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Dense medium cyclone

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ABSTRACT

This paper outlines the importance of dense medium cyclones in coal cleaning along with process optimisation through modelling. Dense medium cyclone was developed by Dutch State Mines in 1940s and since inception it has gained tremendous importance for coal cleaning application around the globe. Indian coal preparation plants largely rely on washing at intermediate size (i.e. -13+0.5 mm) because of drift nature of our coals as well as the ease of material handling at this size. Dense medium cyclones are widely used in Indian washeries due to their ability to handle larger tonnage and ease of operation.

Dense medium cyclone operation is very sensitive to the variation of process and design variables. The author and his co-workers have developed simple empirical models to predict and optimise the performance of dense medium cyclone. The usage of these models developed at the laboratory level to improve the plant performance has been discussed. Such optimisation works undertaken by the author resulted in 3-5% increase in yield of clean coal from dense medium cyclone circuits at the same ash level.

***Key words** : Coal cleaning, Dense medium cyclone, Mathematical modelling*

INTRODUCTION

Dense medium cyclones are the conical dynamic dense medium separators developed by Dutch State Mines in 1940s. These units are mainly used for coal cleaning applications. Geometrically DM cyclones are similar to hydrocyclone and generally use magnetite as a media to separate lights from heavies. DM Cyclone operation is very simple and gained popularity many folds over conventional techniques for treating particularly intermediate size coal i.e. -50 +0.50 mm. Figure 1 shows the superior performance of DMC over Batac Jig treating (-19.0 + 0.5 mm) coal[1]. The merits of DM Cyclones are listed below.

- Residence time of particles inside the unit is very less due the usage of centrifugal force and hence it can handle very large tonnages
- Required cut densities can be achieved easily by manipulating operating and design variables based on feed characteristics or product specifications
- No moving parts and so the wear and tear is less
- Ability to treat wide size range
- Low cost of operation and high capacity per unit floor area

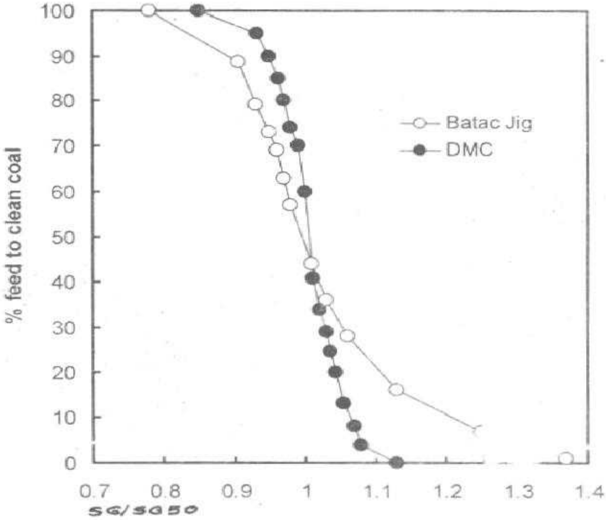


Fig. 1 : Comparison of performance of Batac Jig and DM Cyclone treating -19.0+0.5 mm coal

India is endowed with 194 billion tonnes of coal and ranks sixth position in the world in terms of reserves. Most of the Indian coal seams belong to lower Gondwana period and are inherently contaminated with ash forming minerals throughout the coal matrix. So before using these coals in metallurgical industries, they have to be washed properly. Cleaning the Indian coals requires crushing to reasonable size for liberation of ash forming material and using efficient coal cleaning technologies. Coal washing at intermediate sizes (-13 +0.5 mm) is more economical because of the following reasons:

- Lower capital and operating costs in size reduction
- Dewatering is easy
- Material handling and transportation at this size is very easy
- Lesser environmental problems for tailing disposal

Among the many conventional gravity techniques available, centrifugal dense medium cyclones gained importance for treating intermediate size coal, because of its ability to separate near density material effectively. So, most of the Indian coal washeries incorporated dense medium cyclones in intermediate size coal washing circuits. Presently, 55-60% of the washed coal is produced by dense medium cyclones.

