Comparative Performance Analysis of Collectors in Flotation

Ashvani Kr. Sahu[1], Shobhana Dey[2], S. Bhattacharya[1] and K. K. Bhattacharya[2]

[1]Indian School of Mines Dhanbad,
[2]National Metallurgical Laboratory Jamshedpur, India

Keywords: Flotation Performance; SER; Comparison.

Abstract

Choice of collector in coal flotation worldwide has been limited to kerosene and diesel oil. For various reasons, mostly related to reagent properties, the latter has been traditionally used in coal flotation in India. In a recent development, commercial synthetic collectors are being launched in the market. Objective of the present work is to compare between the performance of two collectors, diesel oil and one such commercial synthetic collector for the size fractions; -0.5+0.1mm &-0.1mm. These are the typical feed sizes in split feed coal flotation. The comparison was done on the basis of a flotation performance evaluation parameter called “Separation Efficiency Rate (SER)” and also the reagent cost.

* Corresponding Author: Ashvani Kr. Sahu, Ph. No. +91-8902494312, ashvani9454@gmail.com

1. Introduction

Indian coal is known to be of high ash content and difficult cleaning characteristics. Majority of coking coal wash plants in India currently operate at a yield level of only 25–45% at 18-23% ash. India is short of indigenous coking coal. The demand – supply gap for quality coking coal has reached such a level that coal blends in SAIL plants usually have a ratio of 70:30 and at times 80:20 between the imported and domestic. It is important therefore to maximize the clean coal yield from the wash plants within India. The depletion of good quality coking coal reserves and inclusion of coal from open cast mines deteriorated the quality of coal, and of fines the ash content of the latter at times is 35% or even more. The coal fines are normally enriched with vitrinite, responsible for increasing the caking propensity of the cleans, whose recovery therefore needs to be maximized. Flotation, commonly employed to process coal fines, is difficult if NGM in feed is >10. That is the case in all coal flotation circuits in India. Same is true for the low volatile coking coals (LVC), which constitute more than half of the existing coking coal reserves.

1.1 Objective of This Work

Coal washing cost, in particular the flotation cost is on a continuous rise. The reagent cost in flotation is around 45-50% of the total cost, major share being collector cost (up to 60-65%). Light diesel oil has been used in India as collector in coal flotation. Diesel price has increased by about 42% in the last seven years. It is essential to use a collector which can deliver high yield at low ash and is cost effective. Synthetic collectors are therefore being developed as a possible substitute for the traditional collectors. Flotation plant operators however need some kind of tool to quickly assess the suitability of different collectors and to select a particular one. Therefore, a comparative performance analysis of two collectors in coal flotation has been made in this work through batch flotation keeping the frother constant.

2. Literature Review

It is quite common to use Efficiency Index (EI) to obtain a quick estimation of flotation performance. The EI however does not directly take into account the “misplacement” between the concentrate and tailing, which is a common phenomenon in all separation processes. Flotation is no exception, particularly with feed with >10% NGM. The EI is calculated by

$$EI = R_{comb} \times A_T/A_C$$

R_{comb}= recovery of combustibles; A_T and A_C = tailing ash and concentrate ash, respectively

Chernosky [1] made a comparative study of 13 coal flotation reagents of 6 different chemical classes on yield – selectivity – cost basis, ignoring however the flotation rate. Chernosky’s method appears to be the only one available in published literature for quick estimation of reagent performance in coal flotation plants. Anderson [2] proposed an empirical formula of separation efficiency, SE in coal cleaning operation for gravity separators. SE takes into account, among others, the misplacement of non-combustibles in clean coal and loss of combustibles in tailings and hence the reagent selectivity in the separation process involved.

$$SE = 100 - [\{(Y_C \times R_{A/CC}) + (Y_T \times R_{C/T})\}/ 100]$$

Y_C = Yield of clean coal, Y_T = Yield of tailing, $R_{A/CC}$ = Recovery of ash in clean coal;

$R_{C/T}$ = Recovery of combustibles in tailings

Taking care of the limitations of EI and Chernosky's approach and building upon Anderson's empirical formula, Dey and Bhattacharya [3] proposed a new index, Cost per Unit SER to evaluate the performance of any coal flotation reagent. The approach takes into account all major performance parameters such as yield, misplacement, ash, selectivity, rate and reagent cost. In this method, convenient for coal flotation plant operators, reagent performance is evaluated through the performance evaluation of the flotation process itself.

