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Separation characteristics of different size and density fractions in batch coal flotation

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Abstract. Batch flotation experiments were carried out using two coal samples to study the behaviour of each size and the density fractions in coal flotation. Different size fractions obtained from sizing of concentrates and tailing were subjected to float and sink analysis using organic liquids. The distribution curve technique was adopted to evaluate the performance of flotation. The results show that selectivity of flotation decreases with decrease in particle size. The specific gravity of separation is influenced more by the level of the frother dosage than by the collector dosage. The specific gravity of separation increases with increase in flotation time. The maximum value attained at infinite flotation time increases with decrease in particle size but the rate at which it is reached decreases.

Keywords. Coal flotation; distribution curve; specific gravity of separation; density fractions.

1. Introduction

Although various processes are available for treating coal fines below 0·5 mm, froth flotation is widely adopted in coal preparation industries. In this process, the effective separation of coal particles from ash-forming minerals takes place depending on (i) difference in surface properties of the particles and (ii) particle-bubble attachment.

Coal is an aggregate of particles of different specific gravities in various sizes. Though pure particles are lighter in specific gravity, the presence of high specific gravity minerals in unliberated state considerably affects the relative density of the composite coal particles. Higher the proportion of mineral matter present in the unliberated state, higher is the specific gravity of the individual particles.

The behaviour of different specific gravity coal particles in flotation process is not clearly understood. Firth *et al* (1978) showed that feed size distribution greatly affects the performance of froth flotation. Based on the recovery of non-ash and ash material in different size ranges, a kinetic model was proposed by Vanangamudi and Rao (1986) to predict the yield of concentrate and its ash content. Vanangamudi *et al* (1987) also showed that an increase in the content of fines during the feed to flotation process decreases the maximum recovery of non-ash material that may be obtained and retards the flotation rate of coarser particles.

The usual practice of assessing the performance of coal flotation system is through yield and ash content of the concentrates obtained. However to compare the performance of flotation with other beneficiation techniques, it is essential to estimate the sharpness of separation in terms of probable error and in this respect, flotation can perform better than a cyclone washer (Misra 1985). Miller *et al* (1967) studied the float and sink analysis of concentrate obtained in flotation and showed that the floatability of coal grains decreases with increase in the specific gravity of grains. The influence of mineral matter on the floatability of coal grains was studied by Bustamante and Warren (1983) who reported that the ash in the concentrate is mainly due to the recovery of composite grains containing both carbonaceous and mineral matter. It was further reported that even 50 μ particles are composite in nature. Therefore it becomes essential to estimate the behaviour of each specific gravity particles in flotation.

In the present investigation, an attempt has been made to study the specific gravity of separation and the effect of time and size of particles on the specific gravity of separation in coal flotation.

2. Experimental

The coal fines (−0·5 mm) collected from an operating coal washery (coal I) were used for flotation tests. The size analysis of the feed sample is given in table 1. Each sieve fraction was further subjected to float and sink tests using organic liquids of specific gravities 1·3, 1·4, 1·5, 1·6, 1·7 and 1·8. The results of float and sink tests on different size fractions in the feed sample are given in table 2. The heavy liquids of specific gravities from 1·3 to 1·5 were prepared by mixing different proportions of carbon tetrachloride and kerosene and liquids above 1·5 specific gravity by mixing carbon tetrachloride and bromoform.

Flotation tests were carried out in a Galighar Agitair unit (model LA-500) which can maintain a constant height of the pulp in the cell during experimentation. The experimental conditions are given below:

(i) Collector (diesel oil) dosage	—	0·50, 0·75 and 1·00 kg/tonne keeping the frother level constant at 0·60 kg/tonne.
(ii) Frother (pine oil) dosage	—	0·40, 0·60 and 0·80 kg/tonne keeping the collector level constant at 0·75 kg/tonne.
(iii) Pulp density (solid by weight)		10%
(iv) Impeller speed	—	750 rpm
(v) Conditioning period	—	60 s.

The experiment number and the reagent dosages used are given in table 3. During each test, the concentrates were collected at the end of 10, 20 and 90 s of flotation period. The concentrates and tailing obtained were filtered and dried. In order to obtain sufficient material in all the concentrates, each test was repeated seven times. The respective concentrates and tailings obtained for one test were mixed and subjected to size analysis using the same set of sieves used for size distribution of the feed. Each size fraction was then subjected to float and sink tests at the specific gravities which were used to estimate the specific gravity distribution of feed sample.

