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STUDIES ON DE-ASHING OF NON-COKING COAL BY FROTH FLOTATION

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This paper presents the results of flotation studies carried out on a non-coking coal sample for reduction of ash. The effects of various process parameters on the floatability of coal have been studied. The effects of ultrasonication and emulsification of the oily reagents have been studied on the flotation behaviour of coal. The data have been analysed kinetically using first order model. It was found that ultrasonication of the oily reagents adds to the selectivity of separation while emulsification improves the recovery of carbon values. The improvement in the flotation performance was attributed to the fine dispersion and selective adsorption of the oily reagents caused due to ultrasonication and emulsification.

INTRODUCTION

Coal is the major source of energy in India. Besides the application in the power sector, some of the important uses of coal are in Iron and Steel, Railways, Cement Industries etc. Ash in coal is undesirable because coal used with higher ash gives lesser net heating value along with other undesirable effects such as low throughput, corrosion etc.

The major coal reserves in India belong to Gondwana and Tertiary periods. These coals are of drift origin and contain large proportion of intergrown impurities. These coals are high in ash and generally low in sulphur content. The Indian coals have difficult washability characteristics due to intimate mixing of a fairly large part of the dirt and mineral matters in most of the coal seams [1-3]. These result in high near gravity materials (NGM), at the stipulated specific gravity of cut, during the coal washing. The yield of clean coal is relatively poor and considerable proportion of middlings and tailings are produced.

In India coking coal reserves are limited. In fact 86% of the reserves are of non-coking coal [4]. However so far beneficiation of non-coking coal in India has been limited. But considering the paucity of coking coal and the advent of new technologies of steel making utilising non-coking coal, complete beneficiation of same is required. Recently coal injection in blast furnace is being widely adopted for decreasing the coke rate to the lowest possible extent. For this purpose, the coal should contain ash less than

10% with particle size all passing 100 microns [5]. The present work aims to study the flotation behaviour of a typical non-coking coal under varying conditions of process parameters. The effects of ultrasonication and emulsification of the oily reagents have also been studied. The data have been analysed using a first order kinetic model.

MATERIALS AND METHODS

The non-coking coal sample used for this study assayed 43.80% fixed carbon, 22.20% ash, 30.79% volatile matter with 3.21% moisture.

Commercial grade light diesel oil, sodium silicate and pine oil were used as collector, gangue depressant/dispersant and frother respectively for batch flotation experiments. Laboratory grade sodium carbonate and sulphuric acid were used as pH modifiers while sorbitol mono-oleate was used as emulsifier for oily reagents.

Standard Laboratory WEMCO Fagergren Flotation Cell was used for conducting flotation experiments. Feed for the flotation experiments was prepared by stage crushing the lumpy coal followed by wet grinding of the crushed product in the laboratory rod mill to the desired fineness. Dispersion and emulsification of the reagents were carried out in ultrasonic disperser from Branson, USA.

During flotation experiments concentrates were collected to have kinetic and equilibrium flotation data. The batch data were assessed in terms of grade, recovery, yield of the concentrate and the flotation rate constant. Flotation rate constant was estimated using the first order rate equation

$$K = 2.303 \frac{\log m_1 - \log m_2}{t_2 - t_1} \qquad (1)$$

where K is the flotation rate constant, and m_1, m_2 are the fractions remaining in the cell at times t_1 and t_2 respectively.

RESULTS AND DISCUSSION

Effects of Particle Size

Experiments were carried out to determine the effects of grinding time and hence the particle size of the flotation feed on the flotation behaviour of coal sample. The flotation results at varying grinding time and hence particle size distribution of the feed are shown in Figs.1 and 2. It can be seen from Fig.1 that an increase in the fineness of particle size from 13.6% -200 mesh to 19.4% -200 mesh, the flotation rate constant increases from 2.14 min^{-1} to 2.27 min^{-1}. This is mainly due to a decrease in top size from 820 microns to 600 microns [6]. This can also be attributed to an increase in liberation of coal particles at finer grinds. But a decrease in particle size at 5 and 7 minutes grinding time, affects the flotation kinetics as indicated by a decrease in rate

constant from 2.27 min^{-1} to1.04 min^{-1}. A decline in rate constant at finer grinds may be due to the increased amount of fines in the flotation feed which are known for poor and slow floatability [7, 8].

It is important to note from these data that although the rate constant is just marginally higher at 3 minutes grinding time than 1 minute but as it is evident from Fig.2 that for a given yield the ash content of the product is much lower with 3 minutes grinding time than 1 minute. The high ash content of the floats at 1 minute grinding time is because of higher degree of locking. Thus the flotation performance is far superior in case of material ground for 3 minutes where the amount of -200 mesh material is 19.4%.

