Frother Dependency in Coal Flotation

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Abstract

Frother dependency in coal flotation was examined using four coals varying in origin, rank, type, proximate analysis and feed size distribution and three different types of frothers, natural product (pine oil), synthetic alcohol (MIBC) and a polyglycol based synthetic frother, N 8586. No frother was found to be unique. MIBC and N 8586 were found to produce the best results for Bhelatand and composite coals, respectively; two coking coals of same origin and maturity with small difference in proximate analysis and feed size distribution. For the two non-coking coals of different origin and maturity with significant difference in proximate analysis and feed size distribution frother dependency appeared to be manifested in the choice of frother, its dosage and in particle surface characteristics and their interaction with the frothers used. MIBC, at a lower dosage produced the best result for Maltby coal, whereas, no frother could deliver encouraging result for the Amlorhi coal. Therefore, frother dependency in coal flotation appears to have many dimensions. These include origin, maturity and surface characteristics of the coal and also the frother type and dosage, collector – frother interaction and finally frother – particle surface interaction.

Keywords: Coal, Flotation, Frothers, Surface characteristics.

Introduction

Coal mining is mostly done through mechanized means. In addition, progressively deteriorating liberation characteristics have led to increasingly fine crushing of the coals prior to washing. Fines present in the crushed coal fed to the wash plants, as a result, has been continuously increasing. Naturally most of the coal wash plants include coal flotation circuits. It is well known that hydrophobicity of coal increases with increase in the carbon content (Wilkins, 1947) and in the rank (Crozier and Klimpel, 1989). According to Aplan (1976) hydrophobicity depends on petrographic composition, degree of carbonificaton, surface oxidation etc. and not necessarily on rank alone. Wierzchowski and Sablik (1994) attribute the hydrophobicity of coal to its mean critical surface energy, which apparently is a function among others of the reagents used and the energetic heterogeneity of its surface.

From commercial point of view, coal flotation frothers can be divided into three categories: nature-based alcohols, synthetic alcohols and proprietary formulations. Pine oil belonging to the first group is the cheapest and the proprietary frothers are the most expensive and claimed to be universally the most efficient frothers. According to Lin and Somasundaran (1994) pine oil has better capability of floating larger particles than corresponding alcohol type of frother and the latter shows better selectivity for finer particle sizes. In contrast, each of the synthetic frother chemistry has a unique particle size range (Klimpel and Hansen, 1987). It has been reported that oxidized coal generally floats well with pine oil (Osborne, 1988). To solve the persisting problems of flotation of oxidised coal, reagents containing a promoter are recommended, along with larger amounts of fuel oil (Wheeler and Keys, 1986).

Table-1: Flotation process parameters

Parameters→ Coal↓	Wetting time, minutes	Conditioning time, minutes	Impeller speed, rpm	Pulp density, % solids by weight	Pulp pH (Ambient)
Maltby	15	3	1800	6.0	6.8-7.2
Bhelatand Composite	60	5	900	12.5	6.6-6.8
Amlorhi	20	30	800	10.0	6.7-7.2

The average bottom line cost of coal preparation, globally, is reported to be \$2.52 per tonne (Laurila, 2000). Private discussions (1999; 2002) with the wash plant managers indicate that the bottom line of coal preparation cost in India is about Rs160/- (\$3.81) per tonne of cleans produced. Average coal preparation cost however, seems to be much higher. On global basis the flotation reagents alone constitute 2% of the total preparation cost (Laurila, 2000). In case of India, this percentage is thought to be higher. It appears that reagents alone constitute about 40% of the coal flotation cost in India, the break-up between collector and frother being seems to depend on collector and frother combination (Private discussions, 1999; 2002).

Objective of this work has therefore been to examine the frother dependency of coal flotation performance.

Experimental Work

Flotation experiments, on duplicate basis, were conducted (Table 1) in a 2.5 liters Denver sub-aeration flotation cell. Flotation feedpPulp density was varied depending upon the content of clay and ultra fines. Three different frothers, pine oil, MIBC at two different purity levels, and a polyglycol based Nalco frother, N 8586 were used in the investigation. Frother dosages were fixed on the basis of private discussion (1999, 2002). 6mole monyl – phenol – ethoxilate, an emulsifier, was used for Amlorhi coal.

