International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:5, No:4, 2011

A Novel Approach for Beneficiation and Dewatering of Coal Fines for Indian Coal Preparation Plant

K.K. Sharma, K.M.K. Sinha, T.G. Charan, D.D. Haldar

***Abstract*—**An attempt has been made to beneficiate the Indian coking coal fines by a combination of Spiral, flotation and Oleo Flotation processes. Beneficiation studies were also carried out on -0.5mm coal fines using flotation and oleo flotation by splitting at size 0.063mm.Size fraction of 0.5mm-0.063mm and -0.063mm size were treated in flotation and Oleo flotation respectively. The washability studies on the fraction 3-0.5 mm indicated that good separation may be achieved when it is fed in a spiral. Combined product of Spiral, Flotation and Oleo Flotation has given a significant yield at acceptable ash%. Studies were also conducted to see the dewatering of combined product by batch type centrifuge. It may further be suggested that combination of different processes may be used to treat the -3 mm fraction in an integrated manner to achieve the yield at the desired ash level. The treatment of the 3/1 mm -0.5 mm size fraction by spiral,-0.5-0.63 mm by conventional froth flotation and -0.063 fractions by oleo flotation may provide a complete solution of beneficiation and dewatering of coal fines, and can effectively address the environmental problems caused by coal fines.

***Keywords*—**coal fines, dewatering, environment, flotation, oleo flotation, spiral

I. Introduction

INDIA is the third largest coal producer [1] in the world and represented about 9-10% of the total world coal reserves [2]. The present geologically known reserves of coals in India are of the order of 267 billion tones [3]. Indicated in-situ reserve of Gondwana coal is over 100 billion tonnes upto 1200 metre depth. Indian coals are generally contains higher amounts of integrated dirt and normally difficult to wash. Consequently controlled crushing of these coals became necessary for better liberation of dirt before the coals are upgraded by washing. The need to crush coal to smaller sizes for better liberation of dirt for its subsequent removal by washing, creates the problem of generation of more coal fines. Added to this the adoption of mechanization in mining has also increased the quantum of fines generation in the recent past [4, 5]. Fine coal treatment and disposal of washery tailings are now creating alarming problems to global environment. In India, the Central coal washeries with their present beneficiation circuits are producing about 1.6 Mt of coking coal fines per annum [1,2]. These slurries are not processed further in most of the washeries because of so many reasons. Froth Flotation is a commercially established process for beneficiation of coal fines [6, 7, 8] and it is incorporated in most of the coking Coal Preparation Plants in India.

K.K.Sharma is with Central Institute of Mining and Fuel Research, Dhanbad, Jharkhand, India.(e-mail:drkamalfri@yahoo.co.in)

However coal fines circuits fail to yield desire results due to various reasons and high moisture content in cleans is one of them. Normally these concentrate is dewatered in vacuum/disc/leaf/drum/belt pressure/steel belt filter etc. These dewatering equipment exhibits poor performance due to presence of ultra fines. So the regular operation of this process is badly affected due to difficulty of dewatering and beneficiation of ultra fines.

In the present investigation an attempt has been made to give a solution to the aforesaid problem by treating the coal fines in combination of Spiral [9, 10,] flotation and Oleo Flotation [11, 12] processes. Laboratory Float & Sink tests using organic liquids in centrifuge were done on coal fines from lower seam of Jharia Coalfield collected form a Indian coal preparation Plant. Taking Ep of spiral in consideration, gravity separation was simulated for practical yield. Beneficiation were also carried out on -0.5mm coal fines using flotation and oleo flotation by splitting at size 0.063mm.Size fraction of 0.5mm-0.063mm and -0.063mm size were treated in flotation and Oleo flotation [13] respectively. Combined product of Spiral, Flotation and Oleo Flotation has given a significant yield at acceptable ash%. Studies were also conducted to see the dewatering of combined product by batch type centrifuge. Due to presence of coarser clean particle from Spiral and flocks (oleo concentrate) from oleo flotation, moisture content was observed to be less than 10 % for combined product of Spiral Flotation and Oleo Flotation.

It may further be suggested that combination of different processes may be used to treat the -3 mm fraction in an integrated manner to achieve the yield at the desired ash level. The treatment of the 3/1 mm -0.5 mm size fraction by spiral,-0.5-0.63 mm by conventional froth flotation and -0.063 fractions by oleo flotation may provide a complete solution of beneficiation and dewatering of coal fines as well environment.