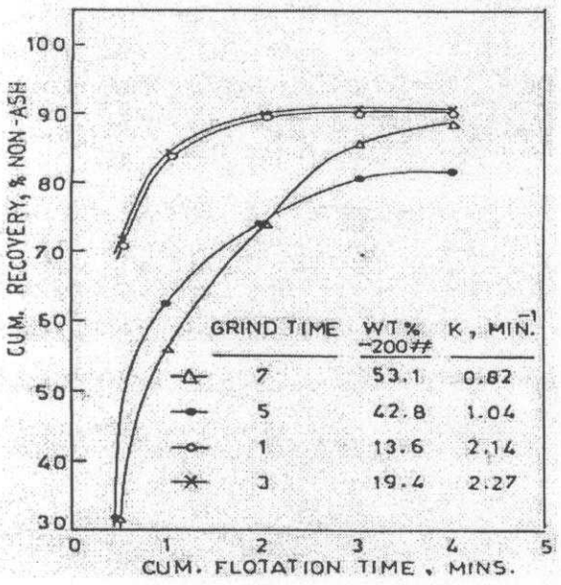

Fig.1 Effect of granulometry on kinetics of coal flotation.

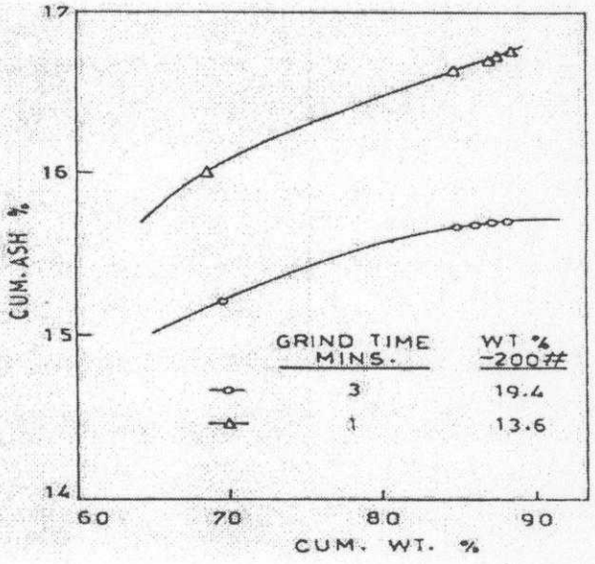

Fig. 2 Effect of granulometry on selectivity of separation

Variation of Collector Dosage

In order to study the effect of collector dosage, experiments were carried out at varying dosage of diesel oil from 1 kg/t to 10 kg/t. All the other conditions were maintained at the same level. A flotation feed with 3 minutes grinding time was taken for these experiments. The results of these experiments are shown in Fig. 3. As we can see from Fig. 3, an increase in the dosage of collector from 1 kg/t to 5 kg/t showed a progressive increase in the flotation kinetics indicated by an increase in the rate constant from 1.46 min^{-1} to 2.81 min^{-1} with an increase in the recovery of non-ash materials from 81.1% to 96.3%. This was attributed to the enhanced degree of hydrophobicity caused by increased dosage of the diesel oil. A further increase in the

collector dosage to 10 kg/t. resulted in froth overloading and lowering of the flotation rate constant to 2.38 $min.^{-1}$[9]. So with respect to kinetics as the response parameter a collector dosage of 5 kg/t seemed a better dosage. But considering the selectivity of separation, it was found that a collector dosage of 2.5 kg/t was a better choice [10]. At a dosage of 2.5 kg/t, product with a yield of 88.4% with 15.73% ash was obtained while for the same yield the ash content in the product with 5 kg/t. of collector was 16.4%.

Variation of pH of Flotation Pulp

Flotation behaviour of coal is influenced by pH of the pulp. Experiments were conducted on the sample by varying the pH of the flotation pulp. The collector dosage and grinding time for these experiments were 2.5 kg/t and 3 minutes respectively. The natural pH of the pulp, without the addition of any modifier was found to be 6. The typical flotation data are shown in Fig. 4. It was very interesting to see that pH had a marked effect on the coal flotation. It was observed that flotation kinetics as well as recovery of non-ash materials increase with an increase in pH from 4 to 7, as also indicated by an increase in the rate constant from 1.74 min^{-1} to 2.34 min^{-1} [10, 11]. But a further increase in pH to 10 affects the kinetics ($K=1.0\ min.^{-1}$) and hence the recovery. The data presented in Fig. 4 further establishes the above fact, indicating a peak in recovery and yield at pH 7 with a drop in % ash in the concentrate at pH 6.5.

