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Influence of Operating Variables on Flotation of High Ash Coking Coal

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Abstract

The paper deals with the results of flotation studies carried out on a high ash coking coal sample. The influence of various operating parameters such as collector and frother dosage, pH of the pulp, pulp density, aeration and agitation were studied in a wide range. The flotation performance was assessed in terms of recovery, grade, selectivity index and flotation rate constants. The flotation rate constants were computed using a modified first order rate equation. Results have been discussed based on the analysis of the flotation data.

1. Introduction

Coking coal is an essential raw material for iron making through blast furnace route. For this purpose the, the coal should contain 17 $\pm$ 0.5 % ash to achieve a level of 22.5% ash in coke with physical strength in the stipulated limits. High coking coals are not suitable for iron and steel making because it increases the coke rate and slag volume and adversely affects the productivity. High ash coal yields coke with low strength and inferior quality which cause problem in operation of blast furnace. Coking coal is a scare commodity all over the world and India is no exception. Reserves of coking coal are only 15% out of which recoverable prime coking coal is limited to 11.5% [1]. Unlike other Gondwana land coals, Indian coking coal has large amounts of mineral matter dispersed intimiately within the coal matrix. They have difficult cleaning characteristics. The present practice of washing of Indian coking coal results in low efficiency of separation. So considering the paucity of coking coal coupled with the problems associated with the beneficiation of coking coal, there is need to develop suitable technology or upgrade the existing technology for optimal utilization of indigenous resources [2,3].

During washing of coking coal substantial quantity of fines below 0.5 mm containing 20-40% ash, are produced. With the deterioration in quality of feed to the washeries, and the need of crushing to lower size has resulted in further increase in generation of fines with inferior quality. Froth flotation is widely used for beneficiation of coal fines (-0.5 mm). But in general, flotation performance is not satisfactory. Coal is a heterogeneous material and its processing by flotation represents a complex process. Efficiency of separation is influenced by several parameters related to coal characteristics, reagents, operation and equipment. The present paper deals with the results of characterization and flotation studies carried out on a high ash coking coal sample under varying conditions of operating variables. The time-recovery flotation data were analysed kinetically using a modified first order rate equation. The effects of process variables have been analysed on the recovery of combustibles, flotation rate constants and selectivity of separation.

2. Methodology

Coking coal sample used for this study assayed 27.45 % ash, 47.30% fixed carbon. 24.95% volatile matter and 0.30% moisture. The size and size-wise ash analyses of the sample is shown in Fig. 1.

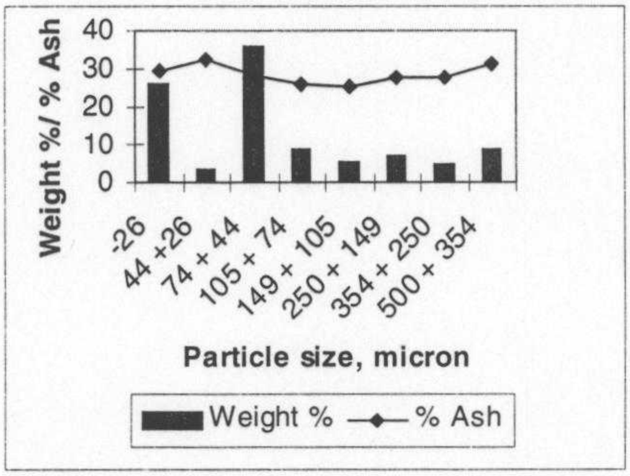

Fig. 1: Size and size-wise ash analyses of coal sample.

Commercial grade light diesel oil (LDO) and laboratory grade methyl iso-butyl-carbinol (MIBC) were used as collector and frother respectively for flotation of coal. Laboratory grade hydrochloric acid and sodium hydroxide were used for maintaining pH of the pulp.

An Automated Laboratory Flotation Cell with provision of control over aeration rate, impeller speed and pulp level was used for conducting flotation experiments. The cell was equipped with a motorized paddle for collection of froth. During flotation experiments timed floats were collected to have kinetic and equilibrium data. The flotation products were dried, weighed and analysed for ash. The flotation results were assessed in terms of grade of the product (% ash /% combustibles), yield/recovery of combustibles, flotation rate constants and separation index (SI).

The flotation rate constant for combustibles and ash forming minerals were computed using the first order model with rectangular distribution of floatabilities, expressed by the equation (1) [4,5].

$$R_t = R_I [1-1/Kt\{1-\exp(-Kt)\}] \quad (1)$$

where, R_t = Cumulative recovery of combustible or ash at time t,
t = time, R_I = Ultimate equilibrium recovery and K is the first order rate constant (time^{-1}).

