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Technical Note

Effect of conditioning on the beneficiation of dilute coking coal fines by froth flotation

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ABSTRACT

The coal preparation plants produce large quantities of coal slurry having very dilute pulp density (3 to 5 percent) during desliming of coals. Froth flotation is a universally accepted process for the beneficiation of coal fines, but the process being sensitive needs careful monitoring of the process variables. One of the prerequisites for flotation of slurry is to have an effective conditioning for proper adsorption of reagents with the coal particles. In this paper attempts have been made to upgrade low pulp density coal fines by designing a suitable conditioner and carrying out laboratory flotation test by varying some important process variables like pulp density, reagent (collector and frother) dosage. The effects of these variables on the results of flotation have been studied. Correlations have also been developed between yield/ ash percent of concentrate and the variables through regression analysis. A statistical analysis is presented to study the effects and interactions of the variables.

Keywords: Beneficiation; Froth flotation; Coal; Statistical analysis

1. INTRODUCTION

The amount of fines generated in Indian Coal Washeries varies from 10 to 15 percent with an average ash content of 25-30%. It has become essential to treat these fines separately before blending them with washed coarse coal. Froth flotation is the only established technique to beneficiate the coal fines effectively. The flotation units of the coal washeries are unable to run under stable conditions mainly due to variation in pulp density of feed slurry, improper conditioning, improper dosing system etc. Conditioning can play a dominant role in the overall performance of the flotation process and it has been recognized for sometime as an important methodology to improve the performance of the flotation process. Special features of conditioning in flotation are (Horsely and Smith, 1951; Gaudin, 1957):

- Uniform distribution of the reagents.
- Collision of distributed reagents with coal particles.
- Adhesion of reagents on the coal surfaces.

In the present study, conditioning followed by flotation tests is carried out in laboratory scale with coal slurry of low pulp density. The effect of variables such as collector oil dosage, pulp density and frother dosage were investigated on the flotation characteristics of coal. The results have been discussed on the basis of development of correlation between variables studied and yield/ ash percent obtained. Attempts have been made to study the effects and interactions of variables using statistical design.

2. EXPERIMENTAL

2.1. Materials used

The fines generated during processing of coal (-75mm) from Jeenagora Colliery of BCCL in 40tph coal washing plant at CFRI was used for the study. The size analysis of the sample studied is shown in Table 1.

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Table 1
Size analysis of the sample

Sl. No.	Size (mm)	Wt%	Ash%
1.	+ 0.315	40.5	25.2
2.	-0.315 + 0.200	20.7	29.0
3.	-0.200 + 0.140	10.9	30.1
4.	-0.140 + 0.071	18.0	29.0
5.	- 0.071	9.9	32.0

2.2. Chemicals used

Diesel oil and pine oil were used as collector and frother, respectively.

2.3. Experimental procedure

The flotation tests were carried out in a laboratory type Denver Sub-A flotation cell of 1 litre capacity under the following conditions:

- Conditioning time, min : 5
- Impeller speed, rpm : 1400
- Time of collecting, sec : 60

The pulp was conditioned with diesel oil (collector) for 5 minutes in a specially designed conditioning vessel fitted with stator and rotor. The impellers of the rotor were designed suiting to the purpose of conditioning. The conditioned pulp was then transferred to a 1 litre capacity flotation cell, wherein pine oil (frother) was added at an appropriate dosage. The aeration was started by opening the air valve and the froth floated as concentrate was collected, dewatered, fried and weighed, sub sampled and ash content of each was determined. All the tests were carried out following the above procedure for each level of variables, which are presented in Table 2 (Vanangamudi and Rao, 1986).

