EFFECT OF COAL SIZE AND PROCESS VARIABLES ON COAL CLEANING EFFICIENCY IN AN AIR DENSE MEDIUM FLUIDIZED BED

THIS PROJECT REPORT IS SUBMITTED IN THE PARTIAL FULLFILLMENT OF THE REQUIREMNT FOR THE DEGREE OF BACHELOR OF TECHNOLOGY

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BY

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CERTIFICATE

This is to certify that the project report entitle" **EFFECT OF COAL SIZE AND PROCESS VARIABLES ON COAL CLEANING EFFICIENCY IN AN AIR DENSE MEDIUM FLUIDIZED BED**" submitted by **KIRAN CHANDRA NAYAK (ROLL NO: 108CH049)** in the partial fulfilment of the requirement for the degree of the B.Tech in Chemical Engineering, National Institute Of Technology, Rourkela is an authentic work carried out by him under my super vision. To the best of my knowledge the matter embodied in the report has not been submitted to any other university/institute for any degree.

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ABSTRACT

The quality of India coal is poor because of high ash content. Some improvement in its quality can be brought using different coal cleaning methods. Wet cleaning methods like Heavy media separator and jigging are extensively in use but they have some limitations like they produce large amount of coal slurry which is difficult to dispose and they degrade friable coal. To overcome these limitation dry cleaning method can be employed and air dense medium fluidized bed is one of the most economic and efficient method. The separation in the fluidized bed greatly depends on the process variables of the gas solid two phase flow. In this project the effect of coal size and process variables on the coal cleaning efficiency is studied using Basundhara coal and magnetite as bed material. The coal cleaning experiments were carried out on three size fraction of coal i.e. -12+10mm,-10+5mm and -4.75+1mm.The efficiency were expressed in terms of percentage enrichment, percentage ash rejection, percentage combustible recovery and separation efficiency. The maximum separation efficiency of 10.5% is achieved for -10+5mm size fraction. It was observed that batch should operate at a flow rate of 50-60lpm and between coal to magnetite weight ratio of 0.2 to 0.3 for maximum separation.

Keywords: Dry cleaning, Air dense medium fluidized bed, Percentage enrichment, Percentage ash rejection, Percentage combustible recovery.

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NOMENCLATURE

F_{gr}	Gravity force (kgm/$s^{2)}$
F_b	Force due to hydrostatic pressure distribution (kgm/s^2)
F_g	Forces contributed by the relative motion between the coal particle and gas (kgm/s^2)
F_d	Forces contributed by the relative motion coal particle and fluidized particle (kgm/s^2)
F_r	Resultant force (kgm/s^2)
d_c	Equivalent diameter of the coal particle(m)
ρ_c	Density of the coal particle(kg/m^3)
ρ_b	Bulk density of the fluidized bed(kg/m^3)
g	Acceleration due to gravity(m/s^2)
C_d	Drag coefficient
u_r	Relative velocity between coal particle and fluidized particles(m/s)
u_t	Terminal velocity(m/s)
Y_c	Clean coal yield (%)
A_c	Ash contents of clean coal (%)
A_f	Ash contents of feed coal (%)
ε	Bed Voidage
ΔP	Pressure difference two point
P1	Pressure at point 1
P2	Pressure at point 2
E	Enrichment (%)
W_p	Weight of Product (g)
A_r	Ash content of reject (%)

CHAPTER-1

INTRODUCTION

The International energy agency predicts that world energy demand will grow approximately 60percent over the next thirty years[1],most of it in developing country like India and China. India ranked third in the world in consumption of coal and its demand for coal continuous to grow much faster than the world average. It is estimated that India's recoverable coal reserve is 101.9 billion tonnes which is 10percent of total world reserve. Coal and lignite meet about 50% of India's commercial energy requirement. More than 75percent of the coal and lignite are consumed by countries power sector and rest are consumed in cement, steel, fertilizer and many other industries [2].

Although India has significant quantities of coal, the quality of coal is poor and often contains 30-50% impurities in the form of ash forming minerals like silica, alumina, iron oxide, lime and pyritic sulphur. Recently, the strict restriction from the Ministry of Environment and Forest, govt. of India on the emissions of harmful sulphur containing gases and ash into the atmosphere have increased the need of impurity free coal. The generic term used for removal of impurity from coal thereby increasing the efficiency of their utilization is called coal cleaning or coal washing [3].

The impurities or mineral matter in coal can be divided into two groups; they are inherent and extraneous mineral matter. The inherent mineral matters which associate with the coal during its early formation stage cannot be removed from coal using mechanical method. Chemical method like acid leeching can be used for this purpose. The content of mineral matter is very small, between 0.1-3percent.The extraneous mineral matter which is due to dirt bands and rock particles which get mixed with coal during mining can be removed by mechanical methods [4].

The cleaned coal is more uniform in size, composition, calorific value and moisture content. When it is consumed, it results in more reliable and uniform operation. Cleaning contributes to reduced slagging and fouling in the furnace, thus increasing boiler on stream availability, decreasing maintenances and lowering overall operating costs. It also reduces sulphur's oxide emissions after combustion and thus, decreases flue gas desulphurization requirement, which may translate into reduces production costs. Removal of the associated mineral matter and sulphur from ROM coal results in lower transportation costs. The other advantages of beneficiation are it creates value for the product and increases usable energy resources base by cleaning high ash high sulphur coal which could not be otherwise used[5].

