Proceedings of the XI International Seminar on
Mineral Processing Technology (MPT-2010)
Editors: R. Singh, A. Das, P.K. Banerjee, K.K. Bhattacharyya and N.G. Goswami
© NML Jamshedpur, pp. 286–294

DEVELOPMENT, TESTING AND PLANT TRAILS OF SINGLE REAGENT SYSTEM FOR COAL FLOTATION

T.V. Vijaya Kumar, S. Subba Rao, G. Bhaskar Raju, S. Prabhakar, S. Shivakumar[1] and Uma Raman[1]

National Metallurgical Laboratory Madras Centre, CSIR Madras Complex, Taramani, Chennai – 600113, India

[1]Somu Organo-Chem Pvt. Ltd., Bangalore – 560076, India

ABSTRACT

Flotation is an important means of upgrading the fine fraction of raw coal, typically particles finer than 0.5 mm. Due to increased use of highly mechanized mining techniques large quantities of fines (< 0.5 mm) are being generated. These fines presently account for approximately 20–30% of the total plant feed. More than 140 million tones of fine coals are beneficiated by flotation worldwide annually. In coal flotation, reagents are required to enhance the hydrophobicity of coal surface. In addition to hydrophobic character, the selectivity, proper froth structure, stability and less sensitive to water chemistry are important.

Water insoluble hydrocarbons are widely used as collectors in coal flotation. These collectors are basically non-polar oils like diesel, kerosene, etc. along with some frothers. Thus, it is necessary to add collector and frother separately in coal flotation. It is generally accepted that in coal flotation a single reagent system is more advantageous than the present practice of two reagent system.

National Metallurgical Laboratory is involved in the flotation of coal fines using alternative single collector systems to developed specially replace fuel oils and frothers. For this purpose NML has entered into an agreement with M/s Somu Organo-Chem Pvt. Ltd. (SOCPL) Bangalore, a leading reagent manufacturer. Under this collaboration M/s SOCPL developed reagents and NML evaluated their selectivity index and application in coal flotation. Among many reagents developed and evaluated one best reagent was selected and full scale plant trails were conducted. The paper deals with the results obtained with several reagents in the laboratory and the plant trails.

Keywords: *Coal, Single reagent, Flotation.*

INTRODUCTION

Coal is a solid combustible material that results from the geologic alteration of vegetable matter, largely in the absence of air. Depending on the oxygen content of the coal, there is a progression in carbon content and hydrophobicity, and hence, floatability of various coals. Coals are susceptible to weathering and oxidation, which, in turn, results in the increased formation of oxygenated functional groups on the coal surface, resulting in more hydrophilic surfaces and hence reduced floatability. The mineral matter in raw coal is comprised of hydrophilic minerals mainly clay, quartz, calcite, dolomite, gypsum and pyrite.

Flotation is the only process which alters the surface properties of substances by chemical means in such a way that separation becomes feasible. Today, one of the major tasks in flotation is to find a suitable reagent system for the specific application, something that is not a simple task. Since the knowledge so far gained is based on empirical formulae flotation designers have to fall back on trial and error basis.

Froth flotation is an important means of upgrading the fine fraction of raw coal, typically particles finer than 0.5 mm. Froth flotation is the most common separation technique used for cleaning fine coals since 1920s. Approximately 142 million tones of fine coals are beneficiated by flotation worldwide annually.

In coal flotation, reagents are required to enhance the hydrophobicity of the coal surface. In addition to hydrophobic character the selectivity, proper froth structure and stability are important. Above all the reagent should be less sensitive to water chemistry.

Due to increased use of highly mechanized mining techniques large quantities of fines (–500 micron size) are being generated. These fines presently accounts for 20–30% of the total plant feed. Since clean coal is a low valued product, production costs must be minimized by maximizing plant yield, which requires the recovery of fine coal fraction.

Both modern mining methods and cleaning processes of coal increase the quantity of fine particles in raw coal. Coal preparation or cleaning is the process of removing non-combustible matter from run-of-mine coal. Conventional coal beneficiation techniques, like heavy media separation, shaking tables, washing cyclones etc, are not effective for fine coal processing. Studies have shown the use of froth flotation as an efficient fine coal particle processing methodology. But coal flotation is a complex process involving several phases.