II. Experimental

A. Material Used

The present studies of the beneficiation of coal fines was carried out on a sample from Indian Washery i.e. Moonidih Coal Washery. The sample was collected as per standard and it was dried and mixed thoroughly and than by refilling method it was reduced to the required quantity for the different characterization and beneficiation tests.

B. Reagent Used

To carry out the experiment by flotation diesel oil and MIBC were used as collector and frother respectively. For oleo flotation wash oil and diesel oil were used.

C. Flotation CELL

A flotation cell of Denver D-12, 2.5 lit caps was used for flotation and oleo flotation tests. This unit has a baffle arrangement at bottom to avoid swirling of the slurry within the cell and an impeller is provided for proper mixing of slurry, the speed of which can be controlled by a speed regulator, a compressor is also provided to supply air to the cell at the rate of 2.07 m3/m2/min.

Experimental Procedure

Size analysis: Size analysis of coal fines was done as per standard at 6,3,1 and 0.5 mm. The fraction of -0.5 mm was also done at 0.5,0.40, 0.125 and 0.063 mm and RRB curve was drawn to see the average particle of the feed size of the spiral flotation and oleo flotation which are presented in Table 1(a), 1(b) and Fig 1.

Two synthetic mixtures of 3-1 mm and 1-0.5mm were also prepared for F&S test. Two fractions were separately prepared for flotation and oleo-flotation by screening the -0.5 mm at 0.063 mm

TABLE I (a)
SIZE ANALYSIS OF MOONIDIH COAL FINES COLLECTED FROM THE WASHER

Size (mm)	Wt%	Ash%
+12	9.7	62.1
13-6	8.2	45.4
6-3	6.0	42.3
3-1	7.9	38.9
1-05	11.8	29.9
-0.5	16.4	29.9

TABLE I (b)
SIZE ANALYSIS OF -0.5MM

Size (mm)	Wt%	Ash%
+0.5	21.9	21.9
0.5-0.250	28.3	24.6
0.250-0.125	29.1	32.3
0.125-0.003	13.0	44.7
-0.063	16.2	53.3
	100.0	33.0

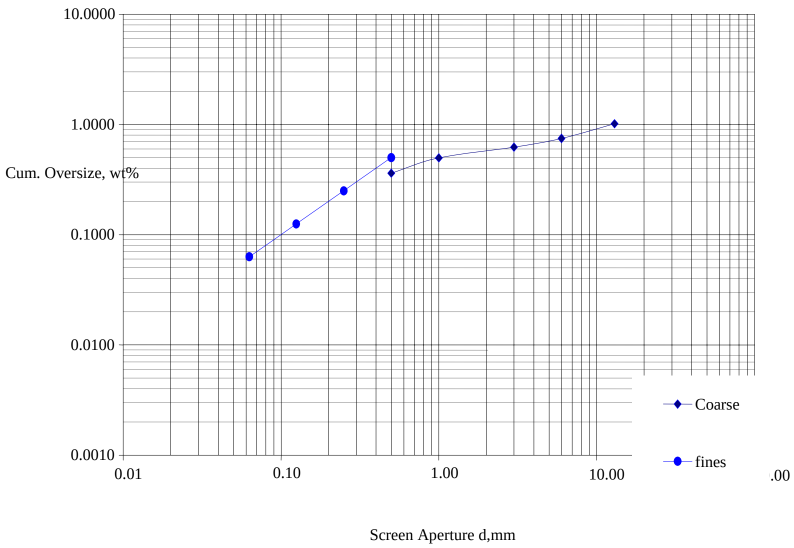

Fig. 1 Particle size distribution of coarse and fine coal

D. F&S by Centrifuge for Spiral

The size fraction of 3-1 mm and 1-0.5 mm were used for Float and Sink test. The full scale washability test at 1.30-2.0 specific gravity range was carried out at laboratory scale centrifuge at 2500 rpm, shown in fig.2, 3, 6. These tested were carried out in order to establish the beneficiation characteristics and also with a view to select the optimum specific gravity cut point for respective size fractions. From float and sink data of 3-1 mm and 1-0.5 mm fractions, approximate specific gravity cut points for spiral separator was chosen through simulation of washability data in Microsoft excel program considering the normal performance efficiency of spiral i.e., ep value as 0.18.