Currently, the cleaning of majority of run of mine (ROM) coal is conducted by wet methods like heavy media separator, jigging and chemical floatation. These techniques use water as a separation medium. But, there are certain inherent advantages of dry cleaning methods that would give it the competitive market. The advantages are [6]

- A dry product is formed resulting in a higher calorific value per ton.
- Availability of air as a separating medium is abundant and offers no difficulties. Whereas in many collieries the supply of water is not abundant and the disposal of spent water is also difficult.
- Dry process can be applied in areas where water supplies are limited relative to the demand or expensive to obtain or of low quality.
- In cold areas such as Europe, Russia, and certain part of North America and China, where the winters are cold and there are many severe handling problems with wet methods because the coal will tend to solidify into frozen mass. In these areas dry process can be taken into consideration for coal cleaning.
- The wet processing often is not the appropriate method because of the inefficiencies due to
    - Chemical breakdown of contained material.

- Physical degradation of coal leading to excessive fines, commonly with friable materials and when clays are present.
- Handling problems, environmental hazards, excessive water consumption and losses.
- High costs for chemicals used in froth flotation.

Water demand, pollution and cold climate have opened up scope of research in the development of dry cleaning process.

There are different types of dry cleaning processes for coal beneficiation. Hand picking of gangue minerals or shale in coarse size is one of the simplest, oldest and labour intensive techniques of dry cleaning processes. The other dry cleaning techniques are mechanical methods (Air tables, Pardee spiral separator, Air jig, and Air dense medium fluidized bed separator), berrisford separator, magnetic separator, electrostatic separator, etc. These processes depend on the differences in physical properties between coal and gangue minerals such as density, size, shape, resiliency, magnetic conductivity, electric conductivity etc. These methods have both advantages and disadvantages. Air dense medium fluidized bed separation is one of the dry beneficiation processes that would offer benefits compared to other dry beneficiation processes .The results of economic evaluation for different processes is given in Table-2. The factor used to assess the main processes under consideration is the cost per heat unit delivered to the power station. This factor takes into account the benefit of reduced transport costs due to lower moisture product.

Table: 1Cost comparison of dry beneficiation process [7]

Process	Product quality, Kcal/kg	Yield, %	Process operating costs, $/t	Cost delivered to power station, $/Kcal
Rare earth magnetic separator	6281.5	68.4	1.55	2.16
Air dense medium fluidized bed separator	6281.5	80.6	1.91	1.91 (minimum)
Electrostatic separator at mines	6639.75	59.9	5.01	2.65
Electro static separator at power station	6639.75	59.9	1.42	2.51
Air table	6281.5	71.4	1.78	2.12
Conventional methods	5947.11	84.2	1.79	1.94

CHAPTER-2

LITERATURE REVIEW

2.1. HISTORY AND DEVELOPMENT

Major efforts have been made in China for developing high efficiency dry coal beneficiation methods. The first commercial dry coal beneficiation plant in the world with air dense medium fluidization bed technology has been set up by the China University of Mining and Technology(CMUT) for beneficiation of −50 + 6mm size coal at the Qitaihe Coal Co. The process was established in June 1994 with a capacity of 50 tph. It was claimed that the construction and operational costs were less than half of those of a wet cleaning plant with no environment pollution of coal slime [8].

Luo et al. [9] studied the mechanism and separation efficiency of coal particles in air dense medium fluidized bed separator (ADMFBS) according to bed density and density distribution in the fluidized bed. Magnetite of a specific size composition (mean size of 210micrometer) was used as a medium to provide homogeneity of the bed density. The dimension of the ADMFBS apparatus was 150mm × 200mm. The size of the ROM coal feed was −50 + 6mm with an ash content of 21.48%. The experimental results showed that the ADMFBS provided a good separation performance for the coal of −50 + 6mm size with a clean coal ash content of 11.80% and a refuse ash content of 85.75% with an *Ep* value of 0.03.

R.A Sahan in the year1997 Lehigh university of Pennsylvania, USA studied the effect of various operating parameter (Bed height, Coal to magnetite weight ratio, Superficial velocity, Time) on the performance of ADMFB separator taking Rushton coal of very small size (44micrometer-297micrometer) as feed material and angular magnetite of size range 212 micrometre-57 micro meter as bed material in a fluidized bed of dimension 15.2×22.9 cm. It was found that the optimum operating parameter required for separation is different for different feed size range [10].For -297+250 micro meter size feed maximum ash removal of

65-72% occurred at superficial velocity in the range of 2-2.75 times of minimum fluidization velocity and coal to magnetite ratio 1.6.

C.Mak and colleagues in the Department of Chemical and Materials Engineering, University of Alberta, Edmonton, AB, Canada studied potential of ADMFB on sulphur rejection in sub bituminous coal of size range -22.6+1 mm using magnetite as bed material of size range -600+75micrommeter in a fluidized bed of dimension 20×40 cm. It was seen that the optimal separation of the coal particles in the -22.6+5.66mm size fraction was achieved at a superficial fluidization air velocity of 60mm/s. By operating at this optimal fluidization air velocity, an ash-forming mineral matter reduction from 19% to 10% was achieved with a yield of 80%.This level of ash reduction was equivalent to an ash rejection of 58% and a combustible recovery of 89%. A significant decrease in separation efficiency is seen for coal particles in the -3.36+1.00mm size fraction. Interestingly, however, the optimum separation was also achieved at a fluidization air velocity of 60mm/s. By operating at this optimal fluidization air velocity, an ash reduction from 23% to 16% was achieved with an 80% yield, corresponding to a slightly lower ash rejection of 44% at a combustible recovery of 87% [11].Good separation of finer coal i.e. -6+1mm was also achieved by C.Mak using a ADMFB of dimension 4cm with Ep value 0.03 but the efficiency of separation decreased for coal size below 1mm because of back mixing [12].

In India in the year 2003 at Institute of Minerals and Material Testing lab, (CSIR) Bhubaneswar an air dense medium fluidized bed was designed and tested for coal in the size range of -25+6mm.The capacity of the unit was 600k/hr. At optimum condition the ash percent in the feed decreased from 40% to 34% with 70% yield of product [13].