Results and Discussion

Proximate analysis (Table 2) indicated all the coals, used in the investigation, were of high rank, except the one from Amlorhi, which was also found to be oxidized (Ahmed, 2003). Size analysis indicated varying size -consist of the flotation feeds (Table 3). Yield obtained with MIBC in flotation of Bhelatand coal was found to be consistently superior than the yields obtained with pine oil and N 8586 (Fig.1). As it appears from the yield-time profiles, flotation rate obtained with MIBC is also quite superior. Since Bhelatand coal is washed at about 16% ash and the final concentrate ash of 15.8% is within that limit, MIBC performance (Table 5) can also be considered to be the very best in both relative and absolute terms (Fig.2).

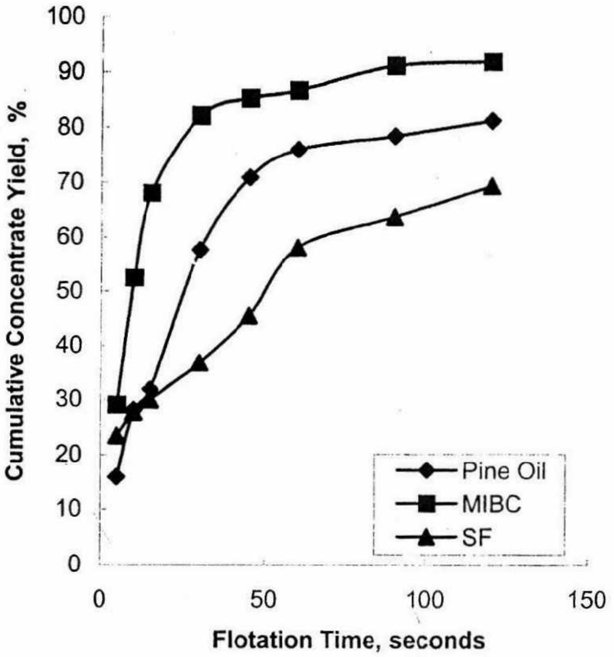

Figure 1 Frother dependent yield-time profiles of Bhelatand coal

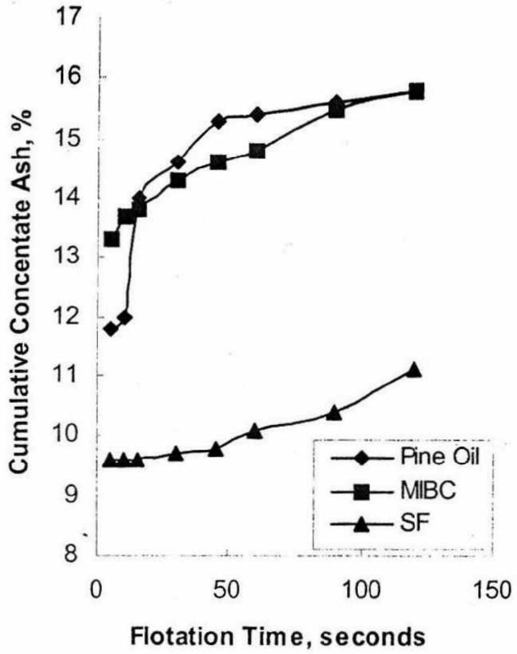

Figure 2 Frother dependent ash-time profiles of Bhelatand coal

Table -2: Proximate analysis (%) of as received samples

Coal	Source	Moisture	Ash	Volatile Matter	Fixed Carbon
Prime Coking: Drift Origin: Bituminous	Bhelatand: Underground	0.52	22.82	22.90	53.76
	Composite: UG:OC = approximately 50:50	0.70	25.18	22.03	52.09
Non-Coking: Drift Origin: Bituminous	Amlorhi: Opencast	3.10	50.20	24.05	22.65
Non-Coking: In-situ Origin: Anthracite	Maltby: Underground	0.98	33.09	24.27	41.66

Table- 3: Characteristic sizes (μm) of the flotation feeds

Coal	D_{50}	D_{80}	D_{100}
Maltby	125	280	500
Bhelatand	160	333	520
Composite	242	390	530
Amlorhi	300	360	710

It is also observed from ash - time profiles obtained with MIBC and pine oil that, the curves assumed asymptotic nature falling just short of the target ash. Yield – ash - time profiles (Fig.1-2) obtained with MIBC and pine oil indicate a better overall selectivity of MIBC. As it appears, because of poor initial dispersion, pine oil induced flotation "picks up" after about 10-15seconds. Performance of the synthetic frother N 8586 is found to be consistently poor.