E. Flotation

Flotation, 250 gm of sample was allowed to wet in a known volume of water. It was then transferred in to the Denver cell. Additional water was added to maintain required pulp density; slurry was stirred at the impeller speed of 1500 rpm. Then pre-requisite diesel oil of 1.25 kg/t was added at 33% pulp density, and conditioned for two minutes. After conditioning pre-requisite amount 0.25 kg/t frother (MIBC) was added. The cell was filled with water up to the marked height, air inlet value was opened and concentrate was collected in a tray for 1 minute. After the completion of the experiment, flotation concentrate and tailings separated filtered, dried and weighed. The ash content of the both product concentrate and tailings were determined. The data is shown in Table 2a.

TABLE II (a)
FLOTATION TESTS AT DIFFERENT SIZE

Size(mm)	Conc/Tail	Wt%	Ash%
3-05	Concentrate	13.7	9.1
	Tailings	86.3	35.6
3-1	Concentrate	23.7	12.7
	Tailings	76.3	40.8
1-0	Concentrate	59.3	15,6
	Tailings	40.7	70.2
1-0.063	Concentrate	77	17.3
	Tailings	23	63.1
1-0.5	Concentrate	29.8	9.4
	Tailings	70.2	37.3
	Concentrate	82.7	18.3
	Tailings	17.3	72.6

F. Oleo Flotation

In oleo flotation the same Denver cell was used, which was used in the flotation test. In oleo flotation the slurry is mixed with comparatively higher doses of combination of specified oil than is normal required in froth flotation test processes. The thickened slurry at about 300 gm/litre solid content is conditioned with two reagents comprising diesel oil and cut fraction of tar oil i.e. wash oil from high temperature carbonization of coal. The diesel and tar oils in the ratio of 10:1 are mixed; dispersed and total amount dosed is generally 1% by weight of dry coal. The data is shown in Table II b.

TABLE II (b)
OLEO FLOTATION TEST OF -0.063MM

	D.oil	3.15 ml
	Wash Oil	0.35 ml
	RPM	1500
	Wt%	**Ash%**
Concentrate	26.5	17.9
Tailings	73.5	29.5
	100.0	26.4

The conditioned pulp after dilution to 200 gm/lit is treated in flotation cell with controlled aeration to separate concentrate as oiled flocks /aggregates in dense phase with better dewatering studies drainage characteristics. After partial removal of water, the concentrate mixed with average cleans and combined clean coals are dewatered in continuous batch basket (centrifuge) as final product having moisture content below 10%.

G. Dewatering in Laboratory Batch Centrifuge

In order to see the effectiveness of the total product of coal fines up gradation and dewatering tests were carried out at laboratory i.e. batch flotation/oleo flotation and centrifuge set up using coking coals deslimed at 0.5 mm size. The partially dewatered total cleans were dewatered in batch type basket centrifuge. It was noted while upgrading affects the quite comparable to that obtained individual washing treatment. The total moisture content of the final product (clean) was less than 11.2%. The data is shown in table 4.

TABLE IV
RESULTS OF DEWATERING TESTS

Spiral # 1		Spiral # 2		Flotation Concentrate		Oleo Flotation Concentrate		Combined product Moisture %		Moisture % After centrifuge	
Wt %	Moist %	Wt %	Moist %	Wt %	Moist %	Wt %	Moist %	Wt %	Moist %	Wt %	Moist %
5.6	12	10.7	21.3	30.2	24	16	19.8	62.5	21.3	62.5	10.4
5.3	12.1	11.2	21.2	30.2	23.9	16	19.7	62.5	21.3	62.7	10.2
6.6	12.4	11.1	21.2	30.2	24	16	19.8	62.5	21.3	63.5	10.0
5.6	11.8	Flotation	1-0.063 mm	37.4	24.0	16	19.8	62.5	21.3	56.0	11.2

III. RESULTS AND DISCUSSION

Size analysis is an important experiment in the coal fines preparation, on the observation of yield and ash for any process of beneficiation. Dose of reagents and utilization is predicted or presumed.

Coarse size distribution: From the curve as depicted in Fig.1, it is clear that coarser size particles have wider size distribution .Slope is around 0.425.Indication of curve is also towards natural crushing. Breakage occurs along natural cleavage. Washing becomes easier at low cost.