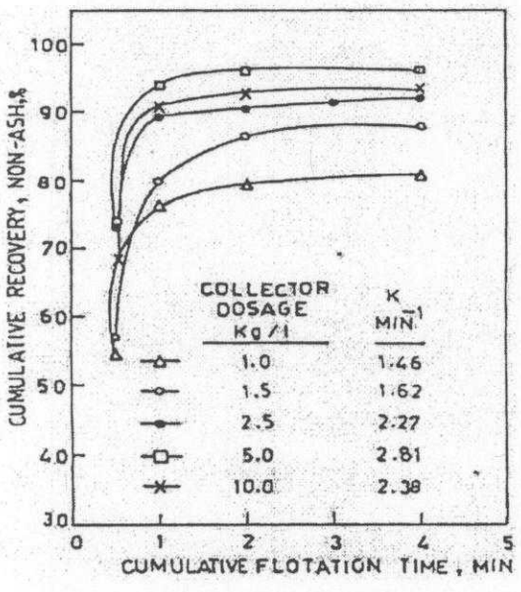

Fig. 3 Effects of collector dosage on kinetics of coal flotation.

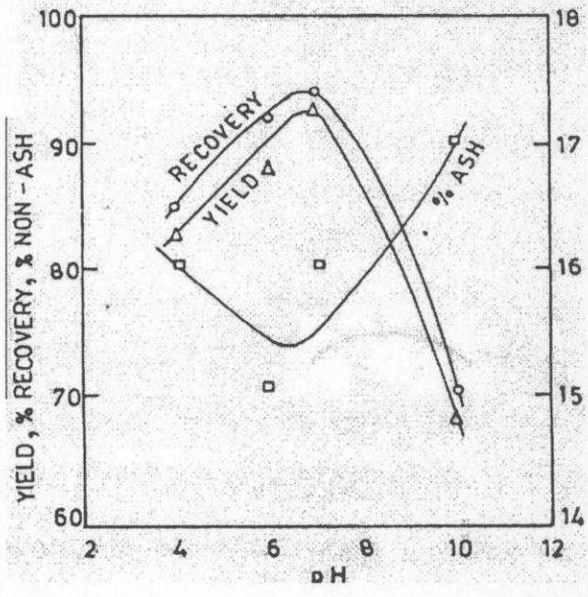

Fig. 4 Flotation behaviour of coal as a function of pH

The effects of other variables like frother and depressant/dispersant (sodium silicate in the present case) were also studied. Analysis of the data indicated 1.0 kg/t and 2 kg/t were the preferable dosage of sodium silicate and pine oil respectively [10-12].

Effects of Ultrasonication and Emulsification

In coal flotation the collector and the frother are oily reagents which are insoluble in aqueous medium. So normally the dispersion of such oily reagents by a conventional flotation machine is not adequate which may lead to non-selective adsorption and reversible and non-equilibrium conditions. In such cases the adsorption of collector may be localised on the coal surface as well as on gangue minerals [13]. Thus for better efficiency of the reagents, these were dispersed ultrasonically [14]. In later experiments sorbitol mono-oleate was used as an emulsifier besides ultrasonicating the pulp for better selectivity. The reagents sodium silicate, diesel oil and pine oil were ultrasonicated and added to the flotation pulp at pH 7. The pulp was further conditioned with reagents. The ultrasonication time was varied from 10 to 30 minutes. The results are shown as time versus recovery plots in Fig. 5. Thus we can see that due to better dispersion and adsorption of the reagents, with an increase in ultrasonication time from 0 to 20 minutes the flotation kinetics and hence the recovery of non-ash materials improves. The rate constant increases from 2.26 $min.^{-1}$ with no ultrasonication to 2.62 $min.^{-1}$ with ultrasonication for 20 minutes. Although a further increase in ultrasonication time to 30 minutes showed a decline in kinetics. This may be probably due to partial decomposition of low volatile reagents at high ultrasonication time. The flotation selectivity analysis of the data indicated that a high dispersion by ultrasonication leads to a selective adsorption of the reagents, which in turn causes selectivity in coal flotation. Fig. 6 presents the flotation data on the effects of ultrasonication and an emulsifier. Thus we can see that use of sorbitol mono-oleate as an emulsifier followed by ultrasonication of the pulp further enhances the coal flotation efficiency.

Cleaning of Rougher Concentrate

An observation of the flotation kinetic data under varying process conditions clearly revealed that one stage of flotation (only roughing) would not be sufficient to give a product with ash less than 10% with reasonably high yield. So the next task was to reduce the ash content of the rougher float below 10% by the cleaning flotation. For this purpose adequate rougher float was collected by repeating the roughing flotation operation under the optimum conditions. The rougher float thus produced was cleaned using fresh volume of water and 0.5 kg/t of additional pine oil. The final concentrate assayed 9.58% ash with 77.4% yield.