Surface area calculation indicates that possibly the dosage used (0.15kg/t) for the N-8586 was actually starvation dosage. Frother dosage per unit surface area for pine oil and MIBC were found to be 6.4 x 10^{-3} gm/ m^2, whereas for the synthetic frother, only 1.3 x 10^{-3}gm/ m^2 (Dey and Bhattacharya, 2003). A comparison of recovery of combustibles and yield values obtained with N-8586 with the corresponding values obtained with MIBC and pine oil (Table 4) indicate that the former also has good selectivity.

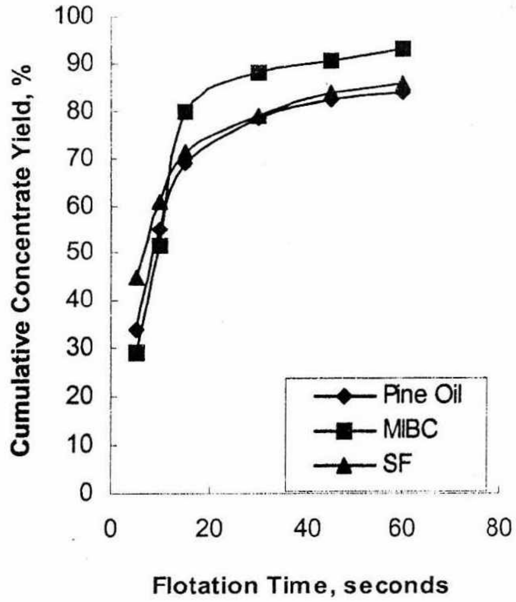

Figure 3 Frother dependent yield-time profiles of composite coal

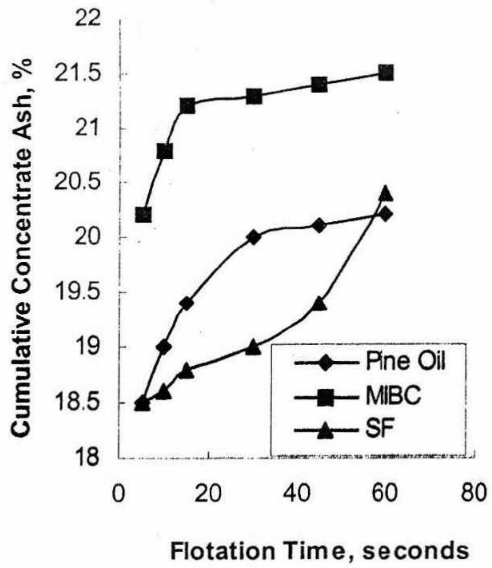

Figure 4 Frother dependent ash-time profiles of composite coal

In contrast, when composite coal of approximately the same maturity as of Bhelatand coal is subjected to flotation the cumulative yield (Fig. 3) and therefore, the flotation rates and at the same time the concentrate ash (Fig. 4) obtained with MIBC are consistently higher than those obtained with the remaining frothers. Since the cut-off ash for the flotation concentrates of composite coal is 19%, it is important to note the minimum concentrate ash obtained with MIBC is 20.2% and that too at the flotation time of 5 seconds, with only 29% yield. Flotation results obtained with pine oil and N 8586 are somewhat similar to each other, though the concentrate ash obtained with N 8586 is visibly better. The synthetic frother shows better selectivity till about 50 seconds (Fig. 3-4). In flotation with N 8586, 79% yield is obtained at 19% cut-off ash at 30 seconds flotation time. Frother dosage per unit surface area for pine oil and MIBC were found to be 7.2×10^{-3} gm/ m^2, whereas for the synthetic frother, only 1.4×10^{-3}gm/ m^2 (Bhattacharya and Dey, 2003). Therefore, in case of composite coal too, the argument of "starvation dosage" of N 8586 can be put forward. Since the best flotation result, in this case, particularly at the target ash (Table 5), has been obtained with the synthetic frother, such an argument does not hold good.

