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# Flotation kinetics of coking coal fines

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## ABSTRACT

***Investigations were carried out on the coking coal fines generated at Bhelatand Washery. The studies include investigations on physical, chemical and flotation characteristics. Different operating parameters were optimised in flotation to get best product with low ash content. Flotation performance was evaluated by studying the kinetics of different size fractions and also on sample ground for different length of time. Flotation rate constant was calculated using Klimpel's model. Maximum Rate constants were obtained for size fraction -300+150μm (-0.0082) and one minute ground product (-0.0077) with low ash content. From these observations it is concluded that less than one minute grinding is sufficient for these coal fines to achieve a better product with minimum ash.***

***Key words** : Flotation, Coking coal fines Kinetics*

## INTRODUCTION

About 28.0 million tonnes of coking coal is being washed every year in 28 washeries to produce clean coal for steel making in India. During washing coal below 0.5 mm size is generated as fines with ash content ranging from 20 to 45%. These fines are beneficiated to reduce ash below 17% to mix with clean coal. The most effective technique to date for cleaning coal fines is flotation [1]. Flotation studies have been carried out for comparing the performance of column cell against conventional flotation cell for the flotation of coal fines[2]. Kinetics of flotation has been studied by many workers and this approach has been used for selection of regent, particle size of the fead, type of flotation cell etc.[2-6] sikh[3] Patnaik[4] have studied the flotation kinetics of graphite and have reported that feed with coarse and very fine sizes show low kinetics. The size fraction between 0.7 and 0.5 mm has shown good response to rousher flotation.

This paper presents the results of flotation studies carried out for assessing the performance of the Bhelatand coal fines with respect to feed size and dosage of collector and frother using kinetic approach.

## EXPERIMENTAL

### Raw material

Coal fines below 0.5 mm size generated at Bhelatand washery, Bihar was used in these investigations. The sample was collected as wet slurry form and the associated water was decanted and the solids were mixed thoroughly. Representative sample was prepared for all the investigations.

### Reagents

Commercial grade diesel oil is used as collector and analytical grade methyl iso-butyl carbinol (MIBC) was used as frother.

### Procedure

All flotation studies were carried out using a laboratory Denver sub-aeration flotation cell with one litre capacity. For these experiments diesel oil was used as collector and MIBC as a frother. About 100 gram of the sample was conditioned with required amount of collector at 40% pulp density for about five minutes at pH 8. The slurry was diluted to10% and floated with frother for three minutes. Both froth and tailings were collected, dried, weighed and analysed for ash content. Initially studies were carried out to optimise the collector dosage. Subsequently the effect of frother dosage was evaluated at constant collector dosage. Flotation kinetics were studied using the best dosage of collector and frother. Flotation kinetic experiments were carried out on different close size fractions and samples ground to different length of time. The froth was collected at different time intervals such as 15, 30, 45, 60, 90 and for 120 sec.

The Klimpel's model[5,6] was used for analysis of kinetic data[5,6]

$$R = R\alpha \, [1 - 1/Kt \, \{1 - \exp.^{(-kt)}\}]$$

where R is the cumulative recovery at time t,

$R\alpha$ is the ultimate equilibrium recovery,

K is the first order rate constant.

From the values of $R\alpha$, the values of $\log [(R\alpha - R)/R\alpha]$ were calculated and these were plotted against time. A straight line was obtained with negative slope. The values of slope are equal to the rate constant (K). Rate constant 'K' has been used as a measure of the performance of flotation. The rate constant was evaluated for different size fractions of coal as well as the coal fines ground to different time intervals.

## RESULTS AND DISCUSSION

The physical and chemical properties of coal fines generated at Bhelatand Washery are presented in Table 1 and 2. The results indicate that $d_{80}$ passing of coal fine was around 340 microns and contained 57% of fixed carbon, 19% ash and 24% volatile matter.