The selectivity of separation was estimated from the ratio of the rate constant for combustible (Kc) to the rate constant for ash forming minerals (Ka).

3. Results & Discussion

3.1 Flotation kinetics: Flotation process can be described in kinetic terms by a first order rate equation [6-8]. As it is mentioned in the previous section, a first order model expressed by equation (1) was used for computing flotation rate constant for combustibles and ash forming minerals. Typical recovery –time and $\log(R_I - R_t / R_I)$ - time plots for combustible and ash with 0.5 kg/t collector and 0.5 kg/t frother are shown in Fig. 2 and Fig. 3 respectively. The rate constant values for combustible and ash obtained from the slope of $\log(R_I - R_t / R_I)$ - time plots were found to be 0.02426 sec^{-1} and 0.01967 $sec.^{-1}$ 1.23 while selectivity index was found to be 1.23.

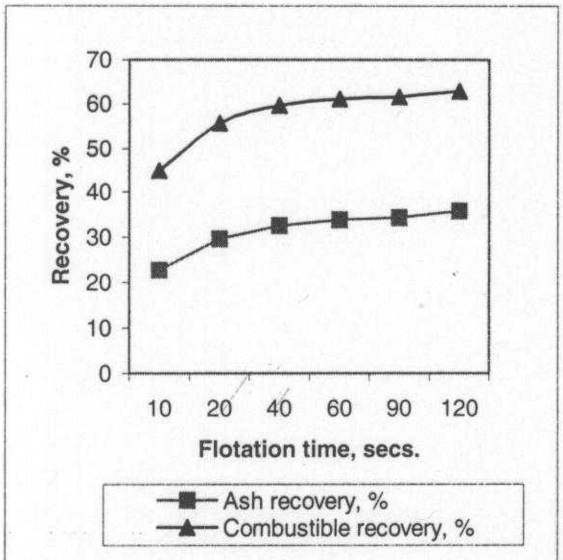

Fig. 2 : Recovery of combustible and ash as a function of time using 0.5 kg/t LDO

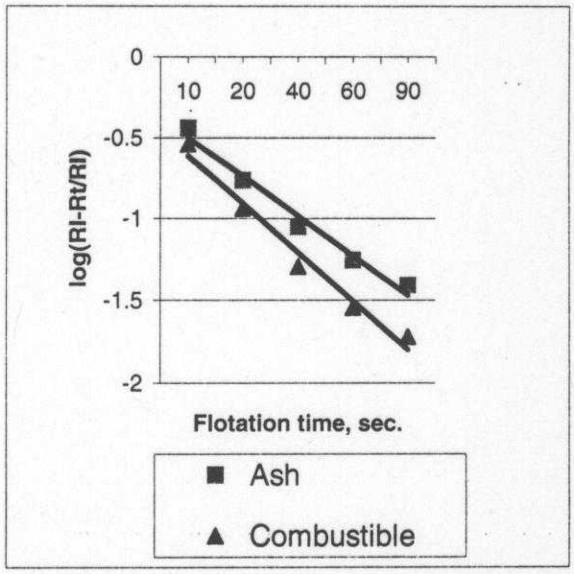

Fig. 3 : First order rate plot of flotation data with 0.5 kg/t LDO

3.2 Effect of dosage of collector: Though floatability of coal is related to the rank of the coal, it can be greatly enhanced by using an oil as the collector for coal flotation. Generally a an oil with low solubility in water is used for this purpose. In the present case light diesel oil (LDO) was used as the collector. In order to study the effects of dosage of LDO on floatability of coal sample, the dosage were varied from 0.25 kg/t to 2.5 kg/t. The flotation results are shown in Figs. 4 and 5. As we can see from Fig. 4 with an increase in dosage of collector there is an increase in recovery of combustibles. This was attributed to the enhanced degree of hydrophobicity imparted by higher dosage of the collector. For 2.5 kg/t, due to the froth overloading and particle drainage from froth to the pulp though there is an initial drop in recovery against 1.5 kg/t but it showed overall higher recovery of combustibles. Similar observations were made by the authors for the flotation of non-coking coal [7]. As evident from Fig. 5, an increase in collector dosage also increases flotation kinetics as indicated by the corresponding increase in rate constant (Kc). But it is important to note that increasing dosage of LDO also enhances value of flotation rate constant for ash forming minerals (Ka). In particular, at 2.5 kg/t there is a marginal difference in Kc and Ka. This trend reflects on the decreasing selectivity of separation with higher dosage of LDO.