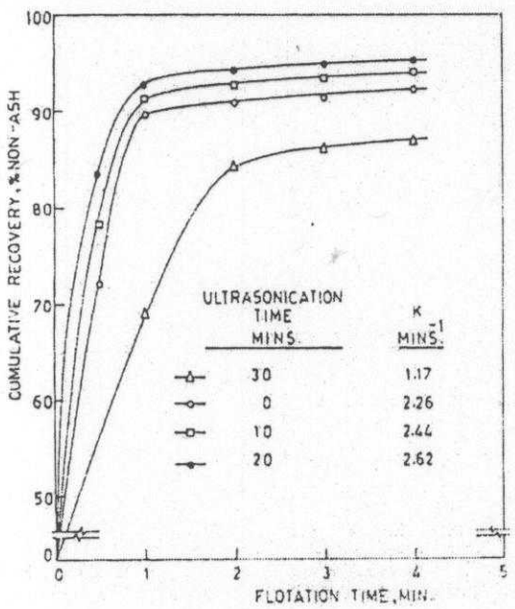

Fig. 5 Effects of ultrasonication on recovery and kinetics of coal flotation

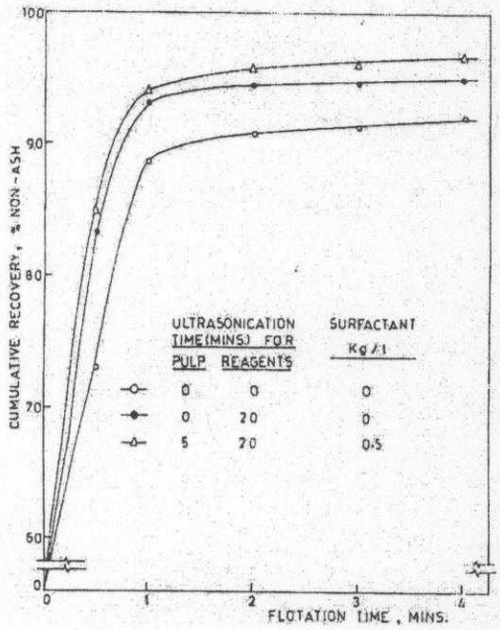

Fig. 6 Effect of ultrasonication and emulsifier on recovery and kinetics of coal flotation

SUMMARY AND CONCLUSIONS

Flotation studies were carried for de-ashing of a non-coking coal sample. The effects of various process parameters were studied and the data were analysed using a first order model. It was found that ultrasonication and emulsification of the oily reagents lead to improvement in the overall flotation performance. Cleaning of the rougher float produced concentrate assaying 9.58% ash.

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REFERENCES

1. Singh, R., Bhattacharyya, K.K. Bhagat, R.P. and Chakravorty, N., *J. of Scientific & Industrial Research* **1** (1993) 64-69.
2. Singh, R., Bhagat, R.P. and Chakravorty, N., Beneficiation of high ash coal for Indian industries, National Seminar on Importance of Coal in Indian Industries, MECON, pp.106-124, 1993.
3. Rao, T.C., Recent advances in fine coal benefication, Indo-US Seminar on Selected Topics in Mineral Processing, TRDDC, pp.II.34-II.65, 1988.

4. Mishra, B.C., Beneficiation of Indian coal, National Seminar on Research and Development in Mineral Preparation, National Metallurgical Laboratory, pp.KII.1-KII.18,1992.

5. Pandey, B.D., Coal injection in blast furnace - theoretical calculations, Advance Course on Blast Furnace Iron Making, Tata Iron & Steel Company Ltd., pp. 15.1-15.40, 1991.

6. Aplan, F.F., *Mining Engineering*, January, (1993) 83-94.

7. Singh, R., Rao, S.S., Maulik, S.C. and Chakravorty, N., *Trans. Ind. Inst. Metals*, **50** (1997) 407-423.

8. Singh, R., Pradip and Shanker, T.A.P., *Int. J. of Miner. Process.*, **36** (1992) 283-293.

9. Mehrotra, S.P. and Singh, R., *J. Metals Materials and Processes*, **6** (1995) 195-216.

10. Singh, R, and Singh, P., Beneficiation of non-coking coal for injection in blast furnace, Coal-96, Allied Publishers, New Delhi, India, 1995, pp.288-299.

11. Singh, R., National Metallurgical Laboratory, RI, July1994.

12. Singh, P., Flotation characteristics of non-coking coal, M.Tech.Thesis, Ranchi University, Ranchi,1996.

13. Mishra, M. and Anazia, I., *Minerals and Metallurgical Processing* (1987) 233-236.

14. Singh, B.P. and Singh, R., *J. Institution of Engineers (India)*, **74** (1993) 34-38.