Table 2
Levels of variables studied

Variables*	Levels		
	1	2	3
1. Collector oil dosage (C) (kg/tonne)	1.15	1.50	2.00
2. Frother oil dosage (F) (kg/ tonne)	0.25	0.50	0.75
3. Pulp density (Percent solids by wt)	3.00	4.00	5.00

*A total of 27 experiments were carried out at three levels of each variables. In the text, variables are designated as C_i, F_j, P_k where i, j, k are levels of collector oil dosage, frother oil dosages and pulp density, respectively.

3. RESULTS AND DISCUSSIONS

3.1. Beneficiation studies

i) The results of the flotation tests have been expressed in terms of recovery and ash percent of concentrate and tailings (Table 3). The combustile recovery of each experiment and also the effects of variables on the flotation performance are given in Table 3.The results are discussed below:
   (a) At low solids concentration (P_1) the number of coal particles per unit volume is less and hence all the particles do not encounter with the reagents within the specified period. As a result yield of concentrate is less and more amount of coal with low ash is reported in the tailings.
   (b) With increase in solids concentration (P_3) the coal particles are more crowded and get more chances of collision and coating. As a result yield of concentrate increases and less amount of coal with low ash is reported in tailings.
   (c) Although coal is inherently hydrophobic the natural contact of coal from different areas within the same seam may vary considerably. Consequently, it is usual to use a collector oil to enhance the hydrophobicity of the coal particle surface. For this purpose diesel oil was used in the present studies. It is seen, in the cases under study, that the increased collector addition increases the hydrophobicity and floatability of coal particles, resulting in an increased recovery of concentrate.
   (d) Increased frother addition rate increases the water recovery and froth mobility. In the present studies it is seen that increase in concentrate recovery due to increased frother addition is marginally significant. However, because the water recovery also increases with increasing frother addition,

entrainment mechanism increases the recovery of high ash components, thereby increasing overall ash content in concentrate.

ii) The flotation performance is evaluated in terms of Gaudin selectivity index:

$$S.I. = Cg\ (100\text{-}Tg)\ /\ Tg\ (100\text{-}Cg) \quad (1)$$

Where S.I. is Selectivity Index, Cg is concentrate grade and Tg is tailings grade and the corresponding results are tabulated in Table: 3. where S.I. ranges from 8 to 40 which shows good flotation performances are noticed in most of the cases.

Table 3
Results of Flotation test

Expt.	Concentrate		Tailings		Feed	Combustile	Selectivity
	Wt%	Ash%	Wt%	Ash%	Ash%	Recovery	Index
$C_1F_1P_1$	28.0	8.0	72.0	34.5	27.1	35.33	37.38
$C_1F_3P_1$	30.0	8.5	70.0	36.0	27.8	37.99	37.18
$C_1F_3P_3$	55.0	15.5	45.0	43.2	28.0	64.5	41.54
$C_3F_1P_1$	36.7	9.5	63.3	37.9	27.5	45.78	37.57
$C_3F_1P_3$	45.0	13.3	55.0	40.0	28.0	54.19	41.52
$C_3F_2P_3$	55.0	15.5	45.0	43.0	27.9	64.44	41.67
$C_3F_3P_1$	42.0	10.8	58.0	39.5	27.4	51.65	38.33
$C_3F_3P_3$	66.0	15.8	34.0	50.0	27.4	76.59	36.43

4. DEVELOPMENT OF CORRELATION

In order to predict the yield and ash percent of concentrate, the following correlations are established:

$$\text{Log } Y = \text{Log }(A_0) + A_1 \log(C) + A_2 \log(F) + A_3 \log(P) \quad (2)$$

$$\text{Log } X = \text{Log }(A_4) + A_5 \log(C) + A_6 \log(F) + A_7 \log(P) \quad (3)$$

Where

Y = yield % of concentrate
X = ash % of concentrate
C = collector oil dosage (kg/ton)
F = frother oil dosage (kg/ton)
P = pulp density (percent solids by weight)
A_0, $A_{1...}$ A7 are constants.