Table 1. Size and size-wise ash analysis of flotation feed.

Size range (μ)	Coal I		Coal II	
	Weight %	Ash %	Weight %	Ash %
−500+355	22·70	30·32	29·05	24·51
−355+250	18·60	29·29	16·63	24·33
−250+150	20·27	27·90	13·69	23·09
−150+71	17·21	27·58	16·13	22·58
−71	21·22	27·49	24·50	24·19

Two more experiments were carried out using another coal (coal II) to confirm the observations made with coal I.

3. Results and discussion

Using the float and sink analysis of different size fractions obtained from the flotation products, the distribution values for all the specific gravity fractions in the bulk feed to the concentrate at different flotation periods were calculated. Typical distribution values for one experiment (experiment 1) using coal I are presented in table 4. The following features on the behaviour of bulk feed may be noted:

(i) At the initial period (10 s), $>50\%$ of the material below 1·7 specific gravity reports to the concentrate.

Table 2. Size-wise sink-float analysis of coal I.

Specific gravity range	−500+355 μ		−355+250 μ		−250+150 μ		−150+71 μ		−71 μ	
	Weight%	Ash%	Weight%	Ash%	Weight%	Ash%	Weight%	Ash%	Weight%	Ash%
Float 1·3	12·40	2·94	13·44	2·79	16·46	2·51	22·80	3·20	1·07	7·30
1·3–1·4	18·60	10·58	24·16	9·88	20·16	9·50	19·25	11·78	27·78	9·30
1·4–1·5	18·40	19·49	16·18	19·67	18·11	18·96	17·15	19·16	35·26	17·64
1·5–1·6	13·60	30·07	14·92	29·58	13·79	29·43	11·92	28·85	13·03	30·31
1·6–1·7	7·40	32·55	5·67	41·22	6·79	38·53	5·44	37·08	4·91	35·70
1·7–1·8	11·20	46·90	6·51	44·26	5·76	45·86	4·81	44·36	3·21	41·60
Sink 1·8	18·40	65·73	19·12	65·58	18·93	66·49	18·62	66·71	14·74	62·07

Table 3. Experimental conditions using coal I.

Expt No.	Collector dosage (kg/tonne)	Frother dosage (kg/tonne)
1	0·50	0·60
2	0·75	0·60
3	1·00	0·60
4	0·75	0·40
5	0·75	0·80

Table 4. Distribution values of bulk concentrates at different flotation periods (experiment 1).

Specific gravity range	Distribution values 10 s	20 s	90 s
Float 1·3	71·43	88·89	96·03
1·3-1·4	63·51	84·84	95·74
1·4-1·5	59·24	85·33	94·02
1·5-1·6	61·59	81·88	92·75
1·6-1·7	51·46	74·76	87·38
1·7-1·8	36·84	56·31	80·87
Sink 1·8	30·69	45·86	67·96

(ii) As the flotation period increases to 90 s, almost all the material with specific gravity < 1·6 reports to the concentrate along with > 50% of the heavier fraction with specific gravity > 1·8. The yield of clean coal at 90 s of flotation is 88·3% which shows that the selectivity or the sharpness of separation decreases with increase of the flotation period.

3.1 *Behaviour of individual size fractions*

To examine the behaviour of the individual size fractions, the distribution values of all the size fractions were calculated. As an example, the distribution values of experiment 1 using coal I at 90 s of flotation for all the size fractions are presented in table 5. The values indicate that as the size of the particle decreases, the distribution values for all the specific gravity fractions increase. Also, in the case of the two finest fractions (−150+71 and −71 μ) in the feed, almost everything reports to the concentrate from all the specific gravity fractions with very little selectivity. Only in the case of coarser size fractions like −500+355 and −355+250 μ, about 50% of the material in the specific gravity above 1·8 are rejected into the tailings while the other specific gravity fractions mostly report to the concentrate.