Realising the role of dense medium cyclones in our washeries, author and his co-workers undertook many research projects on DM cyclones during the last two decades. This paper summarise the performance evaluation, modelling and optimisation studies carried out at laboratory level as well as plant level.

DENSE MEDIUM CYCLONE

Design and Separation Mechanism

Figure 2 shows the sectional view of dense medium cyclone. It consists of cylindrical section followed by inverted conical section at the bottom. There is a tangential feed entry near to the upper side of the cylindrical section. At the top of the cylindrical section there is an axial opening called vortex finder, which facilitates passage for clean coal. The vortex finder extends below the feed inlet to avoid short-circuiting of feed material with clean coal. It has another discharge opening for rejects at the bottom called spigot or apex. The angle of the conical portion is usually about 20°.

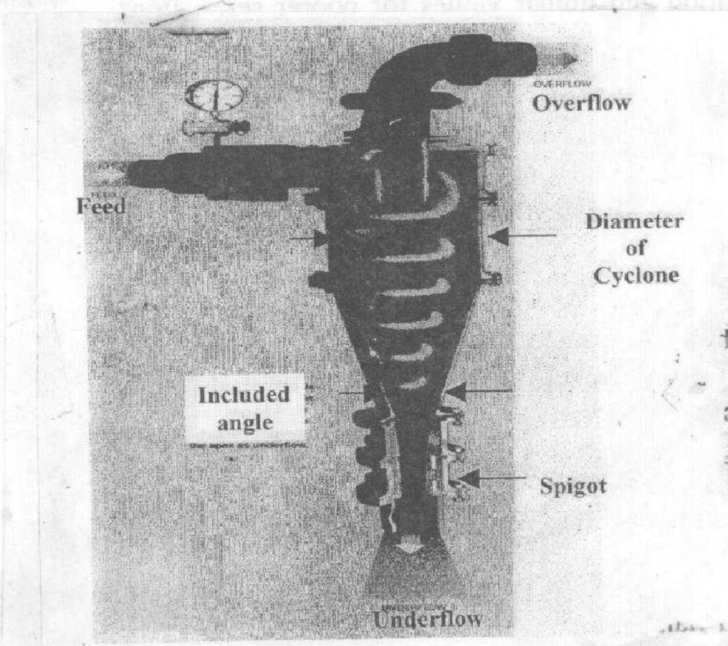


Fig. 2 : Sectional view of dense medium cyclone

Feed coal along with media is introduced tangentially. The centrifugal force imparts swirling motion to the slurry that generates a vortex along the cyclone. The heavies thrown towards the wall of the cyclone and are discharged through the spigot as a rejects. The lighter particles reverse its path and move towards the longitudinal axis of the cyclone and pass through the vortex finder as a clean coal.

Performance Evaluation

Performance of any gravity concentration unit can be evaluated using distribution curves[2]. Distribution curve for each individual test can be obtained by using sink-float data of the overflow and underflow products. Figure 3 shows one such typical distribution curve. It is a plot between average relative density (SG) and percentage of that density fraction reporting to the overflow (clean coal). From this curve the two important performance factors were measured, which are cut density (SG_{50}) and Ecart probable error (E_p). Cut density is the relative density corresponding to 50% of feed material reporting to the overflow. Ecart probable error measures the deviation of actual curve from the ideal curve. It is estimated from the relation given below.

$E_P = (SG_{25} - SG_{75})/2$

Where SG_{25} and SG_{75} are the relative densities corresponding to 25 % and 75 % of feed material reporting to the clean coal. Probable error value will be zero for ideal separation and higher values for poorer separations.