Since, flotation rate is a vital parameter for the selection of reagents the separation efficiency (SE) has been multiplied by flotation rate to obtain Separation Efficiency Rate (SER).

$$SER = SE \times K$$

Where, K = Rate constant = $[-1n\ (1 - R_{comb}/100] / t$; t = flotation time in hour

Table 1: Frother performance analysis [3]

Size, mm	Frother	EI	SE	Rate Constant	SER	RC	Cost/ SER
–0.5 (SF = Synthetic Frother)	Pine oil	480	38	119	4491	5681	1.26
	MIBC	410	40	197	7866	3563	0.45
	SF	188	49	106	5135	5893	1.15
–0.5+0.1	Pine oil	301	45	74	3298	4538	1.38
	MIBC	450	40	229	9034	5550	0.61
	SF	271	50	118	2326	5893	2.53
–0.1	Pine oil	185	55	47	2569	5849	2.28
	MIBC	352	44	167	7292	2350	0.32
	SF	74	54	30	1455	5893	4.05

Since, reagent cost has been calculated in terms of hour, flotation time, "t" has also been expressed in hour. Higher the value of the SER the better would be the reagent performance. To take into account the reagent dosage and therefore cost, the concept of cost per unit SER has been introduced. Reagent cost has been calculated taking into consideration both collector and frother dosage for a typical 100tph circuit.

$$\text{Reagent Cost} = 100 \times (\text{CD in kg/t} \times \text{cost in Rs/ kg} + \text{FD in kg/t} \times \text{cost in Rs/ kg})$$

Where, CD = collector dosage and FD = frother dosage. Total reagent cost is divided by SER to get cost per unit SER, which could also possibly be termed cost per unit performance. Table 1 shows comparative performance evaluation of frother through batch flotation for a LVC coal with three different feed sizes. Best frothers on the basis of cost per unit Separation Efficiency Rate has been indicated by bold fonts. The same index has been used in this work to make a comparative analysis of collector performance in batch coal flotation.

3. Experimental Work

The LVC coal used in this work was obtained from combined V, VI and VII seams of Goluckdih

Size (mm)	Weight	Moisture	Volatile Matter	Ash	Fixed Carbon
-0.5	100	1.026	19.34	28.89	50.74
-0.5+0.1	76.7	1.045	19.230	29.20	50.525
-0.1	23.3	0.96	19.705	27.890	51.445

Colliery of Jharia coal field. Table 2 shows the proximate analysis of the flotation feed samples.

Experiments	X1	X2	X3
1	–1	+1	0
2	–1	–1	0
3	–1	0	+1
4	–1	0	–1
5	0	+1	+1
6	0	+1	–1
7	0	–1	+1
8	0	–1	–1

Table 2: Size by size proximate analysis (%) of the flotation feed

Table 3: Coding of variables

Pulp density (PD), collector dosage (CD) and frother dosage (FD) are the three operating variables, which affect the coal flotation performance most. Therefore the experiments were performed using an arbitrary design of experiments using these three variables (Table 3). Keeping the typical coal flotation practice in India in mind, pulp density and reagent dosage levels were selected with some arbitrariness.

Table 4: Experimental Design

S.N.	Name of Variable with Unit	Code Name	Code Levels and Actual Level		
			-1	0	+1
1	Pulp Density (% Solids by Weight)	X1	10.0	12.5	15.0
2	Collector(kg/t)	X2	0.75	1.25	1.75
3	Frother(kg/t)	X3	0.5	0.75	1.0

Flotation tests were carried out on split feed basis in a standard Denver cell. To carryout maximum number of experiments within the stipulated time, BOX BEHNKEN design was followed. Initially experiments were done at low pulp densities of 10 %(-1) and 12.5 % (0). Concentrate ash obtained at these pulp densities was never below the target level of 18%. Therefore it would have been more difficult to obtain the same at higher pulp densities. Hence, the experiments having +1 coded value of the variable X1 were removed from the design and a simpler experimental design having eight experiments were formulated (Table 4). Table 5 shows the remaining experimental parameters.

Impeller speed	Air flow rate	Wetting time	Conditioning time		Reagents used
900 rpm	7 lpm	1 hour	3min with collector	2min with frother	MIBC; Diesel oil (DO) & synthetic collector (SC)

Table 5: Other experimental parameters at constant level

4. Results and Discussion

Eight experiments were carried out per collector per feed size. The best flotation results have been defined in terms of clean coal yield at the same target ash 19%. Comparative performance analysis of the two collectors (Table 6) indicates that yield and floatation rates for both the collectors are different for both the flotation feeds; coarser and finer. It is a well known fact that fairly adequate liberation of LVC coal takes place only at a size of -0.1mm. SC appears to be a stronger frother because of its superior performance with the coarser feed consisting essentially of un-liberated or partially liberated coal particles.

The yield obtained with DO for the finer feed is 28.5%, substantially more than that obtained with the SC. Flotation rate with DO however is less than half of that obtained with the SC. Corresponding tailing ash contents obtained with the collectors show hardly any difference, indicating little difference in selectivity between the SC and DO. It is to be noted that the best results for the finer feed with both the collectors have been achieved under the same experimental conditions. That includes as expected a low pulp density level of 10% solids by weight.