Table 5 A Summary of results at fixed flotation time and at target ash

Collector Dosage, kgpt	Frother (Dosage, kgpt)	Concentrate		Recovery of Combustibles, %	
		Yield, %	Ash, %	Fixed Time	Target Ash
Bhelatand Coal: Flotation Time, 120seconds; Target Ash=16%					
Diesel Oil	Pine Oil	81.2	15.8	88.6	Could not be determined
	MIBC	91.8	15.8	99.6	
	N 8586	69.3	11.1	79.8	
Composite Coal: Flotation Time, 60seconds; Target Ash=19%					
Diesel Oil	Pine Oil	83.8	20.2	89.4	74.6
	MIBC	92.9	21.5	97.3	30.7(20.2% ash)
	N 8586	85.7	20.4	91.2	85.7
Maltby Coal: Flotation Time, 120seconds; Target Ash=6%					
Kerosene (0.82)	Pine Oil (0.16)	56.3	6.1	79.0	95.8
	MIBC (0.16)	70.0	6.1	98.2	98.7
Kerosene (1.15)	MIBC (0.22)	70.0	6.7	97.6	42.2
Amlorhi Coal: Flotation Time, 100seconds; Target Ash=34%					
Diesel Oil (0.60)	Pine oil (0.65)	19.9	46.1	21.5	Not determined
Diesel Oil (0.80)	MIBC (0.60)	11.5	33.1	15.4	
Diesel Oil (0.80)+E (0.02)	MIBC (0.18)	8.5	19.9	13.6	
	Pine oil (0.18)	11.4	22.6	17.7	

Notwithstanding the dosage variation, kerosene + MIBC combination indicates a superior concentrate yield in the flotation of Maltby coal (Fig. 5). Kerosene + pine oil requires significantly longer residence time to achieve approximately the same yield level and also recovery of combustibles at target ash (Table 4), possibly because of the longer dispersion time required by the pine oil in general. Effect of kerosene + MIBC dosage variation is also evident on the concentrate ash (Fig. 6) and on selectivity, particularly at the target ash level. Lower dosage of kerosene + MIBC seem to improve the selectivity. Pine oil seems to be however the better frother for the Maltby coal in respect of selectivity.