The above constants A_0 to A_7 are evaluated (using the data in Table 3) by the least square method. The equations obtained are again used to interpolate the yield and ash percent separately. After evaluating the constants, the relations between yield percent of concentrate with variables and ash percent of concentrate with variables reduces to:

$$Y = 22.47(C)^{0.35}\ (F)^{0.36}\ (P)^{0.60} \quad (4)$$

and

$$X = 10.09(C)^{0.19}\ (F)^{0.44}\ (P)^{0.32} \quad (5)$$

The estimated yield and ash percent of concentrate and the corresponding interpolated values are depicted in Figures 1 and 2. Students t-test is used to check whether the calculated values obtained from the regression equations match closely with the actual values at 5% level of significance. The calculated value of statistic 't' is 0.019 for yield percent of concentrate and 0.113 for ash percent of concentrate, both at 52 degrees of freedom. Since $t_{(tabulated)} = 2.01$ at 5% level of significance and at 52 degrees of freedom. Hence $t_{(cal)} < t_{(tabulated)}$ which shows a good agreement between actual and calculated values of yield as well as of ash percent concentrate.

It can be observed from Figures 1 and 2 that the calculated values match closely with the actual values, hence equations 4 and 5 give an accurate relationship of the yield and ash percent with the operating variables within experimental limits.

From the correlations developed, it is indicative that the extent of influence of variables is in the following order for

(i) the recovery of the concentrate P > F > C
(ii) the ash percent of the concentrate F > P > C

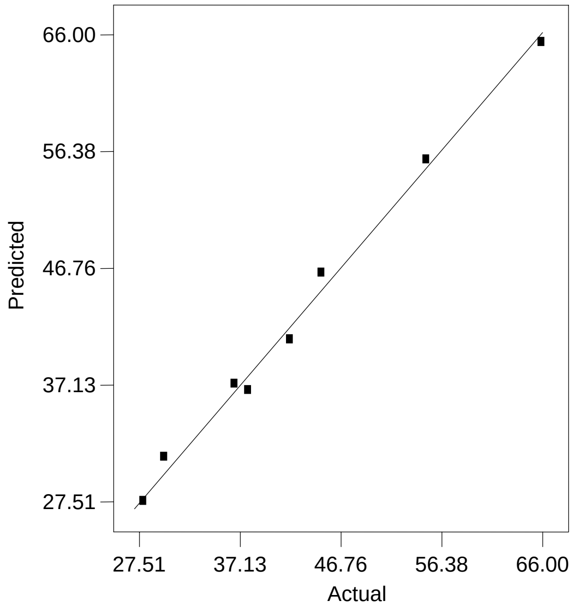

Figure 1. Predicted versus actual for yield%

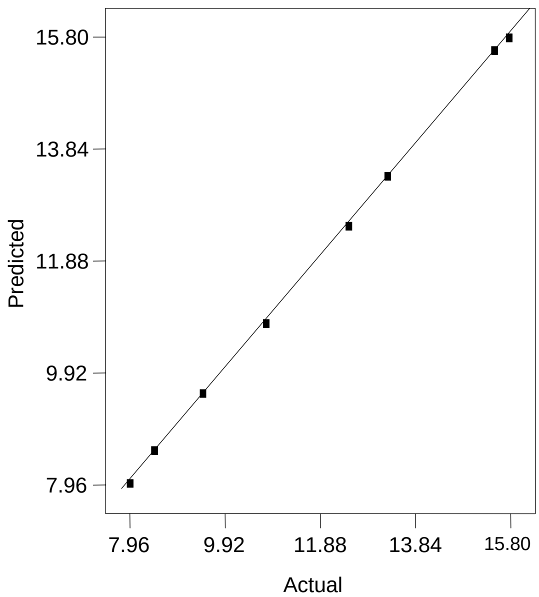

Figure 2. Predicted versus actual for ash%

5. STATISTICAL ANALYSIS

In coal preparation research, the conventional practice is to conduct tests as a function of one variable at a time. However, this can be deceptive as it does not indicate any change of other variables in the system. Lack of reproductivity and coherence are characteristic of one variable at a time.