Water insoluble hydrocarbons are widely used as collectors to increase the affinity of coal particles towards the air bubbles. These collectors are basically non-polar oils like diesel, kerosene and certain coal-tar distillates along with some frothers in many cases. Thus it is necessary to add collector and frother separately in the coal flotation. It is generally accepted that in coal beneficiation a single reagent system is more advantageous than the present practice of two reagent system. The most widely used reagent of coal flotation is the high speed diesel (HSD) as collector in combination with different frothers.

National Metallurgical Laboratory (NML) Madras Centre is involved in the flotation of coal fines without using the conventional fuel oils as collectors, but with newly developed collectors. In pursuing such new collectors, NML has entered into an MOU with M/s Somu Organo Chem Pvt. Ltd. (SOCPL), Bangalore, a leading reagent manufacturer for the development of new reagents for the flotation of minerals and coal.

In this study, coal sample was floated with a single reagent system developed by SOCPL and NML. The response of coal flotation was evaluated by estimating the ash in float by using different reagents as collectors. Among many reagents evaluated one best reagent was selected for the plant trail. For the plant trail M/s Tata Steel was kind enough to sponsor the plant trail as project and permitted NML to conduct the plant tests at the flotation plant of their West Bokaro works.

EXPERIMENTAL

Materials

The coal sample was obtained from West Bokaro coal works of M/s Tata Steel. The details of the coal sample were given below.

Location	: W #3	Collection Date	: 15-05-2007
Shift	: C	Product	: –0.5 mm
Seam	: VIII SEB		

The sieve and chemical analysis of the sample is given below.

Table 1: Sieve and ash analysis of the coal fines received

S.No.	BSS Sieve No	Size Microns	Weight %	Cumulative Wt %	Ash %	Cumulative ash %
1	+25	+600	0.40	0.4	26.20	0.40
2	–25+ 52	–600+300	23.6	24.0	21.86	21.93
3	–52 +100	–300+150	26.2	50.2	18.52	20.15
4	–100+200	–150 +75	19.4	69.6	18.47	19.68
5	–200+300	–75 +53	10.1	79.7	18.60	19.54
6	–300	–53	20.3	100.0	18.95	19.43
			100			

Different reagents of the following trade names were prepared by SOCPL for evaluation in the laboratory flotation tests.

530 Series: SOKEM 531C, SOKEM 532C, SOKEM 534C, SOKEM535C,
SOKEM 536C, SOKEM 537C, SOKEM 538C, SOKEM 539C

570 Series: SOKEM 570C, SOKEM 571C, SOKEM 572C, SOKEM 573C

HSD and Nalco 9840 frother were received from Tata Steel.

Methods

The experiments in the laboratory were conducted in a Denver Laboratory flotation machine, D-12. The flotation cell has a volume of approximately 3000 ml and 300 g sample + 1000 ml water was used in all the tests. Ordinary tap water of near neutral pH was used throughout the test work. The stirring speed of the flotation cell impeller was kept at 1200 rpm constantly in all the tests. In each flotation test the coal and water was mixed thoroughly in the cell then the single reagent collector was added and the suspension was conditioned for 5 min and then the air was opened for flotation. The froth was collected for 5 min. or till the froth formation stopped whichever is earlier. The collected froth and sink, the tailings were dewatered, dried in the oven at 100^{o}C, weighed and taken for ash determination. The ash content of both froth and the sink were determined adopting the standard method of ASTM Designation – D 2415 – 98 (Reapproved 2003). The ash content of the samples was calculated as follows.

Ash % = 100 × A/B
Where A = weight of ash
B = weight of the sample

RESULTS AND DISCUSSION

Tests with diesel and NALCO frother

Before attempting the plant trails it was decided to conduct a few laboratory flotation tests using the same reagent system being practiced at the coal flotation plant of Tata Steel, West Bokaro. The Diesel was purchased from the local outlets of IOC and the frother (NALCO 9840) was supplied by Tata Steel. A few tests were conducted by varying the dosages of both diesel and frother and the results of the same are given in Tables 2 to 5.

At constant frother dosage the effect of diesel on yield and ash rejection is shown in the Table 2, where it is clear that the ash rejection efficiency is poor. Similarly at constant diesel dosages the effect of frother on the ash rejection is shown in Tables 3 to 5.