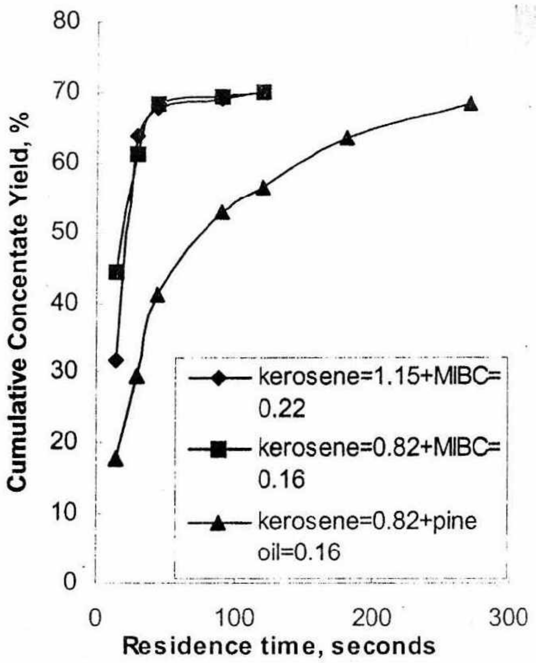

Figure 5 Frother dependent yield-time profiles of Maltby coal

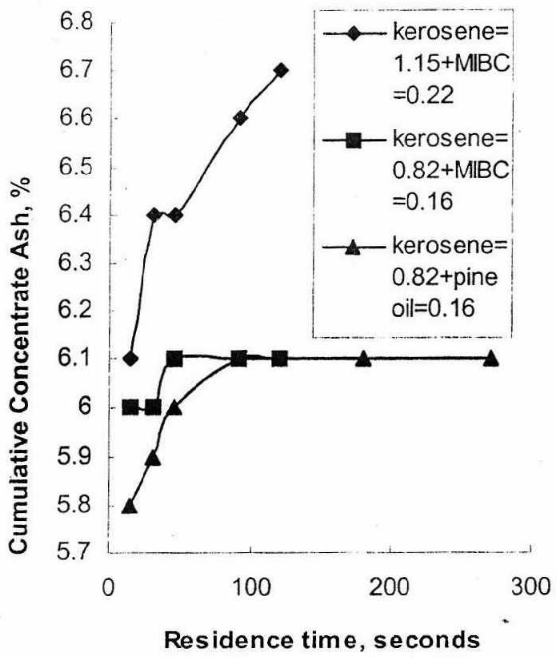

Figure 6 Frother dependent yield-ash profiles of Maltby coal

In spite of all the three types of frothers being used in varying dosages, flotation response of Amlorhi coal (oxidized in nature) is observed to be poor. It has been reported that oxidized coal generally floats well with pine oil (Osborne, 1988). This is evident to some extent, as in comparison with MIBC; pine oil shows better yield and flotation rate, in spite of its slow dispersion characteristics. Purity of MIBC appears to have an adverse effect on the flotation result. Addition of emulsifier seems to make no contribution to the flotation performance. None of the flotation results is anywhere near the flotation target ash of 34%. Change in pH with MIBC as the frother and variation in wetting and conditioning time made no impact on the flotation performance (Ahmed, 2003). Currently work is in progress to examine the flotation performance under changing pH with pine oil as the frother.

The results obtained and discussed here before have shown significant frother dependency in coal flotation performance. Though the two coking coals are of same origin, type and maturity with small difference in proximate analysis and feed size distribution (Table 2 & 3), their flotation response appears to be greatly dependent on the choice of frother. MIBC and N 8586 have been found to produce the best results for Bhelatand and composite coals, respectively. Frother dosage does not seem to play a major role in case of the two coking coals. Did the different mining methods used influence the particle surface response to the frothers? It would be very difficult to comment. It is known however, that collector – frother interaction plays a significant role in frother performance in coal flotation (Dey, 2003).

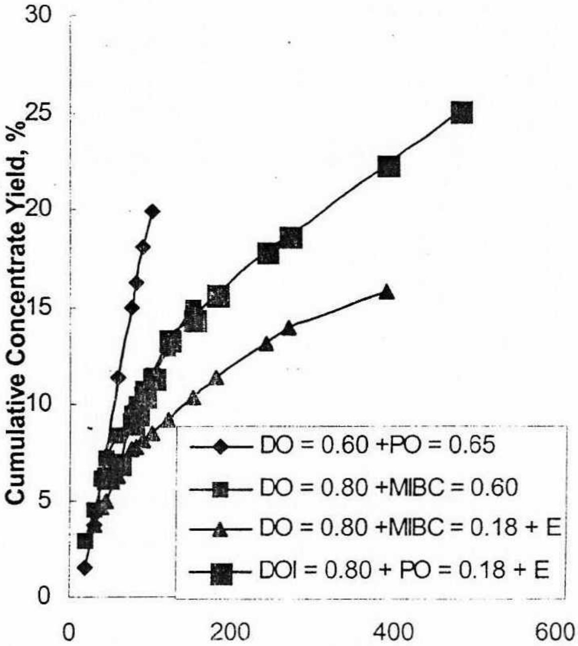

Figure 7 Frother dependent yield-time profiles of Amlorhi coal

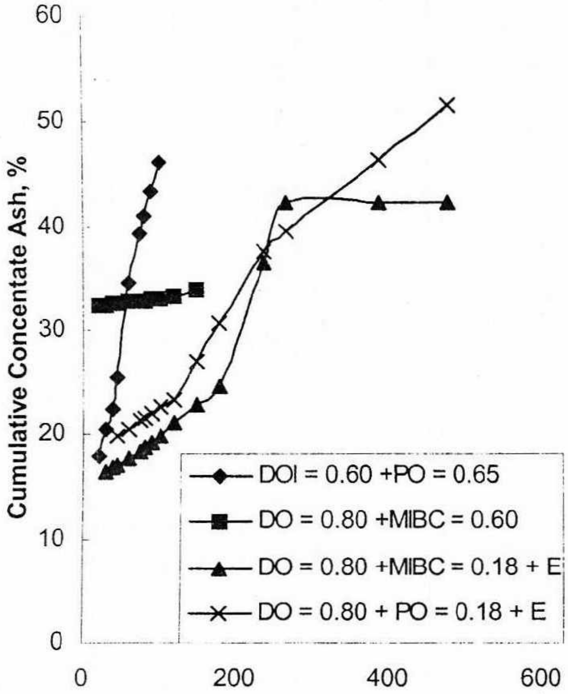

Figure 8 Frother dependent yield-ash profiles of Amlorhi coal

Maltby coal, which is of different origin and maturity with significant difference in proximate analysis and feed size distribution with the other three coals, appears to indicate a different kind of frother dependency in coal flotation. Possibly because of the in-situ origin, which generally excludes fine dissemination of mineral matters, notwithstanding the high ash of the coal fines, good results are obtained with both pine oil and MIBC, at a considerably lower frother dosage. Pine oil however requires a longer flotation time. In this case, possibly because of the very high maturity and in-situ origin of the coal, frother dependency appears to be less in comparison with the two coking coals and seems to be manifested in frother (MIBC) dosage and frother (pine oil) dispersion characteristics.