Finer size distribution: Indication of curve is towards balanced crushing. Breakage is combination of natural as well as forced crushing. There is a chance of middling's, which makes washing difficult and costly.

Normal practice of flotation of coal fines is done at -0.5 mm but in this experiment upto 3 mm flotation experiments were done. It is observed from the table 2 A that 3-1 mm and 3-0.5 mm fraction produced a yield of 23.7 and 13.7 with an ash of 12.7 and 9.1 respectively. Only significant flotation test results was observed in the size fractions of 1-0 mm, 1-0.063 mm and -0.063 mm which was 59.3, 77.0 and 82.7 with an ash level of 15.6, 17.3 and 18.3 respectively. In conclusion it may be drawn from the above experiment that the feed size of the flotation may be enhanced to at least 1 mm, which may increase the yield and better the dewatering characteristics.

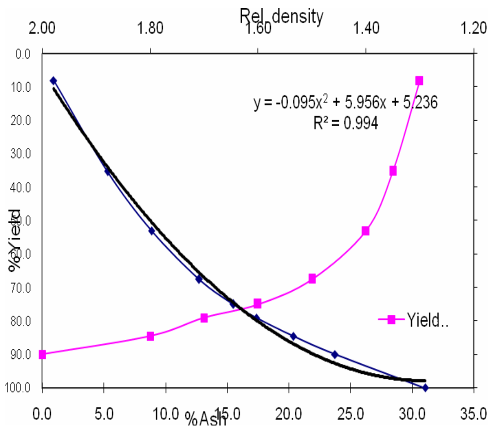

Fig 2 Washability Curves for -3 + 1 mm

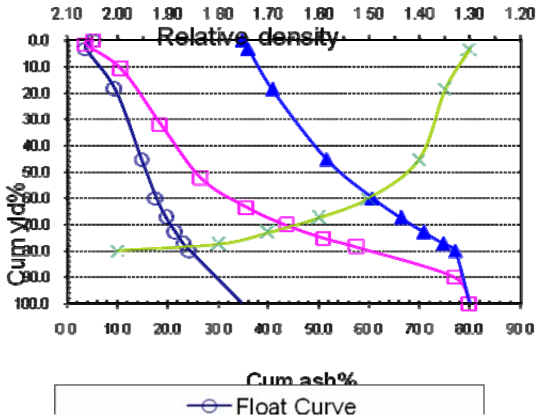

Fig:3 Mayer's washability curve of 3-1 mm

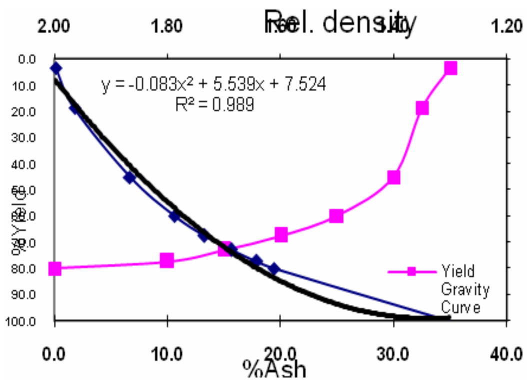

Fig: 4 Mayer's washability curve 1-0.5 mm

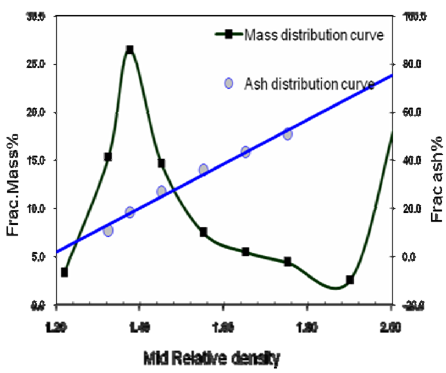

Fig: 5 Mass & Ash Distribution curves 3-1 mm

The float and sink data obtained with these two samples to construct M Curve from which yield of product obtainable for a given level of ash in product has been computed the experimental relation of yield vs. ash is seen in Fig.2, It reveals that the washability characteristics are easy.The Mayers curve depicted in Fig.3 also reveals that most of the mineral matter is liberated form. Mass distribution is also observed from Fig 5. This shows that the most of the mass is lying in the range of 1.30-1.50. To establish the beneficiation characteristics by considering the normal performance efficiency of spiral i.e., ep value the help of visual Microsoft excel program. Prediction of yield for spiral was considered by normal efficiency of spiral as 0.18. Program was also run to see the prediction yield at 0.14 and 0.16 ep at d50. It can be seen from Table 3 this also proves the theory of ep that if it increases the quality of product is to the worst side, which is true for the size 3-1 mm and 1-0.5 mm.