Recently, Prof. B. C. Meikap and others at IIT Kharagpur has studied the effect of feed coal size on the efficiency of ADMFBS using four different coal samples of different washability data of size range -50+6mm in a bed of dimension 15×100cm.It was concluded that the separation efficiency is maximum for size range -50+25mm with ash rejection of maximum 63% and minimum for size range of -13+4.75mm with ash rejection 21% [14].The decrease in efficiency of ADMFBS is because of back mixing of bed material in the bed.

2.2. AIR DENSE MEDIUM FLUIDIZED BED SEPARATOR (ADMFBS)

The air dense medium separation uses a dense fluidized medium of air and fine magnetite particles for beneficiation of coal. By means of a two phase gas and solid a pseudo-fluid separating medium is created, the light and heavy particles stratify in the fluidized bed according to their individual densities. The bed density is more or less same throughout fluidizing region. As the bed density of medium is presumed to be equal to the separating density and the distribution of pressure in fluidized bed is the same as in the static fluid, the motion of particles in the bed has been considered to explain the mechanism of the beneficiation process.

2.3. MECHANISM OF SEPARATION IN AN AIR DENSE MEDIUM FLUIDIZED BED SEPARATOR

In dry air dense medium fluidized bed separator, a medium is created by suspending solid particles in an upward direction of air flow. This acts in the same way as hydraulic dense medium separator, allowing clean coal to float to the surface of the medium and rejects to sink. By means of a two phase gas-solid pseudo-fluid separating medium, the light and heavy particles stratify in the fluidized bed according to their individual densities. The bed density is more or less same throughout fluidizing region. As the bed density of medium is presumed to be equal to the separating density and the distribution of pressure in fluidized bed is the same as in the static fluid, the motion of particles in the bed has been considered to explain the mechanism of the beneficiation process.

The average density of the bed ρb is given by

$$\rho b \;= (1-\varepsilon)\rho s - \varepsilon\rho a \;= \frac{W}{Lag} \qquad (2.1)$$

To explain the separation mechanism, Archimedes' principle can be applied. However, practically, due to the misplacement of near gravity materials, Archimedes' principle cannot explain the experimental results well. Thus, the separation mechanism can be understood by considering different forces acting on the coal particles.

The various forces acting on a coal particle, immersed in a fluidized bed, are the gravity force (F_{gr}), the effective buoyancy force due to hydrostatic pressure distribution (F_b), and drag forces contributed by the relative motion between the coal particle and gas (F_g) and between the coal particle and fluidized particles (F_d). The drag forces contributed by the relative motion between the coal particle and gas can be neglected. Therefore, the resultant force (F_r) acting on the coal particle can be expressed as follows:

$$Fr \;= Fgr - Fb - Fd \qquad (2.2)$$

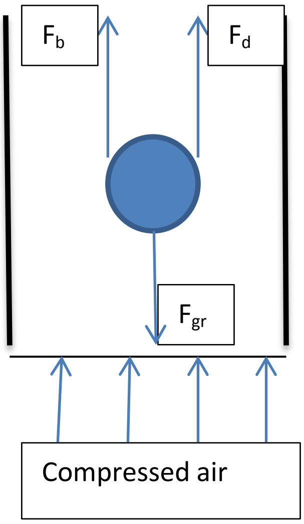

Figure: 1 Forces exerted on the coal particle in the bed.

However, these forces can be defined as:

$$Fr = \left(\frac{\pi}{6}\right) dc3\rho ca \qquad (2.3)$$

$$\mathrm{Fgr} = \left(\frac{\pi}{6}\right) \mathrm{dc3\rho cg} \qquad (2.4)$$

$$Fb = \left(\frac{\pi}{6}\right) dc3\rho bg \qquad (2.5)$$

$$\mathrm{Fd} = \mathrm{Cd}\left(\frac{\pi}{4}\right) \mathrm{dc2}\left(\rho\mathrm{b}\frac{\mathrm{ur2}}{2}\right) \qquad (2.6)$$

where d_c is the equivalent diameter of the coal particle, ρ_c and ρ_b are the density of the coal particle and bulk density of the fluidized bed respectively, a is the acceleration of the coal particle, g is the gravitational acceleration, C_d is the drag coefficient, and u_r is the relative velocity between coal particle and fluidized particles. By substituting the forces from eq 4 to eq 7 into eq 2 and on simplification gives.

$$a = \left(1 - \frac{\rho b}{\rho c}\right) g + \left(\frac{3Cd\rho bur2}{4\rho cdc}\right) \quad (2.7)$$

For gravity settling in a fluidized bed, the terminal velocity (u_t) of the coal particle can be expressed as

$$ut = \sqrt{\left(\frac{4g(\rho c - \rho b)dc}{3Cd\rho b}\right)} \qquad (2.8)$$

Equation (2.7) and (2.8) yields

$$a = \left(1 - \frac{\rho b}{\rho c}\right) \qquad \text{When } u_r=0 \qquad (2.9)$$

$$a = -\frac{3Cdur2}{4dc} \qquad \text{When } \rho_c=\rho_b \qquad (2.10)$$

$$a = \left(a - \frac{\rho b}{\rho c}\right)\left(1 - \frac{ur2}{ut2}\right) g \qquad \text{When } u_r(\rho_c\text{-}\rho_b) > 0 \qquad (2.11)$$

$$a = \left(1 - \frac{\rho b}{\rho c}\right)\left(1 + \frac{ur2}{ut2}\right) g \qquad \text{When } u_r(\rho_c\text{-}\rho_b) < 0 \qquad (2.12)$$

Equation 2.9 to2.12 indicates the necessary conditions for perfect separation.