Table 2: Effect of diesel at a constant frother 9840 dosage of 50cc/t

Coal – 500g

Test No.	Reagent Dosage cc/t	Yield,% (wt% of float)	Ash % in Froth	Ash rejection,%	Combustible Recovery,%	Efficiency Index
48	HSD-200 Frother-50	82.0	13.59	45.64	89.13	34.77
46	HSD-400 Frother-50	74.6	12.80	53.42	81.83	35.25
47	HSD-500 Frother-50	93.5	16.25	25.88	98.50	24.38

Table 3: Effect of frother at a constant diesel dosage of 200cc/t

Test No.	Reagent Dosage cc/t	Yield,% (wt%. of float)	Ash % in Froth	Ash rejection, %	Combustible Recovery, %	Efficiency Index
73	HSD-200 Frother-25	35.0	8.37	85.71	40.34	26.05
74	HSD-200 Frother-50	76.0	12.84	52.40	83.32	35.72
75	HSD-200 Frother-75	92.4	16.55	49.62	96.99	46.61

Table 4: Effect of frother at a constant diesel dosage of 400cc/t

Coal – 500g

Test No.	Reagent Dosage cc/t	Yield,% (wt% of float)	Ash % in Froth	Ash rejection %	Combustible Recovery %	Efficiency Index
76	HSD-400 Frother-25	49.7	10.40	74.79	56.01	30.80
77	HSD-400 Frother-50	88.9	15.63	32.22	94.35	26.57
78	HSD-400 Frother-75	93.3	16.61	24.40	97.87	22.27

Table 5: Effect of frother at a constant diesel dosage of 600cc/t

Coal – 500g

Test No.	Reagent Dosage cc/t	Yield,% (wt% of float)	Ash % in Froth	Ash rejection %	Combustible Recovery %	Efficiency Index
79	HSD-600 Frother-25	67.0	11.58	62.15	74.52	36.67
80	HSD-600 Frother-50	92.5	16.03	27.67	97.70	25.37
81	HSD-600 Frother-75	94.6	17.36	19.89	98.34	18.23

Tests with SOKEM reagents

The optimal composition of the reagent system depends on the degree of coalification, the process in which organic matter matures into coal. Natural hydrophobic properties grow with advancing coalification. Compounds that contain polar groups such as carboxyl groups, alcoholic carboxyl groups, keto groups and methoxyl groups are decomposed in the course of time. This process is accompanied by the separation of CO_2. The result is that, as the polar portion in the coal decreases, the hydrophobic properties increase with the increasing maturity of the coal. As the hydrophobic property of coal increase, the non-polar portion of the reagents becomes more important. Various types of coal have different compositions, surface properties and surface charges, which are influenced by the adsorption rate of various reagent groups.

Selective laboratory tests have been conducted to derive a specific reagent for the type of coal to be floated. The quality of the froth is a critical factor in determining the rate of recovery. A stable froth with good carrier properties will give the best results. However, it is important that the froth should break up on leaving the cell. The behavior of coal in the flotation process is determined not only by a coal’s natural hydrophobicity (floatability), but also by the acquired hydrobhobicity resulting from the use of flotation reagents such as collectors and frothers.