*Table 1 : Proximate analysis of coal fines*

| Constituents | Percent |
|---|---|
| Moisture | 0.08 |
| Volatiles | 23.96 |
| Ash | 19.40 |
| Fixed Carbon | 56.56 |

*Table 2 : Size and ash analysis of coal fines*

| Size, microns | Weight % | Ash, % |
|---|---|---|
| -500 +300 | 21.7 | 20.8 |
| -300 +150 | 21.0 | 19.3 |
| -150 +75 | 53.1 | 19.0 |
| -75 | 4.2 | 18.6 |
| Total | 100 | 19.4 |

The size and ash distributions of coal fines shown in Fig.1 also indicate that the ash distribution in different size fraction is almost uniform.

Flotation result of coal fines for studying the efforts of collector dosage and frother dosage are shown in Figs. 2 and 3 respectively. The effects of collector and frother dosages were evaluated with respect to yield, combustibles, combustible recovery and separation efficiency[7]. From Fig. 2 it can be seen that, as expected the recovery of combustible increases with increase with collector dosage. It is also observed that the increase in collector dosage in shows a marginal decrease in % combustibles. It is further observed that the separation efficiency increases up to 0.8 kg/t of collector dosage, beyond this dosage a marginal decreasing trend is observed. Based on these observations, 0.8 kg/t of collector is considered to be the best dosage and the same was used for further studies.

Keeping this collector dosage constant the effect of frother dosage on flotation of coal was evaluated. In this case also combustible recovery increases with increase of frother and also it is found that as the frother dosage increases the grade of clean coal is significantly decreases and further the separation efficiency also decreases. Hence lower frother dosage is preferable.