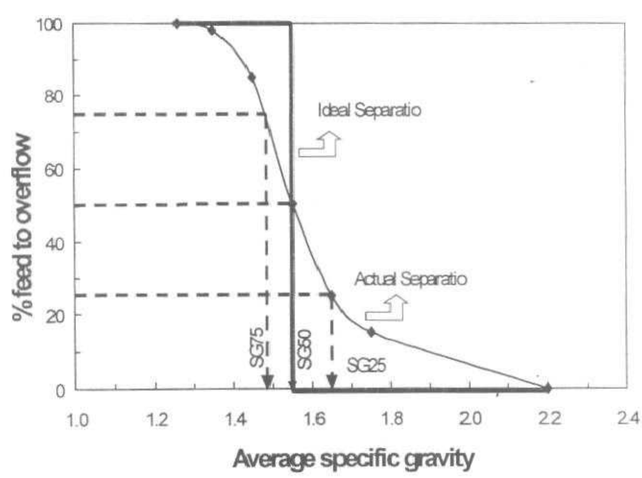


Fig. 3 : Typical distribution curve

LABORATORY STUDIES

Detailed laboratory experiments have been carried out on 76 mm DMC treating -2 + 0.5 mm coal to study the following objectives[3].

- Study the effect of operating and design variables on DMC performance
- Evaluation of DMC performance
- Development of mathematical models to represent the performance of DMC

The results of the modelling studies on laboratory DM cyclone operation is discussed here. Separation characteristics and effects of variables on 76 mm DM cyclone can be found elsewhere[3-5].

To model the DM cyclone process, generalised distribution curve concept is utilised. Generalised distribution is a single curve that represents the performance of any dense medium unit in total. To generate generalised distribution curve, initially distribution curves were drawn for each test carried out at different experimental conditions to determine the distribution points and cut density. Generalised distribution curve for a series of test runs can be obtained by plotting distribution points against (SG/SG_{50})[6]. Using this curve it is possible to generate distribution curve for any given process condition by knowing the value of cut density. Then the distribution curve can be used to calculate the yield and ash content of clean coal.

Based on the above, it may now be noted that for prediction of yield and ash content of clean coal at any conditions, the following things have to be evaluated first.

- Quantification of generalised distribution curve for a particular feed coal
- Correlation between cut density and process variables
- Sink-float data of feed coal

Many equations have been proposed to describe the generalised distribution curve and the following one is the most widely used[6,7].

$$Y = 100 \exp \{-(X-X_0)^a / b\}$$

Where Y - % feed coal to overflow at each relative density.

X- SG/SG_{50}.

a, b and X_0 are constants

The generalised distribution curve obtained for a typical -2 + 0.5 mm coal is shown in Fig. 4, which has been quantified as below.

$$Y = 100 \exp - (X - 0.688)^{2.944} / 0.0469 \quad \text{... (1)}$$

The following equation has been developed to correlate with process variables to estimate cut density at different process conditions.

$$SG_{50} = 0.521\ VFD^{0.514}\ SPD^{-0.441}\ FSG^{0.575}\ MCR^{0.573} \quad \text{... (2)}$$

Where VFD - Vortex finder diameter (mm),

SPD - Spigot diameter (mm),

FSG - Feed medium density and

MCR - Magnetite to coal ratio.

By using sink-float data of feed coal and Eqs. 2 and 3, the yield and ash content of clean coal at other experimental conditions of DMC can be easily predicted.