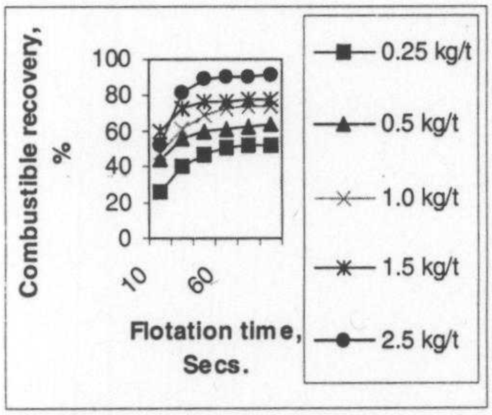

Fig. 4 : Effect of dosage of collector (LDO) on coal flotation.

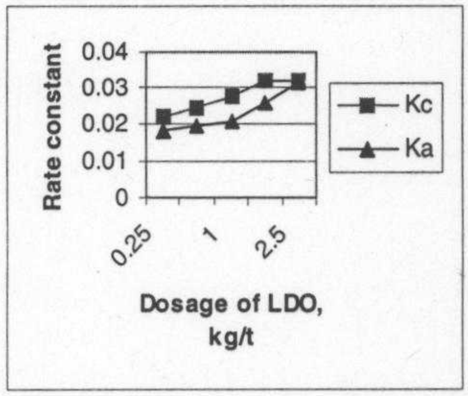

Fig. 5: Flotation rate constants as a function of dosage of LDO

3.3 Influence of frother: Short branced-chain alcohols, such as methyl-iso-butyl-carbinol (MIBC), are commonly used as frother for coal flotation. The role of frother is to form stable froth to facilitate separation of coal from ash but they also have some collecting property, in particular excessive high dose is reported to encourage flotation of ash forming minerals [9]. In the present study MIBC was used as frother and the dosage were varied from 0.25 kg/t to 2.0 kg/t. The results are presented in Figs.6 to 8. As it is evident from Fig. 6 that an increase in frother dosage from 0.25 kg/t to 0.75 kg/t, there is an improvement in yield of clean coal with a sharp increase in ash content. Beyond 0.75 kg/t the improvement in yield and ash is marginal. Beyond 0.75 kg/t of MIBC, there is lowering in flotation rate constant (Fig. 7) and a sharp decline in the value of selectivity index (Fig.8). The increased ash content of the product with higher dosage of MIBC is mainly due to increased water recovery. Water carries more gangue particles due to entrainment and increases the ash content of clean coal [9, 10].

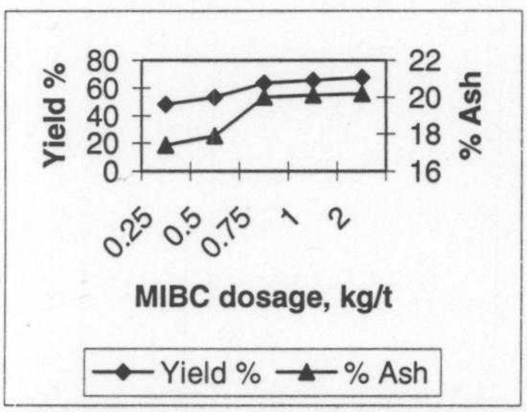

Fig. 6: Effect of dosage of MIBC on yield and ash content of product.

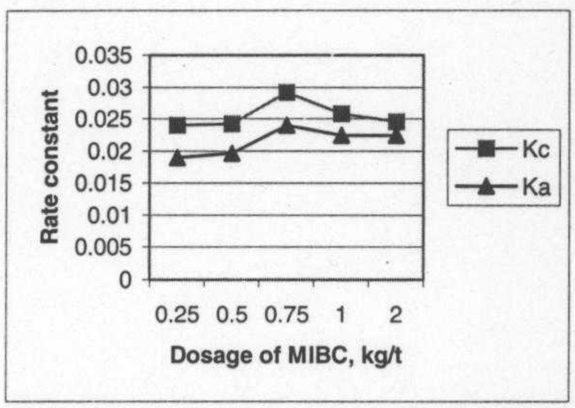

Fig. 7: Flotation rate constants as a function of dosage of MIBC.