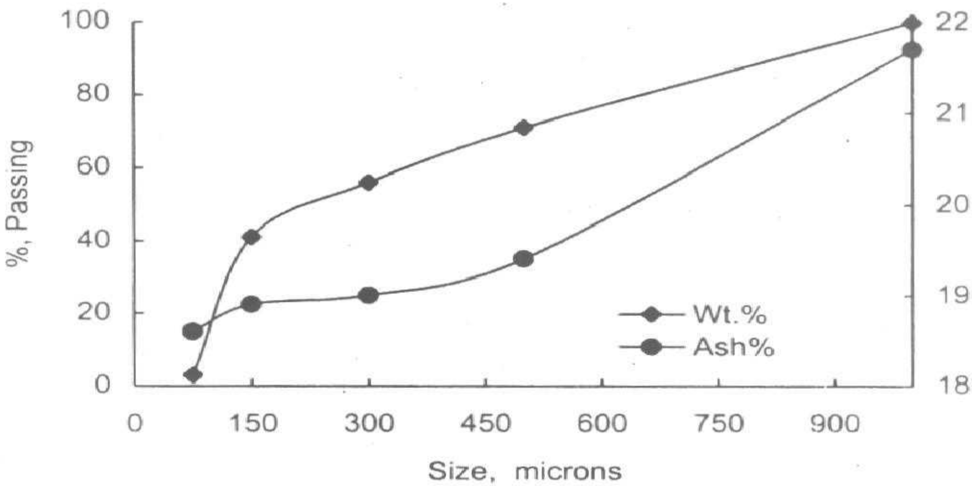


*Fig. 1 : Size and ash distribution of coal fines*

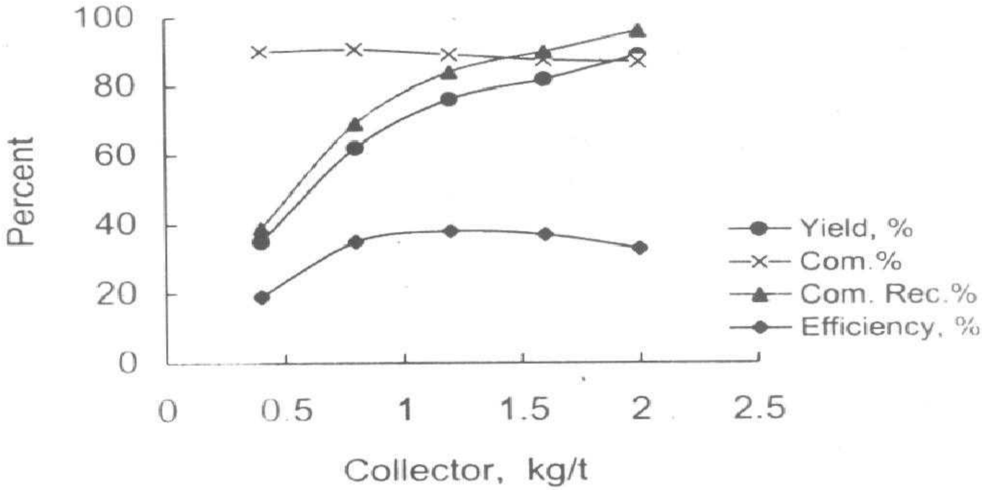


*Fig. 2 : Effect of collector dosage on flotation fo coal fines (feed sample)*

A typical data on flotation characteristics of two close size fractions (a) coarse size (-500 +300μm) and (b) the fine size (-150 +75μm) of coal fines are shown in Fig. 4. The data in Fig. 4 indicate that both yield and combustible recovery increases with time. The kinetic data is plotted in Figs. 5(a) to 5(d). These figures indicate that both size fractions follow first order flotation kinetics. However, it is observed that the coarser size (-500 +300μm) exhibits slower rate compare to finer feed size (-150 +75μm).

In order to understand the flotation behavior of different size fractions, the kinetic data were calculated using Klimpel's model. A typical flotation kinetic data for size -300+150 μm are shown in Table 3 and 4. The rate constant was calculated for different size fractions using linear regression, to evaluate the flotation performance.

The first order plots of different size fractions are shown in Fig. 5. The data indicate that all the size fractions of coal fines follow first order kinetics. However interestingly, it is observed that the rate constant of (-0.0082) is found maximum for size fractions (-300 +150μm) and lower (-0.0048) for coarser size fraction (-500 +300μm). It is expected that the coarser fraction exhibits lower rate constant due to slower rate of flotation. In case of very fine particle, the rate is lower as there may be less selective separation between macerals and coal particles. Hence, the size fractions of -150+75μm and -75μm have shown further decreasing trend of rate constant (-0.0032 and -0.0023 respectively).