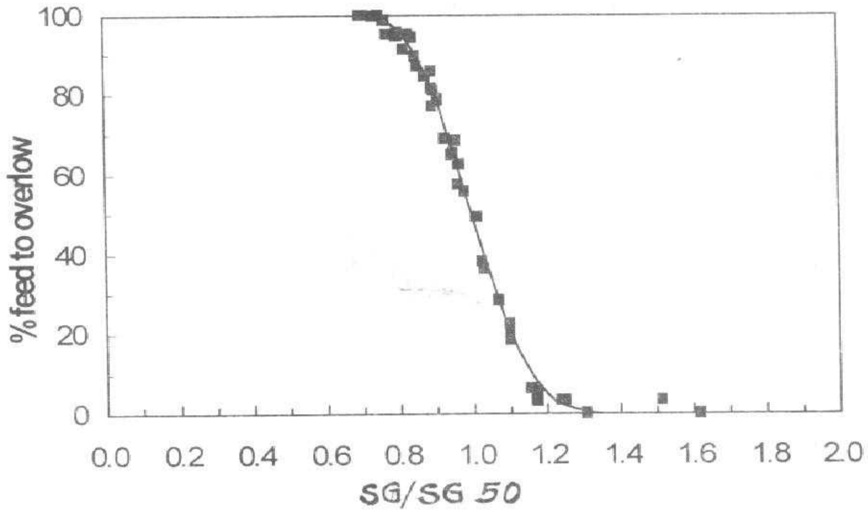


Fig. 4 : Generalised distribution curve obtained for DMC treating -2+0.5mm coal

PLANT STUDIES

Based on the laboratory studies, plant scale investigation was taken up to study the operational characteristics of industrial size dense medium cyclone. Initially plant trials were carried out on 600 mm and 500 mm DM cyclones at TISCO washery[8,9]. Significance of these studies is discussed below under the heading case-I and II. With the success of these trials, process optimisation of DM cyclone circuit at Dugda washery II was undertaken and is discussed under the heading case-III.

Case-1

Tests were carried out in 600 mm DMC treating -13+0.5 mm coal by varying spigot diameter and feed medium density[8]. The selection of variables was based on the exhaustive laboratory work[3-5] and due to the easiness of changing these parameters in an operating plant. The experimental results obtained are presented in Fig 5 in-terms of clean coal yield variations with respect to experimental conditions. These results are in agreement with the laboratory results[3-5]. To evaluate the performance, experimental products were subjected to sink-float analysis. The sink-float data were utilised to analyse misplaced material and distribution curves.

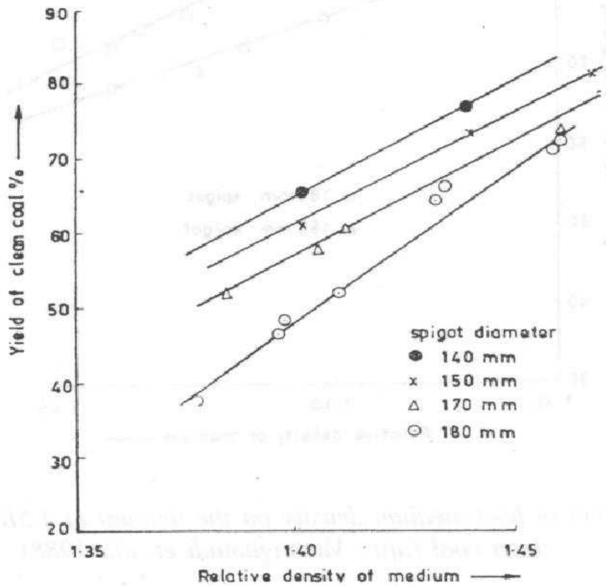


Fig. 5 : Variation of yield of clean coal with feed medium density at different spigot diameters (after Vanangamudi et. al., 1988)

Figure 6 shows the variation of floats of 1.5 relative density (RD) in clean coal with feed medium density for two different spigots i.e. 150 mm and 180 mm. From Figs 5 and 6, it is noted that for the same proportion of heavier fraction in the clean coal, larger spigots accompanied with higher feed medium density would give more yields than smaller spigots operating with lower feed medium densities without increasing clean coal ash content. For example, clean coal with 80% of 1.5RD floats can be obtained with 150 mm and 180 mm spigots at relative densities 1.375 and 1.422 respectively (Fig.6). At these relative densities yield of clean coal will be 55 % and 57 % for 150 mm and 180 mm spigots respectively (Fig. 5). Proper selection of spigot and feed medium density from Figs. 5 and 6 would thus help to achieve higher yield of clean coal without affecting the quality.