3.2 *Specific gravity of separation*

From the distribution curves of bulk feed and individual size fractions, the specific gravity of separation (SG_{50}) values corresponding to 50% distribution value was estimated at different flotation periods and these values for coal I are given in table 6. It is seen that the specific gravity of separation increases with increase in frother dosage while the increase is marginal with increase in collector dosage. Further, the specific gravity of separation increases with decrease in particle size upto 71 μ below which it drops down. The rate of increase of specific gravity of separation with decrease in size is greater at a higher flotation period.

The specific gravity of separation of the bulk feed and the individual size fractions increases with increase in flotation period. However, the rate of increase decreases and the value of SG_{50} tends to attain an asymptotic value at higher flotation periods. The variation of SG_{50} with flotation time can be represented by a first order kinetic equation of the form

$$SG_{50} = SG_{50\infty}[1 - \exp(-kt)], \tag{1}$$

Table 5. Distribution values for different size fractions at 90 s of flotation (experiment 1).

Specific gravity range	Distribution values −500+355 (μ)	−355+250 (μ)	−250+150 (μ)	−150+71 (μ)	−71 (μ)
Float 1·3	95·05	95·52	99·30	96·71	100·00
1·3-1·4	94·25	94·93	95·31	96·08	97·12
1·4-1·5	88·64	92·17	94·83	96·76	96·68
1·5-1·6	83·25	91·77	94·60	95·59	97·25
1·6-1·7	71·71	83·23	91·23	95·49	94·87
1·7-1·8	63·41	77·27	87·16	92·50	91·80
Sink 1·8	43·75	54·54	68·84	88·52	85·03

Table 6. Specific gravity of separation values of individual size fractions and bulk concentrates at different flotation periods (coal I).

Expt. No.	Flotation time (s)	Individual size fractions −500+355 (μ)	−355+250 (μ)	−250+150 (μ)	−150+71 (μ)	−71 (μ)	Bulk conc.
	10	1·48	1·60	1·69	1·84	1·80	1·67
1	20	1·64	1·76	2·05	—	—	1·83
	90	1·92	2·35	—	—	—	2·20
	10	1·61	1·69	1·86	1·91	1·71	1·68
2	20	1·76	2·11	—	—	2·21	2·36
	90	—	—	—	—	—	—
	10	1·60	1·72	1·79	1·92	1·64	1·69
3	20	1·74	1·94	2·40	—	2·07	1·93
	90	2·04	—	—	—	—	—
	10	1·37	1·44	1·47	1·69	1·66	1·41
4	20	1·67	1·84	2·21	2·40	1·78	1·78
	90	1·86	2·21	—	—	—	—
	10	1·57	1·68	1·88	1·72	1·59	1·64
5	20	1·72	1·93	—	—	1·75	2·38
	90	—	—	—	—	—	—

where $SG_{50\infty}$ is the specific gravity of separation that may be obtained at infinite time and k is the first order rate constant (s^{-1}).

Figure 1 shows the first order plot ln $(SG_{50\infty} - SG_{50})/SG_{50\infty}$ versus time for the bulk concentrate. It may be seen that the rate of change of SG_{50} with time is proportional to $(SG_{50\infty} - SG_{50})$. This observation reveals that the change of SG_{50} with flotation period is similar to the kinetic of recovery in coal flotation.

3.3 *Verification of the observations*

To verify the above observations, two more experiments were carried out with another coal (coal II) at collector dosages 0·5 and 1·0 kg/tonne keeping the frother dosage constant at 0·6 kg/tonne. The specific gravity of separation values of the bulk and individual size fractions for one experiment is given in table 7. The variation of SG_{50} with time for all the size fractions (figure 2) reveals that at all the flotation periods, the specific gravity of separation increases with decrease in particle size.

The first order plots of SG_{50} for the bulk and the size fraction −500+355 μ shown in figure 3 indicate that the variation of SG_{50} with flotation time can be adequately represented by the first order kinetic equation. Therefore, SG_{50} values for both the bulk feed and individual size fractions follow the first order kinetics.