In contrast to finer feed, the yield obtained with DO for the coarser feed is low, whereas that obtained with the SC is about 22.5%. Flotation rate with the latter one in this case too is far superior to that with DO. Tailing ash in this case too indicates little difference in selectivity between the two collectors. Best results for the coarser feed had been obtained with both the collectors at different reagent dosages but at the same expected pulp density of 12.5% solids by weight. Ideally finer feeds because of increased surface area might require larger reagent dosage. That proved to be rather true with DO. Yields obtained with the SC for both the feeds are however quite similar though reagent consumption is more and flotation rate is higher for the coarser feed. That can possibly be explained by the inadequate liberation in the coarser feed and by the interaction between collectors and MIBC at their respective dosage levels. Different reagent dosage levels for differently sized feeds could possibly improve the performance of both the collectors. The results obtained however are in agreement with the flotation results already reported by ISM and CIMFR. Therefore, the methodology can be used to compare the performance of collectors through batch flotation.

Table 6: Best collector performance for both the feed size at target ash of 19%

Feed Size	Collector	Yield %	RT (Sec)	Tailing Ash %	Experimental Conditions
-0.1 mm	SC	21.70	11.55	29.82	PD=10%; CD=1.25kg/t; FD=0.5 kg/t (Exp No. 4)
	DO	28.49	25.25	30.66	PD=10%; CD=1.25kg/t; FD=0.5 kg/t (Exp No. 4)
-0.5+0.1 mm	SC	22.30	6.45	32.99	PD=12.5%; CD=1.75kg/t; FD=1.0 kg/t (Exp No. 5)
	DO	13.60	3.80	31.58	PD=12.5%; CD=0.75kg/t; FD=0.5 kg/t (Exp No.8)

Table 7: Performance Comparison at 19% Clean Coal Ash

Coal Size	Collector	EI	SE %	SER %	Cost per SER
-0.5+0.1mm	SC	43.14	38.89	6393.30	6.36
	DO	25.22	25.83	4139.10	2.46
-0.1mm	SC	38.94	37.57	3272.06	8.02
	DO	52.50	44.84	2465.62	5.11

Table 7 shows a comparison between the different performance indices calculated for the two collectors for both the feeds based on Table 6. Efficiency index which ignores misplacement, flotation rate and reagent cost, indicates the synthetic collector and diesel oil to be the best collector for the coarser and finer feeds respectively. Separation efficiency though takes into account the selectivity indicate the same though the respective performance figures get reduced. Once separation efficiency rate is considered, the synthetic collector becomes the universal best collector, whereas diesel oil becomes the same as the reagent cost comes into play. Cost difference between the two collectors is so vast that poor flotation rate and low yield for the coarser feed obtained with diesel oil overshadows the merits of the synthetic collector.

5. Conclusions

Statistically designed batch flotation experiments with two collectors have been carried out for a LVC coal on split feed (-0.5+0.1 and -0.1mm) basis. Keeping the typical coal flotation practice in India in mind, pulp density and reagent dosage levels were selected with some arbitrariness.

A new reagent performance index, cost per unit SER, has been used to compare the performance of two collectors; traditional diesel oil and a synthetic collector. The former is found to be a superior collector for the liberated coal particles of -0.1mm size, whereas the latter for un-liberated or partially liberated coal particles of -0.5+0.1mm size; as long as flotation rate and reagent cost are not taken into consideration. Once rate is taken into account, then synthetic collector and when in addition cost is considered, then diesel oil becomes the better collector for both the feeds. Therefore, the index used to evaluate the collector performance is also important.

Though the yields of 20-30% obtained at 19% ash are in agreement with the flotation results already published for LVC coal, a separate study also presented at this MPT [4] indicates that 60-

65% yield at the same ash with the same feeds are possible to achieve with appropriate selection of collector and its dosage.

5. Acknowledgement

The authors are grateful to the Director National Metallurgical Laboratory Jamshedpur for his permission to carry out the work.

6. References

[1] Chernosky, F.J., 1963, Evaluation of coal flotation frothers on yield–selectivity–cost basis, Trans SME, 226, P.24–27.

[2] Anderson, W.W, 1950, Quantitative efficiency of separation of coal cleaning equipment, Trans AIME, 187, P.256- 264.

[3] Bhattacharya S. and Dey S., 2010, An Operator Friendly Performance Index for Frother Selection and Optimization in Coal Flotation, XVI International Coal Preparation Congress 2010, Lexington, SME, P.432-440.

[4] Singh, H., Dey S., and Bhattacharya S., 2011, Release analysis of coal, MPT 2011, Udaipur