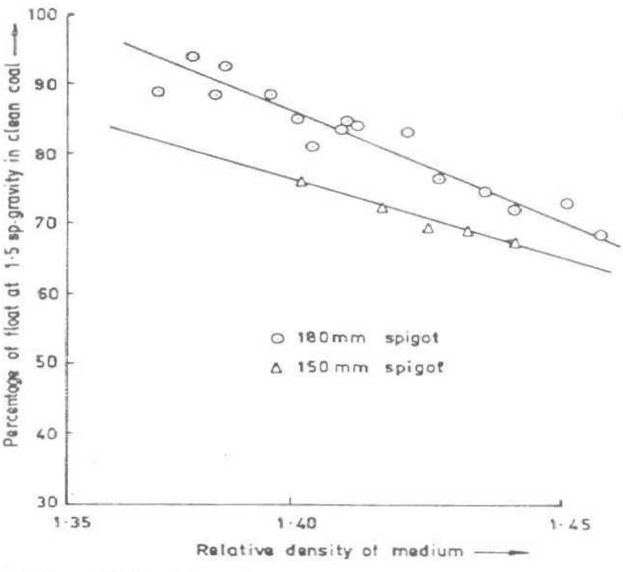


Fig. 6 : Effect of feed medium density on the amount of 1.5RD material in clean coal (after Vanangamudi et. al., 1988)

Generalised distribution curve obtained for a series of tests is shown in Fig. 7. It is noticed from the generalised distribution curve that lesser density fractions are separated more sharply than the higher density fractions because of extended tail of the lower side. Generalised distribution curve is quantified as given below by using Gottfried equation.

$$Y = 100 \exp -(X - 0.808)^{3.456}/0.00481 \quad \ldots (3)$$

Using the above equation along with correlation for cut density it is possible to predict the performance at any given condition. Relation for cut density for 180-mm spigot is derived as follows.

$$SG_{50} = 1.459\ SG_{f} - 0.553 \quad \ldots (4)$$

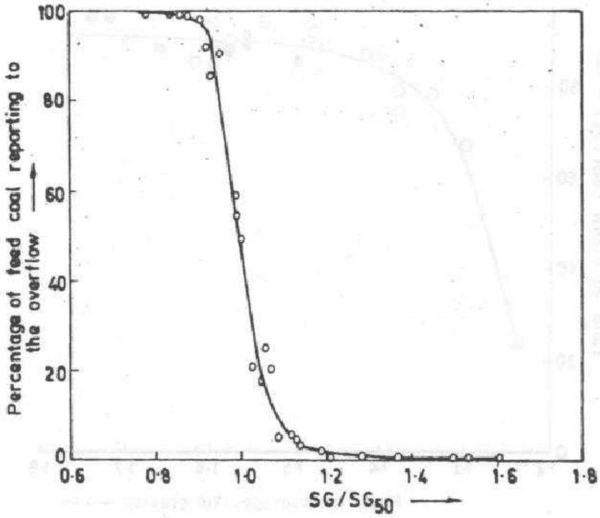


Fig. 7 : Generalised distribution curve obtained for -13+0.5 mm coal in 600 mm DMC (After Vanangamudi et. al., 1988)

Case-II

Investigation was carried out on a 500 mm DMC treating -12+0.5 mm coal[9]. From this study simple method was derived to estimate the required level of feed medium density for a given product specifications. Experimental results are furnished in Figs. 8 and 9, showing the effect of feed medium density on yield and ash content of clean coal. For constant feed characteristics and operating conditions, Figs 8 and 9 may be used to determine the feed medium density to be maintained for required separation level.

The generalised distribution curve obtained for 500 mm DMC treating -12+0.5 mm coal is shown in Fig. 10. Using the experimental data obtained, relations for cut density and probable error were developed as follows.

$$SG_{50} = 1.43\ SG_f - 0.413 \quad \text{... (5)}$$

$$E_p = 0.08\ SG_{50} \quad \text{... (6)}$$

Case-III

The modelling approach has been extended to 600 mm DMC at Dugda II washery for process improvement[10]. In this plant feed coal ash increased from 29.1% to 35% during the period 1977 to 1987 and correspondingly the yield of clean coal dropped from 53% to 45%. About 85% of feed coal was treated in DM cyclones and even a small improvement in clean coal yield would lead to major monetary benefits to the washery.