- When u_r is equal to zero, the coal particles can be separated perfectly according to the bed density, whereas when the bed density and the density of coal particle are equal, the position of the coal particle inside the bed depends on the relative velocity between the coal particle and medium solids.
- The drag force has a negative contribution for the heavier coal particles that settle to the bottom and has a positive contribution for the lighter coal particles that float toward the top surface of the bed. Hence, for better separation, the drag force that depends on gas velocity should be at an optimum level.
- At too low gas velocity, the misplacement of the low density coal particles is more than the high density coal particles, whereas at too high gas velocity, the misplacement of high density coal particles is more than the low density coal particles.
- Similarly, as the size of coal particle decreases, the specific surface increases and the terminal velocity decreases, resulting in the increase of ratio of drag to gravity force exerted on the coal particle and thus enhancing the misplacing effect.

CHAPTER-3

MATERIAL AND UTILITIES

3.1 MATERIALS

- The coal used for the experimental work was collected from Basundhara open cast project (Seam-3).
- The magnetite powder was collected from IMMT Bhubaneswar.

Table 2: Magnetite Particle Characteristics

Particle Properties	**Observation**
Particle size range	0-45 µm
Arithmetic mean diameter	25.61 µm
Iron (Fe) content	69.25%
Silica(SiO_2) content	0.75%
Alumina(Al_2O_3)	0.5%
True Density	4.8 g/c.m^3

3.2 UTILITIES

- The filter cloth used as air distributor was of the type PL 2511.
- Compressor connected through dryer.
- Rotameter air (0-200) lpm range.
- Manometer (CCl_4).
- Vacuum pump.

CHAPTER-4

EXPERIMENTAL METHODS

4.1 SAMPLE PREPARATION:

At first the collected lumpy coal was subjected to jaw crusher. For proximate analysis some amount of coal was kept aside crushed manually and subjected to sieve analysis using 72B.S.S sieve screen and the rest of the coal was subjected to sieve analysis to obtain coal of desired size range.

4.2 PROXIMATE ANALYSIS:

Proximate analysis was done for finding out the moisture content, volatile matter content and fixed carbon content of the coal sample.

Determination of Moisture Content:

Approximate 1 g fine coal was taken in a weighed porcelain crucible and was placed in a hot air oven at temperature100 – 105 degree C for 1 hour. Then the loss in weight of the coal was measured to finding out the moisture content.

$$\%\, Moisture\ in\ coal = \frac{Loss\ in\ weight\ of\ coal}{Weight\ of\ coal\ initially\ taken} \text{x } 100 \tag{4.1}$$

Determination of Volatile Matter in Coal:

This was determined by measuring the loss in the weight of moisture free coal by heating it in a muffle furnace at 950 degree C for exactly 7 minutes in the absence of air.

$$\%\, Volatile\ matter\ in\ coal = \frac{Loss\ in\ weight\ of\ moisture\ free\ coal}{Weight\ of\ moisture\ free\ coal} \text{x } 100 \tag{4.2}$$

Determination of Ash in Coal:

This was determined by measuring the weight of residue left in a crucible after burning approximate 1 g weighed quantity coal in an open crucible (i.e. in the presence of air) at 750 degree C in a muffle furnace for duration of 90 minutes.

$$\% \, Ash\ in\ coal = \frac{Weight\ of\ residue\ ash\ formed}{Weight\ of\ coal\ initially\ taken} \text{x } 100 \qquad (4.3)$$

Determination of Fixed Carbon:

It was mathematically calculated and was determined indirectly by deducting the sum of total of moisture, volatile matter and ash percentage from 100.

$$\% \, Fixed\ carbon\ in\ coal$$
$$= 100 - (moisture\ \% + volatile\ matter\ \% + ash\ \%) \qquad (4.4)$$

The proximate analysis was carried out for 3 specimens from the same sample to check the correctness and to ensure uniform result throughout. It was reported in tabulated manner and average value of Ash percentage and Fixed Carbon percentage were reported.

4.3 WASHABILITY STUDIES:

Cleaning or washing process generally depends upon the differences in density between coal particles and its impurities. The extent of removal of free dirt or the amenability of a coal to improvement in quality is more commonly known as the ‘Washability’ of coal and is usually carried out by Float and Sink test. This Washability study helps us in design of washeries and coal processing plants, in techno-economic evaluation and day-to-day plant control .

4.3.1 Float and Sink Test:

The crushed coal sample was sieved and size fraction of -2 mm + 1 mm was obtained. The organic liquids used in this method were Carbon Tetrachloride (sp. Gravity 1.595, Benzene (sp. Gravity 0.878) and Bromoform (sp. Gravity 2.889). By inter-mixing these liquids, liquids of specific gravities 1.3, 1.4, 1.5, 1.6, 1.7, 1.8 were prepared. Due to limited availability of organic liquids, the test was carried out in small scale in 250 mL beakers. The beakers were arranged in the increasing order of their specific gravity. The specific gravity was measured using Hydrometer; when any deviation was found w.r.t. the desired specific gravity, further organic liquids were added to achieve correct specific gravity.