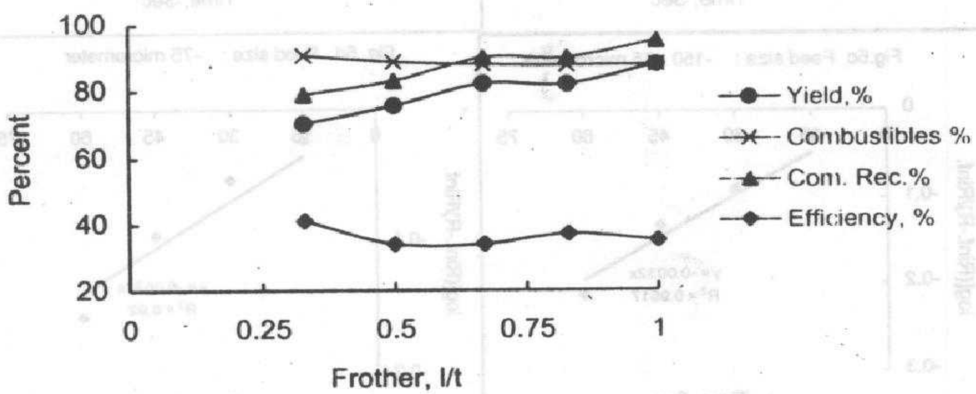


*Fig. 3 : Effect of frother dosage on flotation of coal fines (bulk sample)*

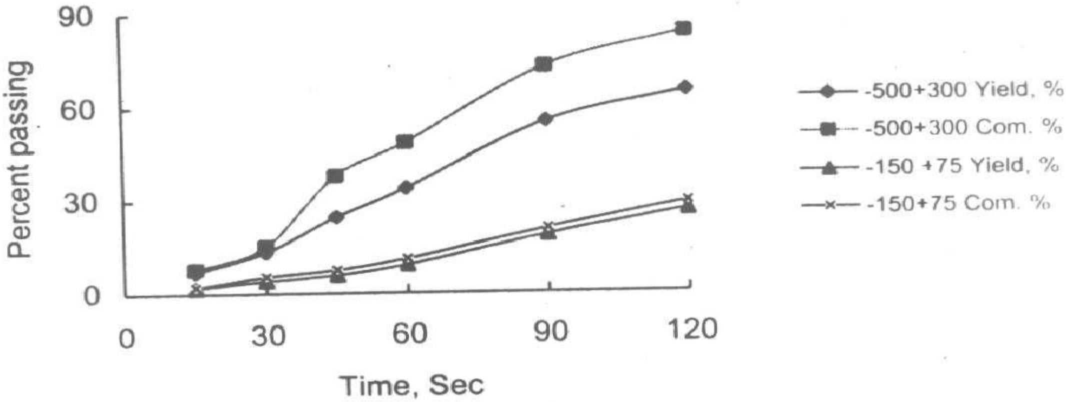


*Fig. 4 : Flotation characteristics for close size fractions of coal fines*

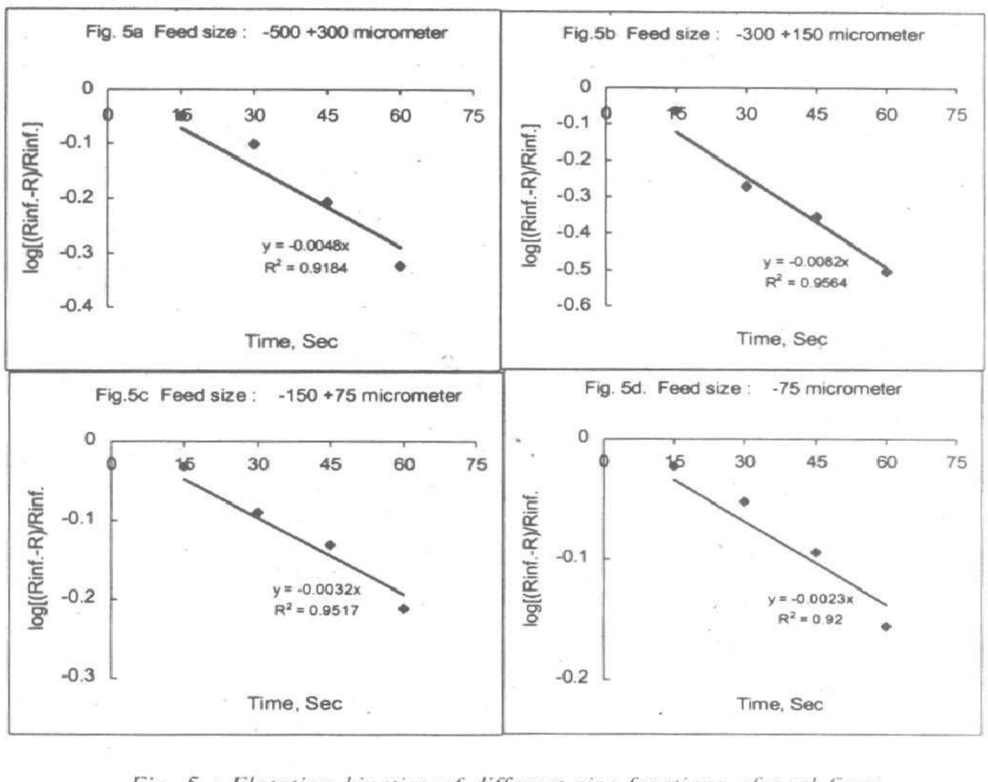


*Fig. 5 : Flotation kinetics of different size fractions of coal fines*

*Table 3: Typical results of flotation on -300 +150μm size fraction*

| Collection time, sec | Weight % | Cumulative weight % | Ash % |
|---|---|---|---|
| 15 | 9.0 | 9.0 | 8.1 |
| 30 | 18.3 | 27.3 | 8.7 |
| 45 | 6.1 | 33.4 | 8.8 |
| 60 | 11.3 | 40.7 | 8.8 |
| 90 | 16.2 | 60.7 | 11.7 |
| 120 | 5.2 | 66.1 | 18.5 |
| Tails | 33.9 | 33.9 | 37.1 |
| Total | 100.0 | 100.0 | 19.3 |