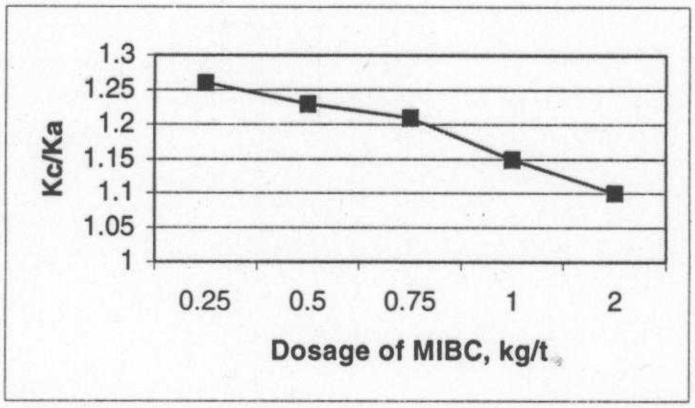

Fig.8 : Lowering of selectivity index with increasing dosage of MIBC.

3.4 Variation of pH of the Pulp: pH governs charge on the surface of the particles and play an important role in separation achieved by froth flotation. In the present study pH of the pulp was varied from 4 to 10. The results presented in Fig.9 indicate that flotation performance was better around neutral pH. The slight deterioration in flotation at higher and lower pH could be due to decreased hydrophobicity of coal. Either lowering or increase in pH is expected to change hydrophobicity of coal particles by adsorption of hydrogen and hydroxyl ions and thereby affecting the floatability [11].

3.5 Variation of Pulp Density: Flotation of metallic ores and industrial minerals are carried out at pulp density of 25-30% but since coal is a low specific gravity material, a lower pulp density is desirable to have particles in dispersed conditions for better flotation performance. In order to study the effect of pulp density, the pulp density was varied from 5% to 25%. The flotation results are shown in Fig.9. As it is obvious from the Fig.10, an increase in pulp density from 5% to 12.5%, there is an improvement in recovery of combustibles with slight a decline in recovery beyond this. The increase in recovery at higher pulp density could be due to enhanced recovery of coarse particle and also the higher probability of collision of particles with air bubbles. But an excessive high pulp density cause over-crowding and sanding of particles and these hinder effective flotation. So far as the selectivity is concerned, an increase in pulp density lowers the combustible content of the product. This was attributed to the decrease in dispersion of particles resulting in loss in selectivity of adsorption of reagents and also the enhanced gangue recovery by entrainment and enrtrapment phenomena [9].

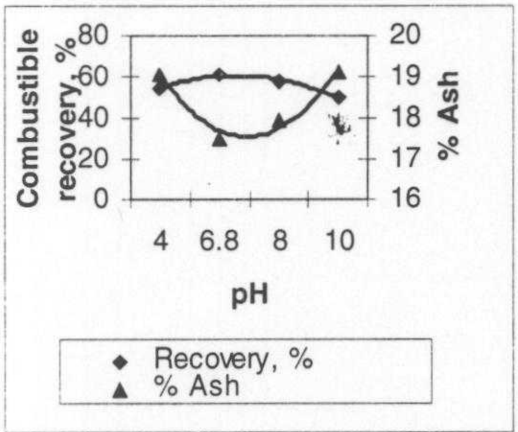

Fig.9: Effect of pulp pH on floatability of coal

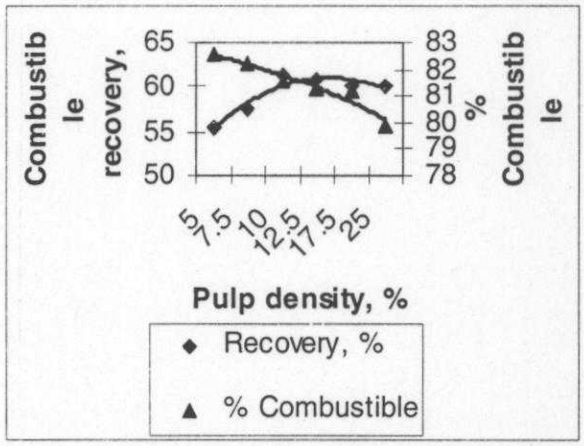

Fig. 10 : Flotation results with varying pulp density.

3.6 ***Effect of Aeration and Pulp Agitation:*** Air flow rate and pulp agitation are important variables for de-ashing of coal by froth flotation. The results on the effects of aeration and impeller speed are shown in Figs. 11 and 12 respectively. An increase in air flow rate from 10 to 40 lpm resulted in improvement in flotation kinetics and combustible recovery. But as it is evident from Fig. 11, increasing air flow rate causes lowering of combustible content of the clean coal. This is mainly because of increased water recovery and hence the gangues with an increase in air flow rate. For the pyritic sulphur coal flotation, Hirt et al reported that increased aeration led to higher yield and faster flotation of coal. But low aeration rate facilitated rejection of pyrite [12].