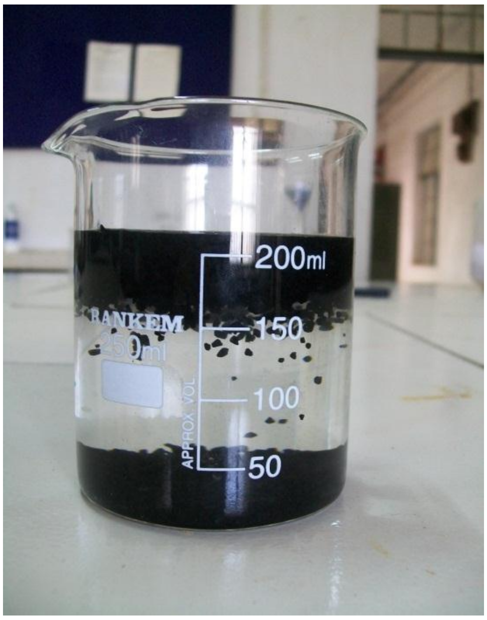

Figure 2: Float and Sink Test

50 g sample was first placed in the lowest specific gravity fluid i.e. 1.30. The fraction lighter than the liquid did float and the heavier fractions did sink. The sink was then dried and placed in the next heavier liquid and as earlier, the float and sink fractions were separated, and the sink was again put into next higher density liquid, it was carried out up to the 1.80 fraction. In

this way the fractions from different densities were collected, dried and weighed. The ash analysis of all coal was done and reported.

4.3.2 Washability Curve:

With detailed calculations for total float-ash %, total sink-ash % and cumulative yield up to middle fractions w.r.t. yield %, washability curves were drawn and reported.

4.4 EXPERIMENTS FOR FINDING OUT THE EFFECT OF PARAMETERS

4.4.1Equipment:

A schematic representation of the experimental setup is used in this study is shown in Figure 3. It consists of three main parts: the air supply, fluidized bed and an arrangement for collecting cleaned coal from the top. Air from the surge tank of a compressor is supplied to the equipment. Air flow rates are measured with rotameter (0-200lpm) and their flow rates are controlled by valves. The fluidizing vessel is a Perspex vertical cylindrical column having 10 cm inside diameter and 120 cm height.PL2511 filter cloth was used as air distributor. A manometer one end open to atmosphere and another end connected to the bottom of column is used to measure the pressure drop across the bed.

The cleaned coal is collected in a vacuum pump arrangement as shown in the Figure.4.The arrangement consists of a side tapping conical flask of capacity 250ml whose one tap is connected to the vacuum pump through rubber tube for creating vacuum inside the conical flask and other end connected to a tube for collecting material from the column.

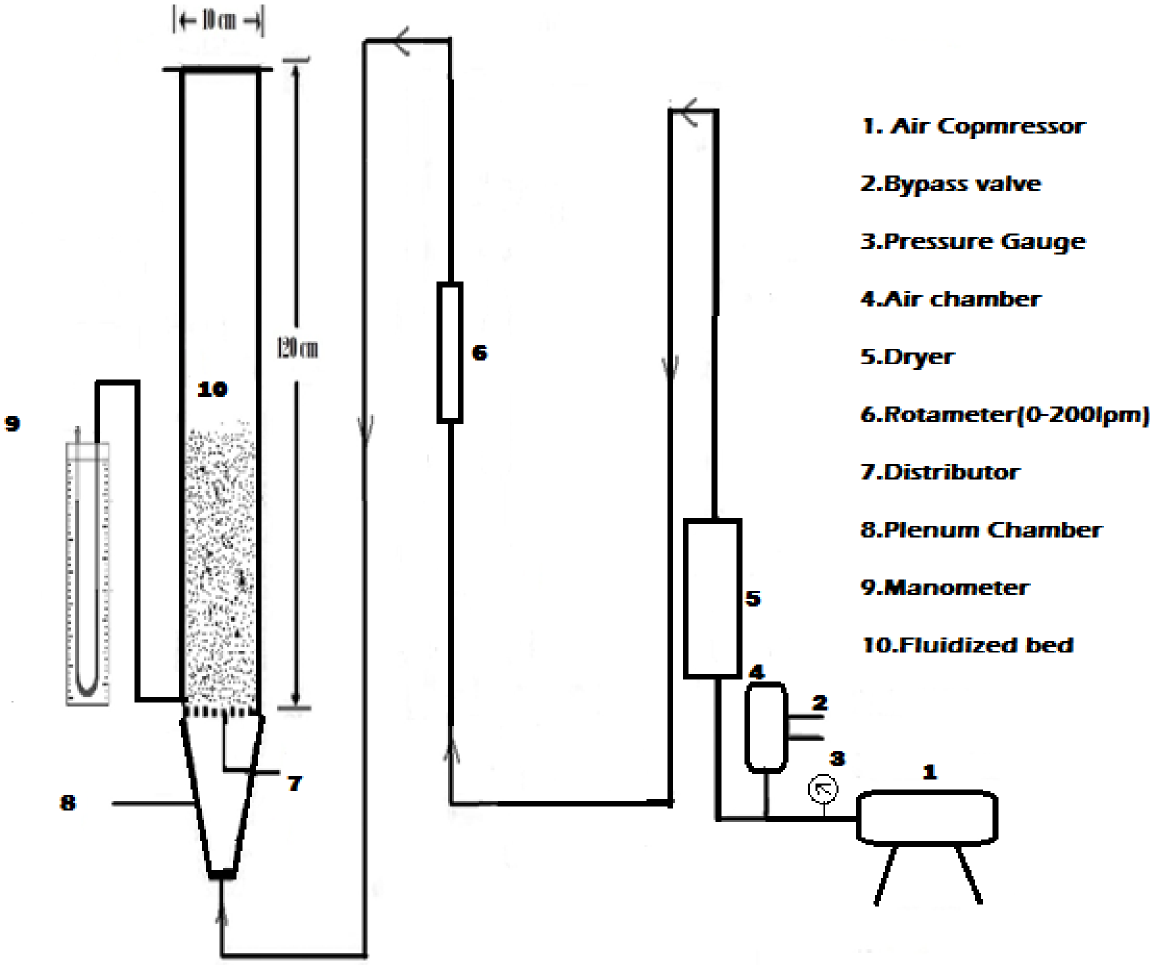

Figure.3: Schematic diagram of experimental set up

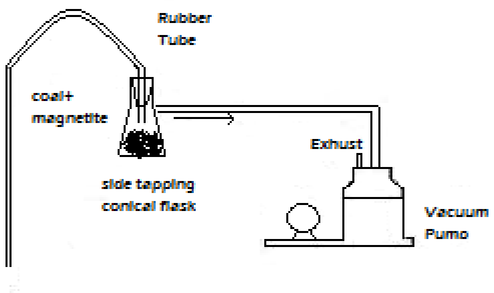

Figure.4: Vacuum pump arrangement for collecting cleaned coal from the bed.