Table 6: Compilation of important results of all reagents evaluated

Test No.	Reagent SOKEM	Dosage Kg/t	Yield %	Ash in froth	Combustible Recovery %	% Ash Rejection	Efficiency Index
30	531 C	0.24	**49.5**	**9.45**	**56.8**	**77.8**	**34.57**
31		0.32	69.9	11.78	78.1	60.9	39.02
69	531 C	0.144	46.8	9.32	53.4	78.7	32.12
70		0.192	60.3	10.88	67.6	68.0	35.60
65	532 C	0.25	**52.2**	**9.93**	**59.1**	**68.5**	**33.82**
6		0.50	59.6	11.15	67.1	75.7	35.53
19	532 C (5 D)	2.44	**58**	**9.71**	**64.3**	**73.3**	**39.60**
20		2.51	**56**	**9.44**	**64.2**	**74.9**	**39.14**
121	532 C (2.5 D)	0.96	46.0	9.37	52.4	79.0	31.38
122		1.12	54.7	10.90	61.3	79.2	32.22
38	534 C	0.31	36.6	8.73	46.3	84.8	31.11
33		0.38	69.3	11.97	77.3	60.6	37.89
57	534 C	0.144	40.5	8.74	46.5	82.7	29.23
58		0.192	61.5	10.84	69.0	67.5	36.48
53	535 C	0.23	**49.4**	**9.46**	**56.3**	**77.2**	**33.50**
54		0.28	69.5	11.95	77.0	59.5	36.49
93	536 C	0.32	42.5	9.04	48.6	81.8	30.36
94		0.40	58.0	10.62	65.2	70.8	35.95
111	538 C	0.25	36.1	8.26	49.7	85.5	32.31
112		0.33	61.0	14.61	65.5	56.5	35.15
115	539 C	0.17	37.6	8.49	43.3	84.4	27.73
116		0.26	61.8	11.16	69.1	66.4	35.46
127	570 C	0.61	45.0	9.92	51.0	78.2	29.22
128		0.69	48.5	10.21	54.8	75.9	30.65
131	571 C	0.35	43.9	9.10	50.2	80.5	30.71
132		0.44	66.1	11.24	73.8	63.8	37.56
138	572 C	0.45	48.7	9.16	55.7	78.2	33.94
139		0.54	60.3	10.83	67.6	68.1	35.74
144	573 C	0.32	**50.2**	**9.35**	**57.2**	**77.1**	**34.32**
145		0.40	62.0	11.16	69.3	66.3	35.55

Several specific reagents were developed by Somu Organo Chem Pvt. Ltd. for the beneficiation of coal fines. These reagents were tested and evaluated in the laboratory Denver Cell. Though each reagent was evaluated separately for their flotation efficiency all the results are not provided here. Table 6 is the extract of the results obtained with various SOKEM reagents. From the results it is clear that SOKEM 573 C showed better efficiency both in coal yield and ash rejection. Also this reagent has advantages in handling and price. Hence, this reagent was taken for plant trails. Though 532 C (5 times diluted) gave better performance the disadvantage is the cost of the solvent required for dilution.

The above results clearly indicate that the flotation efficiency of SOKEM 573 C is comparatively better than the other reagents. Hence, few tests were conducted to see the effect of reagent (SOKEM 273C) dosage and percent solids on coal grade and recovery and the results of the same are presented in Tables 7 and 8 respectively.

Table 7: Effect of reagent SOKEM 573C dosage on coal yield and recovery

Coal – 300g

Test No.	Reagent Dosage kg/t	Yield,% (wt%. of float)	Ash % in Froth	Ash rejection,%	Combustible Recovery,%	Efficiency Index
143	0.24	40.0	8.66	83.10	46.0	29.10
144	**0.32**	**50.2**	**9.35**	**77.12**	**57.2**	**34.32**
145	0.40	62.0	11.16	66.25	69.3	35.55
146	0.48	72.2	12.21	57.00	79.7	36.70
147	0.56	76.4	11.91	55.61	84.7	40.31
148	0.64	79.5	13.71	46.83	86.3	33.13

Table 8: Effect of solids (1lit of water in all experiments) Reagent SOKEM 573 C

Test No.	Reagent kg/t / raw coal g	Yield,% (wt%. of float)	Ash % in Froth	Ash rejection,%	Combustible Recovery,%	Efficiency Index
159	**0.35 / 150g**	**65.3**	**10.50**	**66.55**	**73.5**	**40.05**
160	0.35 / 300g	43.0	7.81	83.62	49.9	33.52
161	0.35 /450g	35.6	8.55	85.15	41.0	26.15
162	0.35 / 600g	29.9	9.18	86.61	34.2	20.81
163	0.35 / 750g	26.5	9.76	87.38	41.4	28.78

The results clearly indicate that the flotation efficiency of SOKEM 573 C is comparatively better than the other reagents. It also seen from the results that the reagent is effective at low percent solids. Hence, this reagent was selected for the plant trails and accordingly 1.5 tons of this reagent was produced and the reagent was to a coal washery plant of Tata Steel, West Bokaro for plat trails.

Plant Trails

The plant trail programme was conducted during 24th to 26th February 2008, with the help and co-operation of M/s Tata Steel. Accordingly 1500 kg of the reagent was transported to West Bokaro in the 2nd week February 2008. In the coal washery plant, there are 4 banks of flotation cells in the plant flotation circuit. Each bank comprises 4 cells of 75 cft each, thus making the cell bank volume to 300 cft. Out of the 4 banks 2 banks consist of round bottom flotation cells and the other 2 banks are of flat bottom flotation cells. The four banks are arranged parallel as shown in the figure given below. 124 B was not working during the test period.