An increase in impeller speed from 500 to 1300 rpm showed a marked improvement in flotation kinetics and recovery of combustible/yield with an increase in ash content of clean coal. The results are shown in Figs.12 and 13. The increase in kinetics and recovery is due to an improvement in conditioning of pulp with reagents and the enhanced collision of particles with air bubbles.

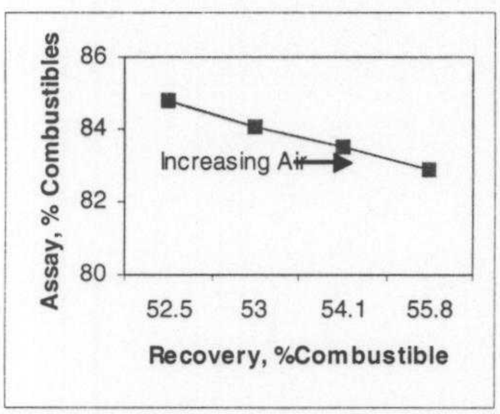

Fig. 11 : Increase in recovery with increasing air flow rate.

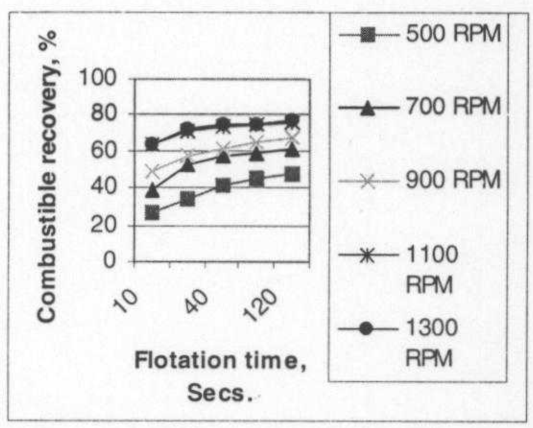

Fig. 12 : Effect of impeller speed on combustible recovery.

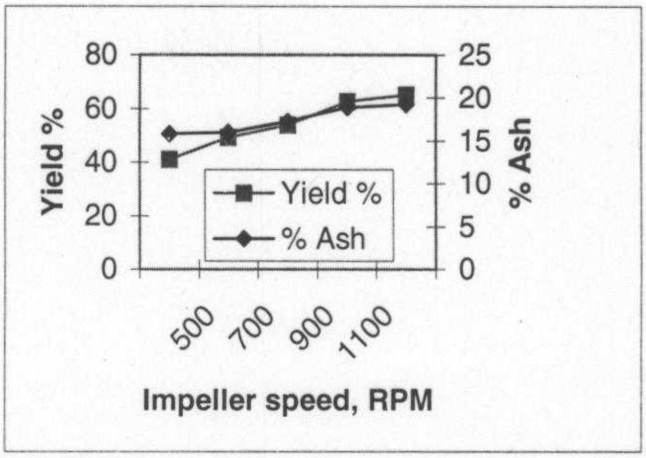

Fig. 13 : Yield and ash content of clean coal as a function of impeller speed.

4. Conclusions

Floatation studies were carried out on a high ash coking coal samples under varying conditions of operating parameters. Following are conclusions from the studies undertaken :

a) Due to higher degree of hydrophobicity imparted by the increased dosage of LDO, an improvement in recovery and flotation kinetics for combustibles was observed. But higher dosage of collector also enhanced the value of rate constant for ash forming minerals leading to increasing ash in the product.

b) Upto 0.75 kg/t, an increase in dosage of MIBC contributed in improving yield of clean coal but with a marked rise in ash content. The flotation rate constants for combustibles and ash also showed increasing trend but beyond 0.75 kg/t these declined. Selectivity index showed a sharp decline for the entire range of frother studied. This was attributed to increased water recovery at higher dosage of frother.

c) Flotation was observed to be better around neutral pH.

d) An increase in pulp density resulted in lowering of grade of clean coal while recovery of combustibles showed improvement upto a pulp density of 12.5% with a slight decline on further increase in pulp density.

e) Increasing aeration and agitation of pulp showed improvement in combustible recovery and flotation kinetics with a reduction in quality of froth product.

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