Though oxidized coals are known to generally float well with pine oil and it has better capability of floating larger particles, flotation response of Amlorhi coal, even to pine oil, in presence of emulsifier, is observed to be poor. Neither the use of 99% pure MIBC could improve the flotation of the same coal, which is oxidized, coarse in nature and of low rank. Rank, feed size distribution and surface oxidation contribute to the surface characteristics of coal. Frother dependency in flotation of Amlorhi coal therefore, appears to be manifested in surface characteristics and their interaction with the reagents used. Perhaps increased collector dosage and or the usage of a promoter would improve the flotation response.

Summary and Conclusions

No single frother could produce the best result for all the four coals used in this investigation varying in origin, rank, type, proximate analysis and feed size distribution. Frothers used were of three different types, natural product (pine oil), synthetic alcohol (MIBC) at two different purity levels, and a polyglycol based synthetic frother, N 8586. For the two coking coals of same origin, type and maturity with small difference in proximate analysis and feed size distribution their flotation response appears to be greatly dependent on the choice of frother and through that on collector – frother interaction. MIBC and N 8586 have been found to produce the best results for Bhelatand and composite coals, respectively. For the two non-coking coals of differing origin and maturity with significant difference in proximate analysis and feed size distribution frother dependency in coal flotation appears to be manifested in the choice of frother, its dosage and in particle surface characteristics and their interaction with the reagents used. MIBC, at a lower dosage has been found to produce the best result for the Maltby coal, whereas, no frother could produce encouraging result for the Amlorhi coal. In summary, it appears that frother dependency in coal flotation has many dimensions. These include origin, maturity and characteristics of the coal as well as the frother type and dosage, collector – frother interaction and finally reagent – particle surface interaction.

References

1. Ahmad, Md Zahid, 2003, Effect of wetting and conditioning time on coal flotation, Dhanbad, India: Indian School of Mines M Tech dissertation.
2. Aplan, F. F. 1976, Coal Preparation In Froth Flotation: A.M. Gaudin Memorial Volume, p. 1255, New York, AIME.
3. Bhattacharya, S. and Dey, S. 2003, Collectorless flotation of a composite feed, Journal of Mines Metals & Fuels, 51: 112-118.
4. Crozier, R.D. and Klimpel, R.R. 1989, Frothers-Plant Practice In Frothing in Flotation, p. 257, New York, Gordon and Breach.
5. Dey, S, 2003, A comparative study on frother performance in coal flotation, Dhanbad, India: Indian School of Mines PhD dissertation.
6. Dey S. and S. Bhattacharya S. 2003, Collectorless flotation of a coking coal, Transactions, IIM, 2003
7. Laurila, Mel. J. 2000, Best Practices in International Coal Preparation: Developing a Benchmark for Coal Preparation in India, In proceedings of coal preparation India, New Delhi.
8. Klimpel, R.R and Hansen, R.D. 1987, Coal Flotation In Fine Coal Processing, p. 78, New Jersey, Nayes Publications.
9. Lin, D. and Somasundaran, P. 1994. Role of collector and frother and hydrophobicity/oleophilicity of pyrite on the separation of pyrite from coal by flotation. International Journal of Mineral Processing, 4: 227-238.
10. Osborne, D.G. 1988, Coal Preparation, Vol. 1, London, Graham and Trotman.
11. Private Discussion, 1999; 2002, Coal India Ltd and TISCO.
12. Wierzchowski, K. and Sablik, J. 1994. Dependence of natural and reagent-activated standard coal flotation response on the surface energy, In proceedings of XII ICPC, Krakow.
13. Wilkins, E.T. 1947. Coal preparation-some development to pulverized practice. In proceedings of conference on pulverized fuel, Harrogate.
14. Wheeler, T. A. and Keys, R. O. 1986. In Chemical Reagents in the Mineral Processing Industry, Ch.31, Littleton, SME.