Flotation feed from upstream falls in the conditioners through a feed box. The two conditioners are internally connected. The slurry flows in the flotation cells from the conditioners. The reagents are added in the conditioners.

The plant trails were started in the 'B' shift on 24th February 2008 and continued up to 26th February 'A' shift, though there are plenty of breaks during the test work. The coal seam being fed to the plant is 8 A, which is branded as most difficult seam consisting lot of non-floatable coal. Though plant officials cautioned about this coal, we decided to start our trail. In the absence of any measurement regarding the feed to flotation circuit, the plant officials indicated that the feed to flotation circuit will be about 70–75 t/hour. Accordingly the reagent dosage was set at 450cc/min. The results of the same are presented in Table 9. The results clearly indicate the consistency in the performance of the reagent in grade of both concentrate and tailings. On prolonged trails there is every chance for further improvement in the concentrate grade.

Table 9: Results of the samples collected at specified time intervals during the trails

Date	Shift	Feed Ash %	Time	Froth ash %	Composite Ash, %	Tailings Ash %
24/2/08	B	25.38	9.00 pm	22.15	–	–
24/2/08	C	27.84	11.30 pm–2.00 pm	11.81	12.96	22.09
			2.00 am–6.00 am	12.10	12.93	33.39
25/2/08	A	29.25	6.00 am–10.00 am	13.08	13.78	37.65
			10.00 am–2.00 pm	–	14.11	33.77
25/2/08	B	30.79	2.00 pm–6.00 pm	12.66	14.10	48.88
			6.00 pm–10.00 pm	12.01	13.02	46.51
25/2/08	C	28.92	10.00 pm–2.00 am	12.08	13.30	41.87
			2.00 am–6.00 am	11.82	12.36	44.83
26/2/08	A	–	6.00 am–10.00 am	–	–	–
			10.00 am–2.00 pm	–	12.73	38.95

Apart from the results in the Table 9, a few spot samples of froth were also collected from the overflow lip of the cell and the results of the same are given in Table 10. These results clearly indicate the erratic behavior of the flotation cells.

Table 10: Assay of the spot samples of froth collected from the flotation cells overflow lip

Date	Time	Location, Cell Bank	Assay
25/2/08	4.00 PM	124 A	10.62
25/2/08	4.00 PM	126A	20.27
25/2/08	4.00 PM	126 B	11.70
25/2/08	8.45 PM	124 A	11.21*
25/2/08	8.45 PM	126A	
25/2/08	8.45 PM	126 B	

** The samples were collected to analyze ash in individual samples as well as composite. But only composite ash analysis was carried out by Tata Steel.*

It is observed from the trails test results that the single reagent system gave positive response at least in tailings ash and the quality of the water from the thickener, especially with a coal seam of having lot of non-floatable coal. Also, it is seen that the trail test results are in comparable or better (at least in tailings ash) with the plant results obtained for the same coal seam earlier.

CONCLUSIONS

Extensive test work has carried out to develop a single reagent system for the flotation of fine coal. Sufficient care was taken to keep cost of the reagent on par with the reagents being used in the present plant practice. 1500kg of the best performed reagent was transported to Coal Washery - 2 of Tata Steel, West Bokaro for the plant trails. Plant trails were conducted during 24-2-08 to 26-2-08. Trails were conducted on a coal seam which is not responding to flotation. The results are comparable or better with that of the plant results obtained earlier. The tailings are cleaner with the new reagent than the regular tailings of the plant. The combustible recovery and SE (Separation Efficiency) figures are in line/better with the regular plant results. The performance of the flotation cells is indifferent. Though the trail test programme is shorter, it is seen from the results that the performance of the new reagent is not very far from the results obtained in the laboratory. However, a longer plant trail is good enough to confirm the efficiency of the reagent. The results of the trail test are encouraging and paved the way for an elaborate and prolonged test work for conformation to use this single reagent system in place of diesel and frother.

ACKNOWLEDGEMENT

The authors are thankful to M/s TATA STEEL LTD. for the financial support and excellent co-operation during the plant trails at West Bokaro coal washery.