TABLE III
PRODUCT OF SPIRAL AT DIFFERENT EP AND SIZE AT D50

Size(mm)	Ep.	Wt%	Ash%
3-1	0.14	57.1	25.4
3-1	0.16	53.5	26.1
3-1	0.18	55.9	26.8
1-0.5	0.14	61.4	19.5
1-0.5	0.16	60.5	20.1
1-0.5	0.16	59.7	20.7

A. Alternative Options for Beneficiation and Dewatering

Different options for the beneficiation and dewatering of the coal fines were tried and the data is shown in Table 5. The options are explained as below:

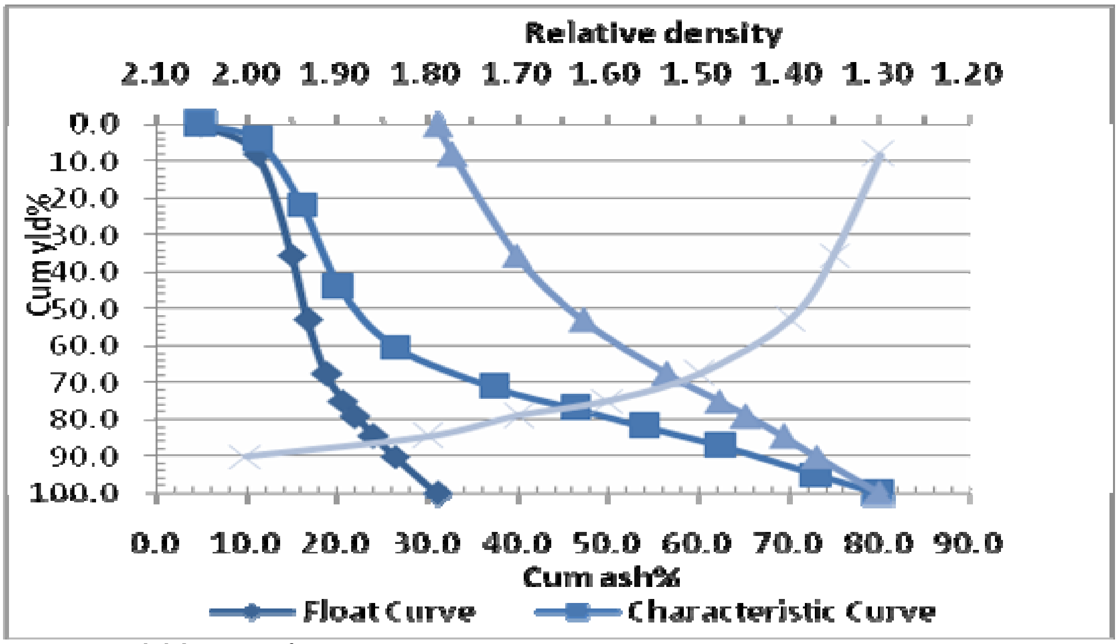

Fig 6 Washability Curves for 1-0.5 mm

TABLE V
VARIOUS OPTIONS FOR BENEFICIATION AND DEWATERING OF COAL FINES FOR INDIAN COAL PREPARATION PLANT
Option No1

Washer	Ep	Size(mm)	Sp.Gr	Wt %	Ash%
Spiral	Ep.18	3-1mm	1.635	5.6	29.0
Spiral	Ep .18	1-0.5 mm	1.895	10.7	27.0
Flotation	Concentrate	0.5-0.063 mm		30.2	11.6
Oleo	Concentrate	-0.063 mm		16.0	14.4
	Total Cleans	3-0 mm		62.5	16.4
	Total Rejects	3-0 mm		37.5	53.5
	Over all	3-0 mm		100.0	30.3