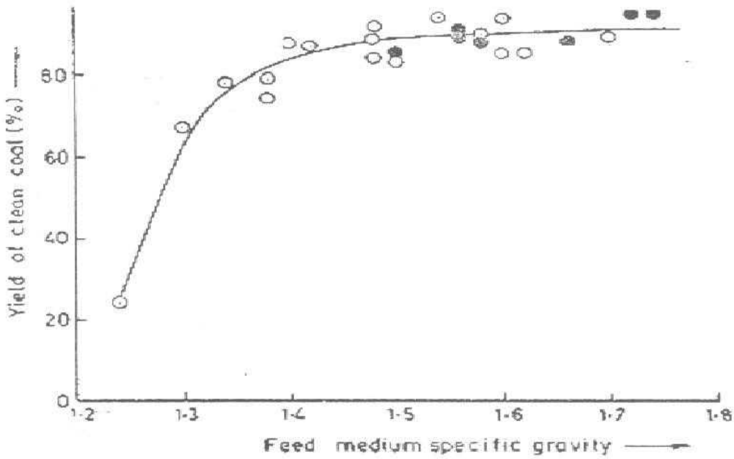
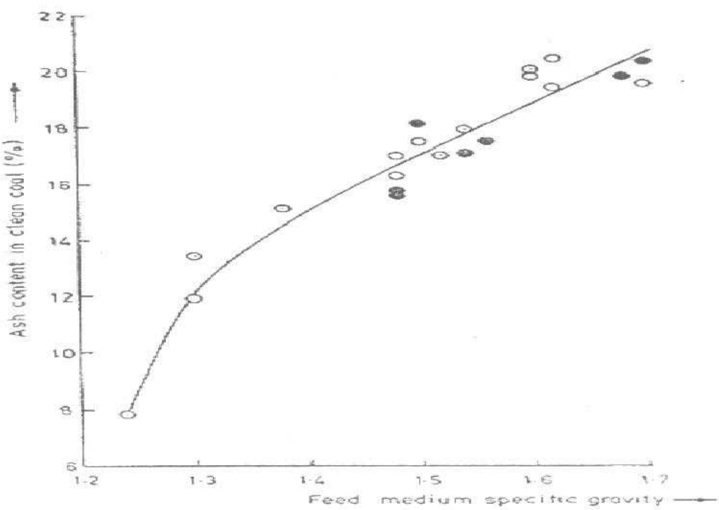


Fig. 8 : Variation of yield of clean coal with feed medium density (after Vanangamudi et. al., 1986)



. 9 : Variation of ash content of clean coal with feed medium densit (after Vanangamudi et. al., 1986)

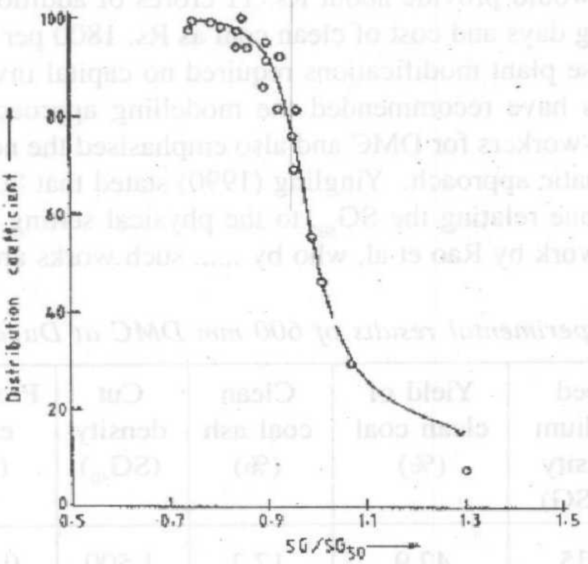


Fig. 10 : Generalised distribution curve obtained for 500 mm DMC treating -12+0.5mm coal (after Vanangamudi et. al., 1986)