Figure.6: Photograph of side tapped conical flask

Figure.5: Photograph of Experimental setup

4.4.2 Procedure

First experiment was conducted for finding out the bed expansion and density variation at different air flow rate taking different amount of magnetite. The magnetite particles of certain quantity were loaded on the distributor of the column. Dry compressed air at 1.5-2 kg/cm^2 gauge pressure was supplied to the column. Pressure was maintained by controlling the bypass valve. Then the air flow rate was increased gradually and the bed height was noted.

For finding out the effect of flow rate and coal to magnetite weight ratio on coal cleaning efficiency magnetite particle of 500g weight is first loaded on the distributor. Then the compressor was turned on and a gauge pressure of 1.5-2 kg/cm^2 was maintained by controlling the bypass valve. Then the air flow rate was maintained at a constant value and the bed was allowed to steady for some time. After the bed got stabilize coal particle of certain amount depending on the ratio was slowly introduced from the top of the column onto the surface of stable fluidized bed. After the coal particle segregated in the bed for 30s the air supply was suddenly shutdown such that all the segregated coal particle retains their original position in the bed. Then the coal and magnetite mixture from the bed was collected in two fractions as product and reject. The product was collected using vacuum pump arrangement upto half of the height of the defluidized bed and the rest half present on the distributor was collected as reject. The mixture of coal and magnetite was separated by sieving. Care was taken to ensure complete separation of the magnetite and coal particle by commencing the sieving for more than 10minutes.Then the ash analysis of the product and reject was done in the same procedure mentioned earlier.

4.4.3 Scope of the experiment

Table.3 Scope of the experiment

Size of coal	Air Flow rate(lpm)	Coal to magnetite weight ratio
-12+10mm	50-70lpm	0.3
-10+5mm	40-80lpm	0.1,0.2,0.3,0.4
-4.75+1mm	50-70lpm	0.3,0.2

4.4.4 Coal cleaning efficiency calculation terminology

The washing efficiency of ADMFB is explained using four different parameters [14]

- Percentage enrichment(E)

  This gives an idea on how much enrichment in the ash % is achieved due to the cleaning process. This is given by mathematical formula

  $$Enrichment(\%) = \left(\frac{Af - Ac}{Af}\right) \text{x } 100 \qquad (4.5)$$

  Where Af ,Ac are the ash % in feed coal and ash % in cleaned coal.

- Percentage Ash Rejection(AR)

  This gives us an idea on how much ash is rejected in the cleaning process. Higher value of AR signifies better cleaning operation. This is given by

  $$Ash\ Rejection(\%) = 100 - \%Ash\ recovery \qquad (4.6)$$

  $$Ash\ Recovery(\%) = \left(\frac{Yc \text{ x } Ac}{Af}\right) \text{x } 100 \qquad (4.7)$$

  $$Ash\ Rejection(\%) = \left(1 - \frac{Yc \text{ x } Ac}{Af}\right) \text{x } 100 \qquad (4.8)$$

  Where Yc is the yield of product.

- Combustible Recovery(CR)

  This gives us an idea on how much combustible is recovered in the product. Combustible in coal includes both volatile matter content and fixed carbon content. This is given by

$$Combustible\ Recovery(\%)$$

$$= \left[\frac{Yc \text{ x } Percentage\ combustible\ in\ clean\ coal}{percentage\ combustible\ in\ feed}\right] \text{x } 100 \qquad (4.9)$$

- Separation Efficiency(SE)

  This gives us an idea on the separation efficiency of the cleaning process..

  Mathematically it can be given by

$$separation\ efficiency(\%) = Combustible\ recovery(\%) - Ash\ removal(\%) \tag{4.10}$$

CHAPTER-5

RESULTS AND DISCUSSION

5.1 PROXIMATE ANALYSIS

The observations and calculations of proximate analysis are reported below:

Table 4: Observations of Proximate Analysis:

Sample No.	Weight of Empty Crucible (g)	Weight of Sample + Crucible (g)	Weight of coal content (g)	Weight after moisture removal (g)	Weight after Volatile matter removal (g)	Weight after ash residue formation (g)
1	21.43	22.43	1.00	22.38	22.06	21.72
2	22.57	23.57	1.00	23.52	23.19	22.86
3	21.07	22.07	1.00	22.02	21.70	21.34

Table 5: Results of Proximate Analysis:

Sample No.	Moisture %	Volatile Matter %	Ash %	Fixed Carbon %
1	5.00	33.68	29.00	32.32
2	5.00	34.74	29.00	31.26
3	5.00	33.68	27.00	34.32

The average ash percentage is 28.33 % and average fixed carbon percentage is 32.63 %.