*Table 4 : Typical flotation kinetic data for -300 +150 μm size fraction*

| Collection time, sec | Combustibles % | Comb Rec., % | Cum comb Rec. % | Rσ | Rσ-R/Rσ | Log $\frac{R\sigma}{R\sigma}$ |
|---|---|---|---|---|---|---|
| 15 | 91.9 | 10.2 | 10.2 | | 0.86 | -0.065 |
| 30 | 91.3 | 20.7 | 30.9 | | 0.53 | -0.272 |
| 45 | 91.3 | 6.9 | 37.8 | | 0.49 | -0.323 |
| 60 | 91.2 | 12.8 | 50.6 | | 0.31 | -0.505 |
| 90 | 88.3 | 17.7 | 68.3 | | 0.07 | -1.142 |
| 120 | 81.5 | 5.3 | 73.6 | 73.6 | — | — |
| Tails | 62.9 | 26.4 | 26.4 | — | — | — |

The effect of time on grinding of coal fines with reference to particle size distribution is shown in Fig.6. The grinding not only helps in reduction in size, but also creating fresh surface for flotation. The flotation performance has been assessed as earlier by using kinetic data. The ideas is to obtain the maximum rate constant as achieved for size fraction of -300 +150 μm at one of the best size ground product, which helps to determine the effective time of grinding to suitable size to obtain better yield with low ash content.

The plots of first order kinetics for unground and ground samples are shown in Fig.7. It is observed that the rate constant was increased from -0.0053 to -

0.0077. It can be explained that by grinding the sample new surface is created, which can help in promoting the flotation performance. It is observed that further increase in grinding time the slope values are decreasing. This may be due to the fact that by further grinding of particles to finer sizes slime formation increases. Due to this the rate constants decrease slightly compared to 1 min grinding.

The flotation kinetic data is summarised in Table 5. The data indicate that

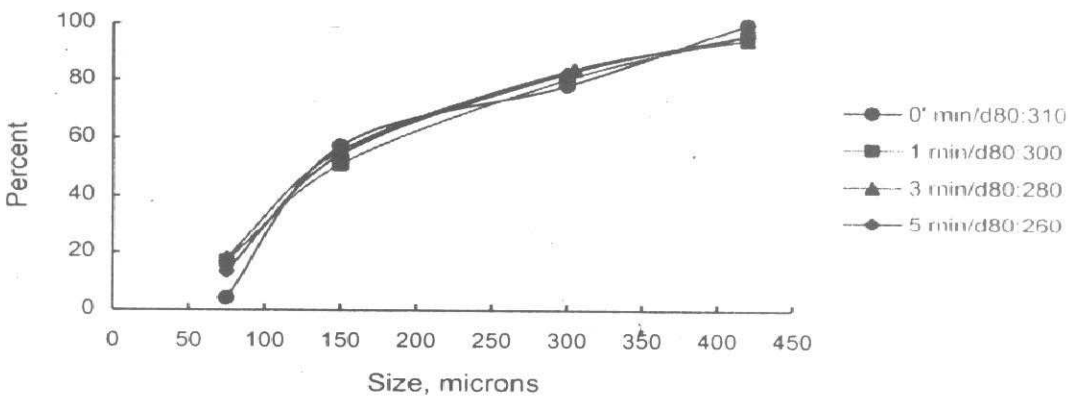


*Fig. 6 : Size analysis of different time ground products*

*Table 5: Summary of flotation kinetic data*

| Size fractions μm/grinding time, mins. | Rate constant K, sec$^{-1}$ |
|---|---|
| -500 +300 | -0.0048 |
| -300 +150 | -0.0082 |
| -150 +75 | -0.0032 |
| -75 | -0.0023 |
| 0 min (feed -500 μm) | -0.0056 |
| 1 min | -0.0072 |
| 3 min | -0.0062 |
| 5 min | -0.0055 |