Experiments were conducted at three different levels of spigot diameters and feed medium densities and the results obtained are furnished in Table 1. The following equations were developed based on the plant trials.

$$Y = 100 \exp \{ -(X - 0.84)^{3.8735} / 0.001192 \} \quad \dots (7)$$

$$SG_{50} = 1.867\ FSG + 0.004\ SPD - 0.345 \quad \dots (8)$$

$$E_P = 0.0266 + 0.1322\ (SG_{50} - FSG) \quad \dots (9)$$

$$(SG_{50} - FSG) = -0.345 + 0.867\ FSG - 0.004\ SPD \quad \dots (10)$$

To see the variation of probable error with the difference between cut density and feed medium density a plot is drawn and shown in Fig. 11. It may be noted from Fig. 11 that, by keeping the difference (SG_{50}-FSG) minimum it is possible to achieve higher sharpness of separation. So to minimise the difference between cut density and feed medium density, modifications were made in the process variables namely FSG and SPD using Eqs. 8 - 10 are provided in Table 2. Which has resulted in about 3% increase in yield without affecting the clean coal quality. Plant data obtained before and after the modifications are presented in Table 3.

For the dense medium cyclone circuit treating 450 tph, this improvement means additional 200 tonnes of clean coal during normal 16 hours of every day operation which would provide about Rs. 11 crores of additional revenue every year (300 working days and cost of clean coal as Rs. 1800 per ton). It may also be noted that these plant modifications required no capital investment. International researchers have recommended the modelling approach adopted by the author and his co-workers for DMC and also emphasised the need for more work using such pragmatic approach. Yingling (1990) stated that "Unfortunately little work has been done relating the SG_{50}, to the physical setting of the vessel. An exception is the work by Rao et al, who by ...... such works are more desirable".

Table 1 : Experimental results of 600 mm DMC at Dugda washery II

Spigot mm	Feed medium density (FSG)	Yield of clean coal (%)	Clean coal ash (%)	Cut density (SG_{50})	Probable error (E_p)	(SG_{50}-FSG)
150	1.35	42.9	17.2	1.500	0.035	0.150
150	1.40	70.3	22.9	1.655	0.050	0.255
150	1.45	79.4	24.8	1.750	0.070	0.300
170	1.35	30.6	15.1	1.440	0.043	0.090
170	1.40	57.0	19.8	1.578	0.055	0.178
170	1.45	60.8	22.4	1.645	0.060	0.195
180	1.35	16.5	13.1	1.400	0.023	0.050
180	1.40	30.4	18.7	1.470	0.040	0.070
180	1.45	40.2	20.1	1.545	0.043	0.095

Table 2 : Modifications made in dense medium cyclone operation

Variable	Before Modification	After Modification
Spigot diameter (mm)	150	180
Feed medium density	1.353	1.420
Cut density (SG_{50})	1.550	1.550
Probable error (E_p)	0.053	0.043
Yield (%)	47.2	49.7
Ash (%)	20.6	20.9

Table 3 : Improvement achieved in plant performance after DMC process optimisation

Month and Year	Feed ash (%)	Yield (%)	Clean coal ash
Dec 1987	35.1	47.2	20.6
Jan 1988	Modifications were made		
Feb 1988	35.7	49.7	20.9
Mar 1988	35.5	50.2	20.7
Apr 1988	35.7	50.0	21.0
May 1988	35.2	50.7	20.7
June 1988	35.5	49.8	20.9
July 1988	35.3	49.1	20.6
Aug 1988	35.4	51.2	20.7
Sep 1988	35.3	50.5	20.6
Oct 1988	35.2	51.9	20.2
Nov 1988	35.0	52.3	20.4
Dec 1988	35.0	51.8	20.3
Jan 1989	34.9	50.1	20.3