5.2 WASHABILITY STUDIES:

Table.6: Composition of Separating Medium (of 200 mL) for Float and Sink Test:

Specific gravity	CCl_4 (ml) [Specific gravity- 1.595]	Benzene (ml) [Specific gravity- 0.878]	Bromoform (ml) [Specific gravity- 2.889]
1.3	117.70	82.30	-
1.4	145.60	54.40	-
1.5	173.50	26.50	-
1.6	197.90	-	2.10
1.7	182.60	-	17.40
1.8	167.20	-	32.80

Table.7: Washability Data:

Specific Gravity	Weight of Each fraction (Float) g	Ash of each fraction (Float) %	Yield of total Float %	Cumulative Yield of Float %	Ash of Total Float %	Yield of Total Sink %	Ash of Total Sink %	Cumulative Yield up to Middle Fraction %
1.30	1.06	6.25	2.13	2.13	6.25	97.88	28.81	1.06
1.40	5.18	10.12	10.36	12.49	9.46	87.51	31.02	7.31
1.50	8.07	16.98	16.14	28.63	13.70	71.37	34.20	20.56
1.60	14.36	22.35	28.73	57.35	18.03	42.65	42.18	42.99
1.70	11.17	32.63	22.34	79.69	22.12	20.31	52.68	68.52
1.80	6.94	39.85	13.88	93.57	24.75	6.43	80.37	86.63
> 1.8	3.22	48.92	6.43	-	26.31	-	-	96.79

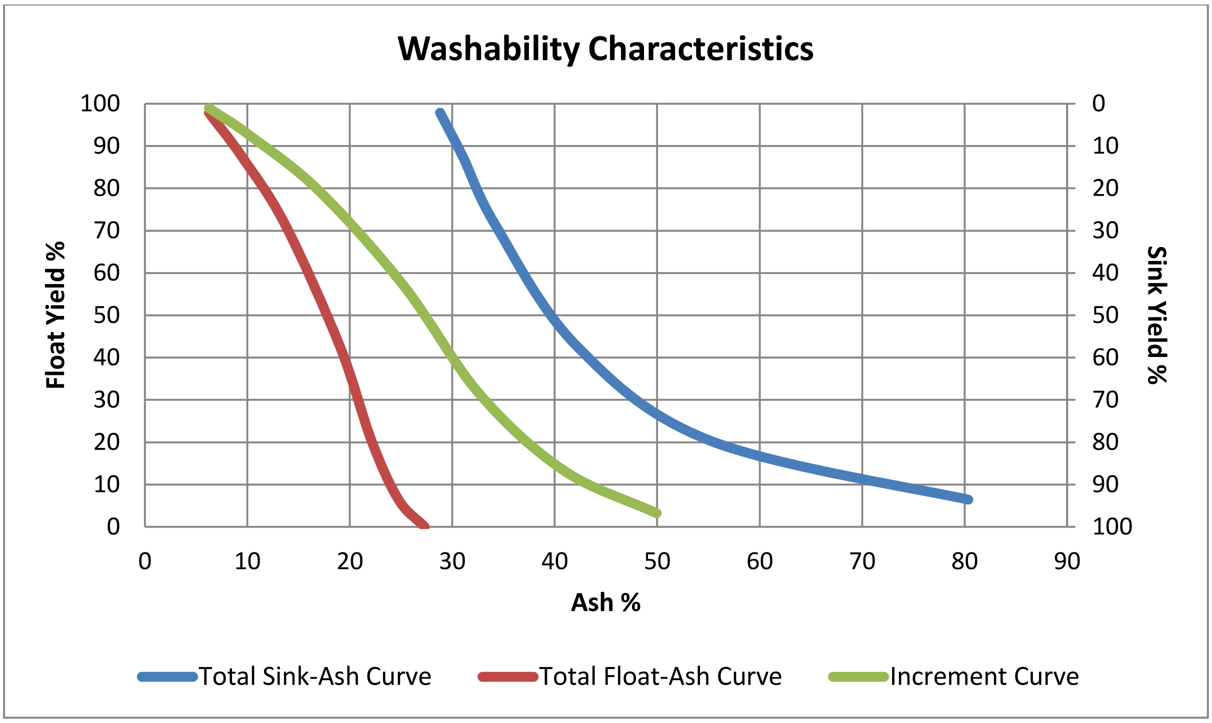

Figure.7: Washability Characteristics Curve

5.3 BED EXPANSION AND DENSITY VARIATION FOR DIFFERENT WEIGHT OF MAGNETITE PARTICLE:

Table.8: Observation of bed height vs air flow rate for varying quantity of magnetite.

Air Flow rates (lpm)	Height of Bed (c.m)			
	400g of magnetite	500g of magnetite	600g of magnetite	700g of magnetite
0	3.00	3.40	4.00	4.50
20	4.20	5.50	6.40	7.00
30	6.00	7.00	7.45	8.50
40	8.25	8.25	9.50	10.25
50	9.50	9.60	10.15	11.00
60	10.25	11.00	11.75	11.50
70	10.75	12.25	12.75	13.50
80	11.00	13.20	13.5	14.00
90	11.50	13.50	14.25	14.75
100	13.00	14.75	15.00	15.25

Table.9: Calculation of bed Expansion and density variation for different weight of magnetite particle

Flow rates (lpm)	400g of Magnetite		500g of Magnetite		600g of Magnetite		700g of Magnetite	
	Bed Expansion (cm)	Bed density (g/cm^3)	Bed Expansion (cm)	Bed density (g/cm^3)	Bed Expansion (cm)	Bed density (g/cm^3)	Bed Expansion (cm)	Bed density (g/cm^3)
0	0	4.8	0	4.8	0	4.8	0	4.8
20	1.20	3.43	2.10	2.97	2.40	3.00	2.50	3.09
30	3.00	2.40	3.60	2.33	3.45	2.58	4.00	2.54
40	5.25	1.75	4.85	1.98	5.50	2.02	5.75	2.11
50	6.50	1.52	6.20	1.70	6.15	1.89	6.50	1.96
60	7.25	1.40	7.60	1.48	7.75	1.63	7.00	1.88
70	7.75	1.34	8.85	1.33	8.75	1.51	9.00	1.60
80	8.00	1.30	9.80	1.24	9.50	1.42	9.50	1.54
90	8.50	1.25	10.10	1.21	10.25	1.35	10.25	1.46
100	10.00	1.11	11.35	1.11	11.00	1.28	10.75	1.42