Option No 2

Washer	Ep	Size(mm)	Sp.Gr	Wt %	Ash%
Spiral	Ep.18	3-1mm	1.590	5.3	27.0
Spiral	Ep .18	1-0.5 mm	1.900	11.2	27.0
Flotation	Concentrate	0.5-0.063 mm		30.2	11.6
Oleo	Concentrate	-0.063 mm		16.0	14.4
	Total Cleans	3-0 mm		62.7	16.4
	Total Rejects	3-0 mm		37.3	53.7
	Over all	3-0 mm		100.0	30.3

Option No 3

Washer	Ep	Size(mm)	Sp.Gr	Wt %	Ash%
Spiral	Ep.18	3-1mm	1.735	6.6	31.3
Spiral	Ep .18	1-0.5 mm	1.951	11.1	27.0
Flotation	Concentrate	0.5-0.063 mm		30.2	11.2
Oleo	Concentrate	-0.063 mm		16.0	14.4
	Total Cleans	3-0 mm		63.9	17.0
	Total Rejects	3-0 mm		36.1	51.3
	Over all	3-0 mm		100.0	30.3

Option No 4

Washer	Ep	Size(mm)	Sp.Gr	Wt %	Ash%
Spiral	Ep.18	3-1mm	1.635	5.3	27.0
Flotation	Concentrate	1-0.063 mm		37.4	17.3
Oleo	Concentrate	-0.063 mm		16.0	14.4
	Total Cleans	3-0 mm		59.0	17.6
	Total Rejects	3-0 mm		41.0	48.6
	Over all	3-0 mm		100.0	30.3

Option No. 1

If it is examined that the ep of spiral is 0.18 and run with size 3-0 at sp. Gr. 1.63 and 1-0.5 at sp. Gr. 1.815 a yield of 16.3 may be achieved at 27.7 ash level which alternatively mixed with the concentrate of flotation and oleo flotation and a final product of 62.5% yield with 16.5% ash may be achieved.

Option No. 2

If it is assumed that ep of spiral is 0.16 and run with the same size as option No. 1 and run at the specific gravity of 1.590 and 1.900 respectively at yield of 16.5 may be achieved at 27.3% ash. The cleans of spiral may be mixed with the concentrate to get a yield of 62.7 with 16.4% ash.

Option No. 3

If it is assumed that ep. of the spiral is 0.14 and it is run to treat the size 3-1 and 1-0.5 mm at sp. Gravity 1.735 and 1.951 respectively that a yield of 17.7% may be achieved and finally mixing the concentrate of flotation and oleo flotation a final clean of 63.9 yield may produce at 17.0% ash level.

Option No. 4

The ep of spiral is kept at 0.18 and the size of 3-1 mm is run at 1-635 and yield of 5-6 at 29.0 ash% may achieved which final mixed with the flotation of 1-0.063 mm concentrate and oleo flotation concentrate to get a final clean product of 59.0% yield at 17.6% ash.

Normally it is observed that the presence of the size fraction of -0.063 mm in the flotation concentrate more that 35% there is a problem of dewatering and choking of filter equipment but in the above alternative options the percentage of -0.063 is utilized as floats by oleo flotation. So a clean of significant amount may be achieved at less than 10% moisture.

IV. Conclusions

The present study indicates that yield and ash content of products are good in respect of quality and quantity. The process adopted i.e., the combination of spiral, flotation and oleo flotation showed good response to dewatering and helped to improve quality by reducing the level of residual moisture content of total cleans which is less than the existing conventional froth flotation and vacuum filtration combination. Considering the good amount of coal fines generated, and lying in the coal preparation plant, this combination of the above process will not only be emerged as complete solution of utilising fines on the same time it may work as a solution to the global environment problem caused by the coal fines.

Operating cost including reagent expenses is comparatively more in oleo flotation process than froth flotation due to higher consumption of reagents doses for effective dewatering of washed coking coals.

It is concluded that the residual moisture content of clean coals can be brought down to permissible limit by the application of above processes i.e. combination of spiral flotation and ole flotation. Since dewatering is much less costly than drying, in the preparation of future inferior coking coals of same size containing higher proportion of fines application of above process is envisaged to minimize dewatering problem.

Acknowledgments

Authors are thankful to the Director, Central Institute of Mining and Fuel Research, Dhanbad for giving permission to publish the paper. The authors are also thankful to all the staff members of the Coal Preparation Division, CIMFR (Digwadih Campus) for their support.

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