Among several existing approaches, the statistical approach has found of much use lately. From the results obtained by the factorial design of experiments it is possible to study the effects and interactions of variables, to test its significance (Davis, 1978).

To study the effects and interactions of variables, viz. collector oil dosage (C), frother oil dosage (F) and pulp density (P), two levels were taken and the same was coded between -1 and $+1$, where -1 represents the low level and $+1$ with high level of factors. The levels of coding of factors are shown in Table 4.

Table 4
Levels of factors for 2^3 design

Variable	Level of factor	
	Low (-)	High (+)
Collector oil dosage	1.15	2.00
Frother oil dosage	0.25	0.75
Pulp density	3.00	5.00

The calculations of the effects and mean square for the yield percent of concentrate using Yate's method are shown in Table 5 and analysis of variance is shown in Table 6.

Table 5
Calculations of effects and mean square

Treatment Combination	Response = yield	(1)	(2)	(3)	Sum of squares = $\frac{(Effects)^2}{8}$
(1)	28.00	64.70	136.70	340.70	14509.56
a	36.70	72.00	204.00	38.70	187.21
b	30.00	83.00	20.70	45.30	256.51
ab	42.00	121.00	18.00	7.30	6.66
c	38.00	8.70	7.30	67.30	566.16
ac	45.00	12.00	38.00	-2.70	0.91
bc	55.00	7.00	3.30	30.70	117.81
abc	66.00	11.00	4.00	0.70	0.06

Repeat tests

abc 66.43

65.56

65.37

66.11

$\overline{X}$ = 65.87, n=4

$$Error\,Variance = \frac{1}{(n-1)}\sum(X_i - \overline{X})^2$$

= 0.239

Table 6
Analysis of variance for the components

Source of estimate		Sum of squares	Degree of freedom	Mean squares
Effect	A	187.21	1	187.21
	B	256.51	1	256.51
	C	566.16	1	566.16
Interaction	AB	6.66	1	6.66
	AC	0.91	1	0.91
	BC	117.81	1	117.81
	ABC	0.061	1	0.061

From (Table 5) the experimental error variance was found to be 0.239 for yield based on three degrees of freedom. At 5%, the value of F for $n_1 = 1$ and $n_2 = 3$ is 10.1. Using the estimate of error variance for yield, the mean square of 10.1 * 0.239 = 2.4 is significant at 5% levels. Thus 'F' test indicates that the main effects of all the variables are significant at the 95% confidence level. The order of significance is: Pulp density > Frother oil dosage > Collector oil dosage

5.1. Interaction effects

The results of ANOVA (Table 6) show that the interactions between A and C have no significant effect (at the confidence level) on the yield whereas interactions of A and B and that of B and C are significant at 95% confidence level.

6. CONCLUSIONS

From the results presented in this paper it may be concluded that:

1. With increase in solids concentration and collector oil dosage, the hydrophobicity and floatability of coal particles increased thereby resulting in an increased recovery of clean coal at acceptable ash levels.

2. All the variables are significant at 95% confidence level with respect to yield of the product. The order of significance of the interactional effects of the variables is as follows: BC > AB > AC
3. The flotation of Indian Coking coal fines at low pulp density is technically feasible. However, its economics need a thorough study and further investigation.
4. The present series of investigations reveal that the flotation at low pulp density may escape a few costly unit operations in a commercial coal preparation plant thereby reducing the capital cost.
5. Responses from the experimental work were correlated with the operating variables through a regression equation which is well within the statistical limits when compared with the experimental values.
6. From the correlation developed and also from statistical analysis it is clear that the effects of variables on the recovery of concentrate is in the following order
   Pulp density (P) > Frother Oil dosage (F) > Collector Oil dosage

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