The k and $SG_{50\infty}$ values in equation (1) have been evaluated for all the individual size fractions. In figure 4, these values have been plotted against the average size of individual size fractions. It can be seen that k increases linearly with increase in size while the constant $SG_{50\infty}$ decreases. This indicates that the maximum value of SG_{50} that may be obtained is greater for the finer size fractions and therefore a greater yield from these sizes. However, the rate at which the maximum value is reached decreases with decrease in size. For the coarser sizes like −500+355 and

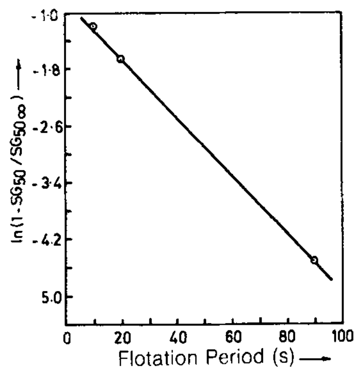

Figure 1. Verification of first order kinetics for specific gravity of separation with flotation period (coal I, experiment 1).

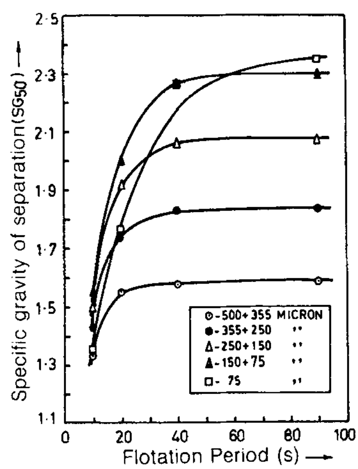

Figure 2. Effect of flotation period on specific gravity of separation of individual size fractions (coal II, experiment 1).

Table 7. Specific gravity of separation values of individual size fractions and bulk concentrates using coal II (collector dosage 0·5 kg/tonne, frother dosage 0·6 kg/tonne).

Flotation time (s)	Individual size fractions −500+355 μ	−355+250 μ	−250+150 μ	−150+75 μ	−75 μ	Bulk conc.
10	1·36	1·45	1·56	1·60	1·35	1·42
20	1·49	1·69	1·815	2·02	1·80	1·62
40	1·60	1·83	2·09	2·21	2·22	1·74
90	1·615	1·86	2·125	2·35	2·42	1·83

−355+250 micron, the asymptotic value is reached faster and beyond 20 s of flotation not much increase in SG_{50} is noted (figure 2). This shows that the coarser size fractions in this feed need less flotation time while the finer size fractions should be given a longer time to achieve a maximum yield.

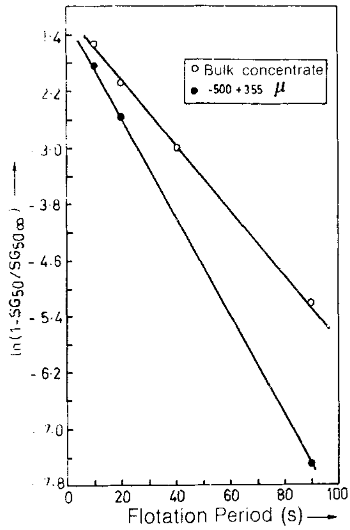

Figure 3. Verification of first order kinetics for specific gravity of separation (coal II, experiment 1).

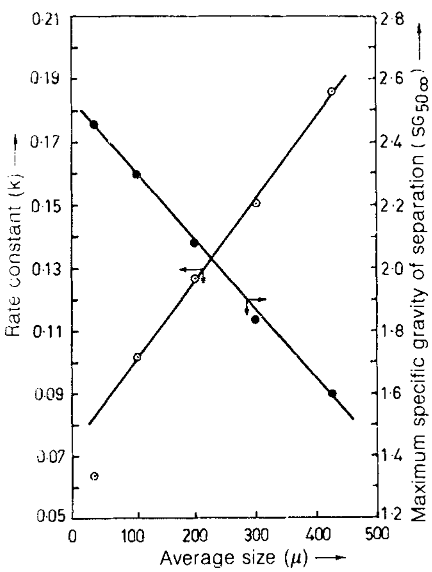

Figure 4. Variation of $SG_{50\infty}$ and rate constant with feed size (coal II, experiment 1).

4. Summary and conclusions

The selectivity and sharpness of separation of froth flotation decrease with increase in flotation period. At higher flotation period, most of the material reports to the concentrate. This is because the rejection of the material into tailing from the finer size fractions is very little. The specific gravity of separation is influenced more by the level of the frother dosage than by the collector level. The variation of specific gravity of separation with flotation time can be adequately described by a first order kinetic equation. The maximum $SG_{50\infty}$ that may be obtained for individual size fractions decreases with increase in size. However, the rate at which it is reached increases with increase in size of particles.

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