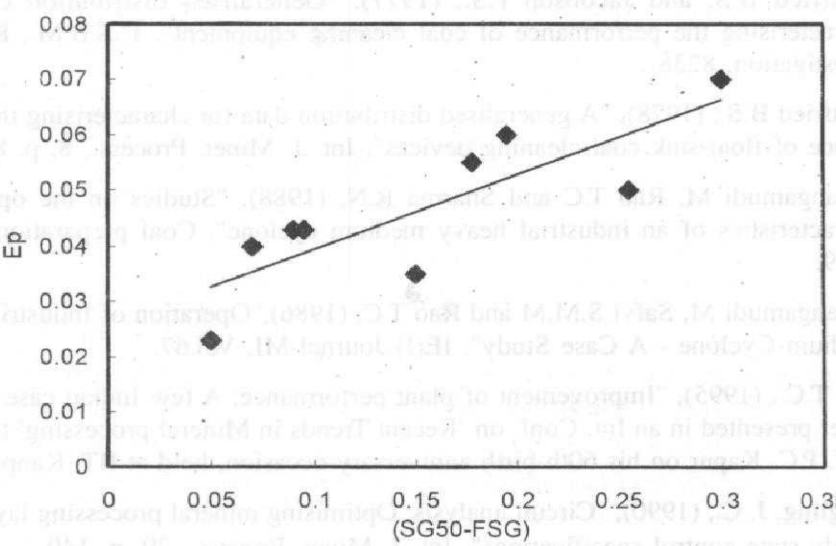


Fig. 11 : Relationship between Ep and (SG_{50}-FSG)

CONCLUSION

Dense medium cyclones are playing vital role in Indian coal preparation plants and optimising the performance of DM cyclone is imperative for the washeries. DM cyclone operation can be tuned to achieve optimum results by manipulating operating and design variables. Systematic investigation in the operating plants and use of suitable mathematical models can significantly improve the performance of the dense medium cyclones.

REFERENCES

1. Killmeyer, R. P., Jr., (1979), "A performance study of Baum and Batac Jigs", American Mining Congr. Coal Convention, St. Louis, Missouri, May.
2. Tromp K F., (1937), "Neue Wege fur Beurteilung der Aufbereitung von Steinkohlen" (New methods of computing the washability of coals), Gluckauf 37, February 6 and 13, 125-131, 151-156. Experts in Colliery Guardian 154 , May 21, 28, 1937, 955-959, 1009.
3. Rao T.C., Vanangamudi M. and Sufian S.A., (1986), '"Modelling of Dense Medium Cyclones Treating Coal", Int. J of Min. Process., 17, p. 287.
4. Vanagamudi M, et.al., (1985), "Effects of some variables on separation characteristics heavy medium cyclone for coal", J Inst. Engrs (India), V65, MI2, p. 69.
5. Verghese P.A and Rao T.C, (1994), "Characteristics of 76 mm diameter dense medium cyclone", Coal Preparation, Vol. 15, p. 71.
6. Gottfried B.S. and Jacobson P.S., (1977), "Generalised distribution curve for characterising the performance of coal cleaning equipment". U.S.B.M., Report of investigation, 8238.
7. Gottfried B.S., (1978), "A generalised distribution data for characterising the performance of float-sink coal cleaning devices", Int. J. Miner. Process., 8, p. 89.
8. Vanangamudi M, Rao T.C and Sharma R.N, (1988), "Studies on the operational characteristics of an industrial heavy medium cyclone", Coal preparation, Vol. 6, p. 79.
9. Vanangamudi M, Safvi S.M.M and Rao T.C, (1986),"Operation of Industrial Heavy Medium Cyclone - A Case Study", IE(I) Journal-MI, Vol.67.
10. Rao T.C., (1995), "Improvement of plant performance: A few Indian case studies", paper presented in an Int. Conf. on 'Recent Trends in Mineral processing' to honour Prof. P.C. Kapur on his 60th birth anniversary occasion, held at IIT, Kanpur, India.
11. Yingling, J. C., (1990), "Circuit analysis: Optimising mineral processing layouts and steady state control specifications", Int. J. Miner. Process., 29, p. 149.