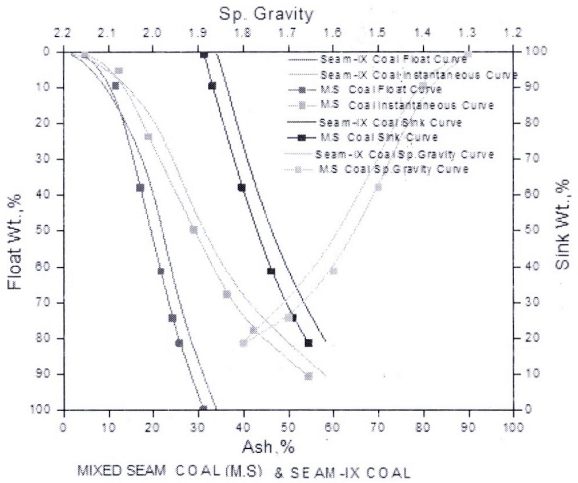

Figure 1 Washability curves of +0.5mm fraction of mixed seam and seam IX coals

From mixed seam coal feed, if it is required to obtain a clean coal product of 15% ash, it could be seen that

(a) The clean coal recovery would be 29%

(b) The sink/rejects contain 38% ash

(c) The particles of ash content 21% will be included in the clean coal

(d) This type of clean coal has to be separated at specific gravity 1.47

Similarly to obtain a clean coal product of 15% ash from seam IX coal,

(a) The clean coal recovery would be 24%

(b) The sink/rejects contain 40.5% ash

(c) The particles of ash content 24% will be included in the clean coal

(d) This type of clean coal has to be separated at specific gravity 1.50

3.3 Contact angle measurements

The contact angle measured between coal and water for mixed seam coal and seam IX coal are given in Table 2.

Table 2 Contact angle of coal samples

Sample	Contact angle, degree
Mixed seam coal	85.43
Seam-IX coal	72.99

The contact angles reported is the average of three measurements. The contact angle of mixed seam coal is 85.43 degrees and 72.99 degrees for seam IX coal. This clearly indicates that the wettability of seam IX coal with water is higher and hence relative hydrophobicity is less leading to lower yields.

3.4 CHNS Elemental Analyzer

The coal samples were powdered to below 212µm and weighed in a tin capsule provided and fed to the sample holding chamber of the instrument. The samples were then heated up to 980°C for an hour and allowed to cool down. The results obtained are shown in Table 3.

Table 3 Elemental analysis of mixed seam and seam IX coals

Sample	C, %	H, %	N, %	S, %	C:H
Mixed seam coal	65.056	3.592	1.400	0.421	18.11
Seam IX coal	55.967	3.310	1.019	0.498	16.91

It could be inferred that mixed seam coal contains relatively higher carbon, hydrogen and C:H ratio resulting in better hydrophobicity and response to flotation.

3.5 Flotation

3.5.1 Flotation tests on coal samples

Slurry conditioning with reagents at 25% solids by weight was maintained. Flotation at 12.5% solids by weight and natural pH: 7.0 was carried out. The results are shown in Table 4.

Table 4 Flotation of coal samples

Mixed seam coal: 24.90% ash (Head); Seam IX Coal: 34.10% ash (Head)

Diesel, kg/t	Frother, kg/t	Product	Seam IX Coal		Mixed seam Coal	
			Yield, %	Ash, %	Yield, %	Ash, %
0.363	0.033	Float	37.19	19.94	47.45	12.66
		Sink	62.81	43.25	52.55	37.17
0.545	0.065	Float	77.78	29.07	67.86	16.60
		Sink	22.22	56.86	32.14	45.62
0.726	0.065	Float	81.22	28.65	81.37	18.84
		Sink	18.78	58.02	18.63	47.86
0.726	0.098	Float	87.50	30.70	84.92	18.94
		Sink	12.50	63.35	15.08	57.19
0.908	0.098	Float	89.90	31.05	85.64	20.66
		Sink	10.10	65.31	14.36	57.09

The minimum ash content of 12.66% at 47.45% yield could be realized at 0.363 kg/t of diesel and 0.033 kg/t of frother on mixed seam coal whereas in case of seam IX coal, the float assayed 19.94% ash with 37.19% yield at the same reagent dosages. Further increase in dosages of reagents resulted in higher ash in floats of both mixed seam coal and seam IX coal with concomitant increase in yield.

The results clearly indicate the poor flotability of seam IX coal even at lower dosages of diesel and frother. This may be due the poor or insufficient liberation and/or high wettability of the coal sample.

3.5.2 Flotation kinetics of coal samples

Flotation kinetics study the variation of floated coal mass according to flotation time. All operational variables are kept constant, the algebraic relationship between the above mentioned parameters is a flotation rate equation expressed as

$dC/dt = -kC^n$, where, C is the concentration of solids, t is the flotation time, n is the order of the process and k is the rate constant.

If n=1, the above equation becomes

$dC/C = -kdt$, which on integration gives

$\ln(C_o/C) = kt$, where, C_o is the initial concentration of coal in the flotation cell, C is the concentration of coal remaining in the cell at the given time t and k is the flotation rate constant.

If the values for $\ln(C_o/C)$ are plotted against flotation time t, the slope of the straight line obtained is the flotation rate constant 'k'. The plots drawn for flotation kinetics tests at

diesel: 0.363 kg/t & Nalco Frother: 0.033 kg/t dosage on seam IX coal and mixed seam coal are shown below (Figure 2 & 3).