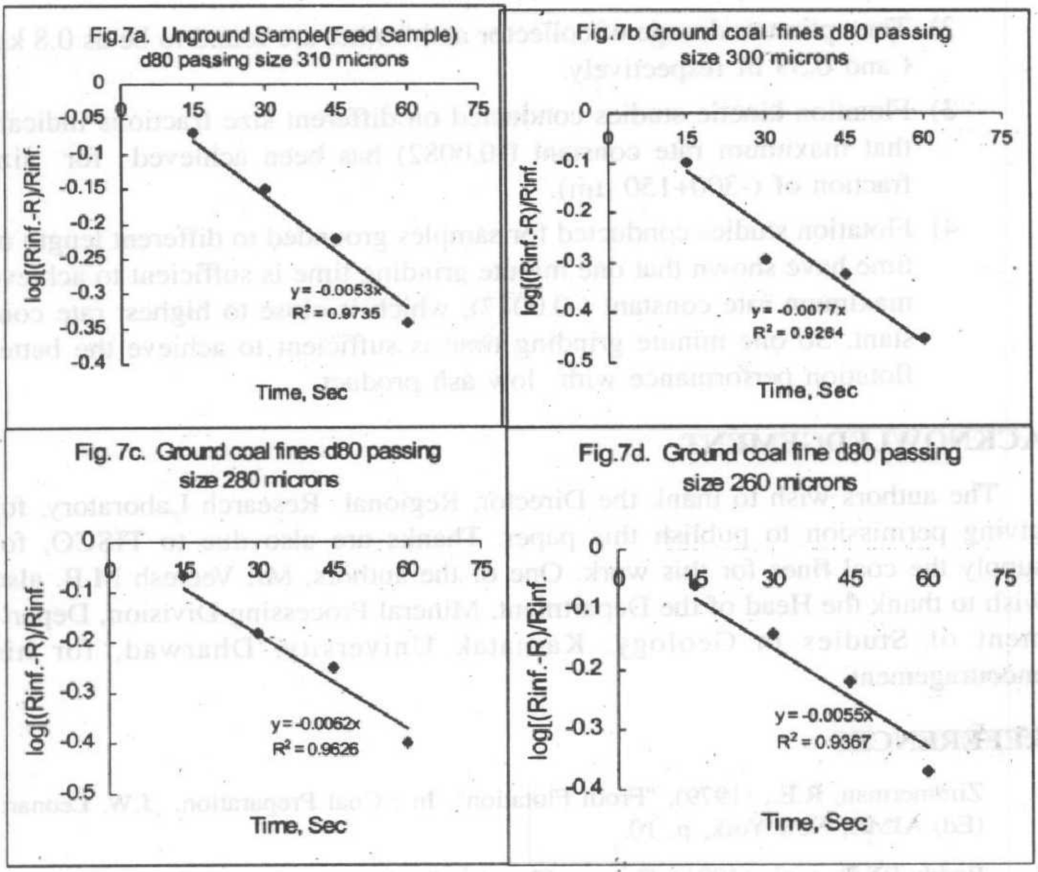


*Fig. 7 : Flotation kinetics of diffeent time ground products of coal fines*

the maximum rate constant of (-0.0082) has been achieved for close range fractions i.e. -300+150μm. This observation is supported by yield, grade, recovery and separation efficiency. Based on these observations the size fraction of -300+150 μm has been considered to be the best with reference to flotation performance as well as low ash in the product. Similarly, the maximum slope value of -0.0077 has been achieved for one minute ground sample and this value is close to the maximum rate constant obtained for -300+150μm size fraction. Based on these observations, it can be concluded that one minute grinding is sufficient for this sample to achieve better flotation performance with low ash product.

## CONCLUSION

The following conclusions are drawn from the above studies :

1) The coal fines contains 19% ash, 24% volatile matter and 57% of fixed carbon.

2) The optimum dosage of collector and frother are found to be as 0.8 kg/t and 0.33 l/t respectively.
3) Flotation kinetic studies conducted on different size fractions indicate that maximum rate constant (-0.0082) has been achieved for size fraction of (-300+150 μm).
4) Flotation studies conducted for samples grounded to different length of time have shown that one minute grinding time is sufficient to achieve maximum rate constant (-0.0077), which is close to highest rate constant. So one minute grinding time is sufficient to achieve the better flotation performance with low ash product.

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