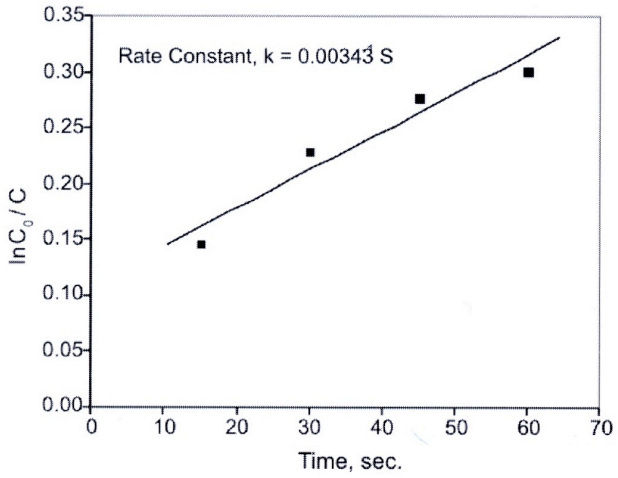

Figure 2 Flotation rate constant plot for seam IX coal

Seam IX Coal

The kinetic test results on both seam IX and mixed seam coal samples clearly show that mixed seam coal gave significantly higher kinetics and hence, higher recovery with lower ash content than seam IX coal. This may be due to the high ash content in the seam IX coal which will contribute for significant changes in the surface properties in terms of relatively lower hydrophobic property.

Mixed seam coal

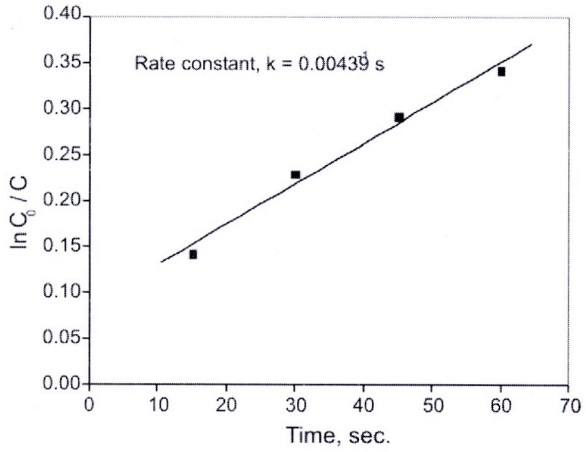

Figure 3 Flotation rate constant plot for mixed seam coal

3.5.3 Flotation studies on ground coal samples

Flotation tests were conducted on ground seam IX coal. 49.15% of clean coal assaying 14.49% ash could be obtained at 0.0108kg/t frother and 0.605kg/t diesel after four-stages cleaning of rougher concentrate obtained from flotation on ground seam IX coal (87.52% -100µm). This is superior to the optimum result obtained in case of flotation tests on 'as-received' seam-IX coal (37.19% yield at 19.94% ash). This could be attributed to better liberation of coal from its inorganic constituents on grinding.

Table 5 Flotation test results on ground Seam IX coal (Flotation feed size: 87.52% -100µm; Diesel: 0.605kg/t & Frother: 0.0108 kg/t)

Products	**Wt, %**	**Ash, %**	**Ash Distribution, %**
Final. Conc.	49.15	14.49	25.23
Cleaner-IV Tails	10.24	28.87	10.47
Cleaner-III Tails	9.90	33.35	11.70
Cleaner-II Tails	10.92	38.91	15.05
Cleaner-I Tails	8.19	46.44	13.47
Primary Tails	11.60	58.59	24.08

Similarly, flotation tests were also conducted on ground mixed seam coal. 72.88% of clean coal assaying 12.60% ash could be obtained at 0.130 kg/t frother and 0.605 kg/t diesel after three stages cleaning of rougher concentrate obtained from flotation on ground mixed seam coal (84.94% -100µm). This is superior to the optimum result obtained in case of flotation tests on unground mixed seam coal (47.45% yield at 12.66% ash). This again could be attributed to better liberation of coal from its inorganic constituents on grinding.

Table 6 Flotation test results on ground mixed seam coal (Flotation feed size: 84.94% of -100µm; Diesel: 0.605 kg/t & Frother: 0.1300 kg/t)

Products	**Wt, %**	**Ash, %**	**Ash Distribution, %**
Final. Conc.	72.88	12.60	39.99
Cleaner-III Tails	5.08	32.86	7.27
Cleaner-II Tails	4.75	41.52	8.59
Cleaner-I Tails	2.71	34.68	4.09
Primary Tails	14.58	63.10	40.06

Conclusions

Mixed seam coal was relatively coarser (d_{80}: 421μm) than seam IX coal (d_{80}: 377μm). The ash content in them was 24.90% and 34.10% respectively.

The washability studies indicated that, at equivalent ash content of 15% in clean coal, the recovery would be 29% and 24% in case of mixed seam and seam IX coals respectively.

Grinding both the samples yielded better yields at relatively lower ash levels in comparison to the unground / 'as received' coal fines.

The flotation kinetics studies indicated that the mixed seam coal floats faster (Rate constant, k= 0.00439s^{-1}) than seam IX coal (Rate constant, k= 0.00343 s^{-1}) at constant reagents dosage of diesel (collector) and Nalco frother.

Better flotation characteristics of mixed seam coal could be attributed to (i) higher carbon to hydrogen ratio in case of mixed seam coal (18.11) as compared to that in seam IX coal (16.91) and (ii) the relatively higher hydrophobicity of mixed seam coal vis-a-vis seam IX coal.

Strategy in terms of different reagents regime needs to be looked into to improve the yield and lower the ash in clean coal in respect of flotation of seam IX coal fines.

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