5.4 EFFECT OF PARAMETERS ON COAL ENRICHMENT ANALYSIS

5.4.1 FOR -10+5 mm SIZE COAL PARTICLE

Table.10: Product and reject ash data for coal size -10+5m.m

Air Flow Rates (lpm)	Coal to Magnetite weight ratio 0.1			Coal to Magnetite weight ratio 0.2			Coal to Magnetite weight ratio 0.3			Coal to Magnetite weight ratio 0.4		
	W_p (g)	A_c (%)	A_r (%)	W_p (g)	A_c (%)	A_r (%)	W_p (g)	A_c (%)	A_r (%)	W_p (g)	A_c (%)	A_r (%)
40	16.29	27	30	39.89	28	30	71.92	27	31	91.23	29	29
50	14.48	26	32	36.81	25	32	63.21	25	33	88.12	26	33
60	15.71	26	31	37.91	25	31	72.31	24	34	83.14	27	31
70	17.51	27	30	33.02	26	36	62.43	26	32	86.61	28	31
80	16.38	28	30	30.95	27	34	68.12	27	32	90.87	28	32

Table.11: Calculation for effect of parameters on feed coal of size -10+5m.m

Coal to Magnetite weight ratio	Air Flow Rate (lpm)	Yield of Clean coal Y_c (%)	Enrichment E (%)	Combustible Recovery CR (%)	Ash Rejection AR (%)	Separation Efficiency SE (%)
Coal to Magnetite weight ratio 0.1	40	32.58	4.69	33.23	68.95	2.18
	50	28.96	8.22	29.97	73.42	3.39
	60	31.42	8.22	32.52	71.16	3.68
	70	35.02	4.69	35.72	66.62	2.34
	80	32.76	1.164	32.92	67.62	0.00
Coal to Magnetite weight ratio 0.2	40	39.89	1.164	40.09	60.57	0.66
	50	36.81	11.75	38.65	67.52	6.17
	60	37.91	11.75	39.80	66.55	6.35
	70	33.02	8.22	34.17	69.70	3.87
	80	30.95	4.69	31.57	70.50	2.07
Coal to Magnetite weight ratio 0.3	40	47.94	4.69	48.90	54.31	3.21
	50	42.14	11.75	44.24	62.81	7.06
	60	48.2	15.28	51.33	59.17	10.50
	70	41.62	8.22	43.07	61.80	4.88
	80	45.41	4.69	46.32	56.72	3.04
Coal to Magnetite weight ratio 0.4	40	45.62	0	45.16	53.30	0.00
	50	44.06	8.22	45.60	59.56	5.16
	60	41.57	4.69	42.40	60.38	2.78
	70	43.31	1.16	43.52	57.19	0.72
	80	45.44	1.16	45.66	55.09	0.00

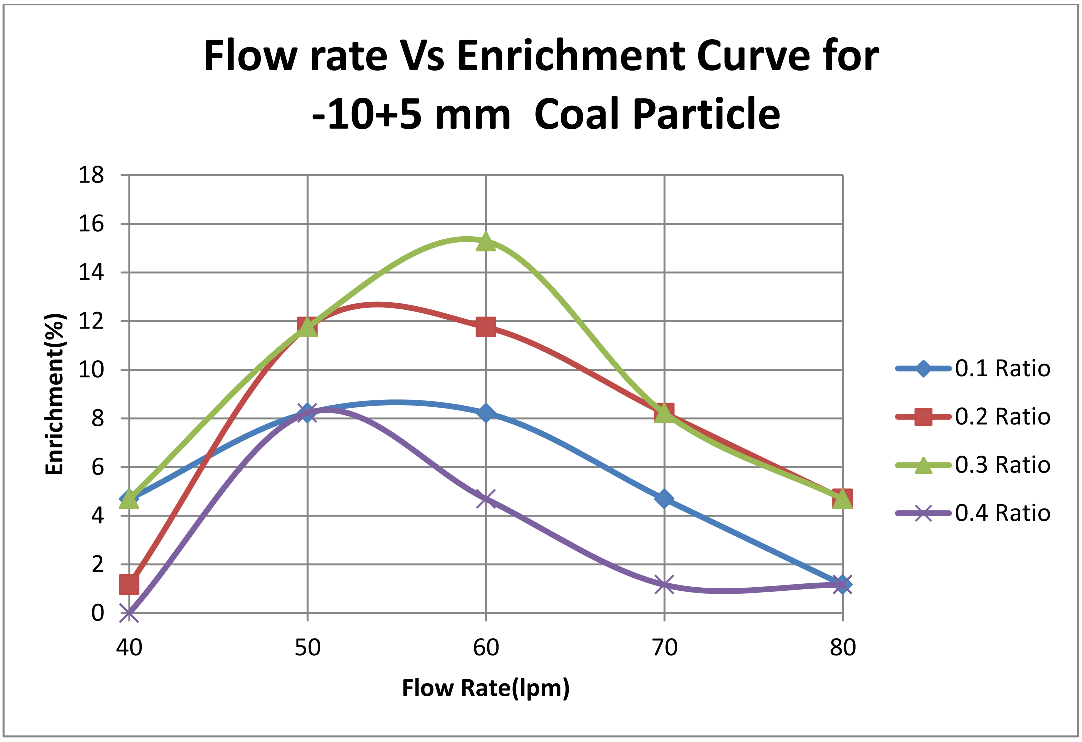

Figure.8: Flow rate vs Enrichment Curve for-10+5 mm Coal Particle at four different coal to magnetite weight Ratio

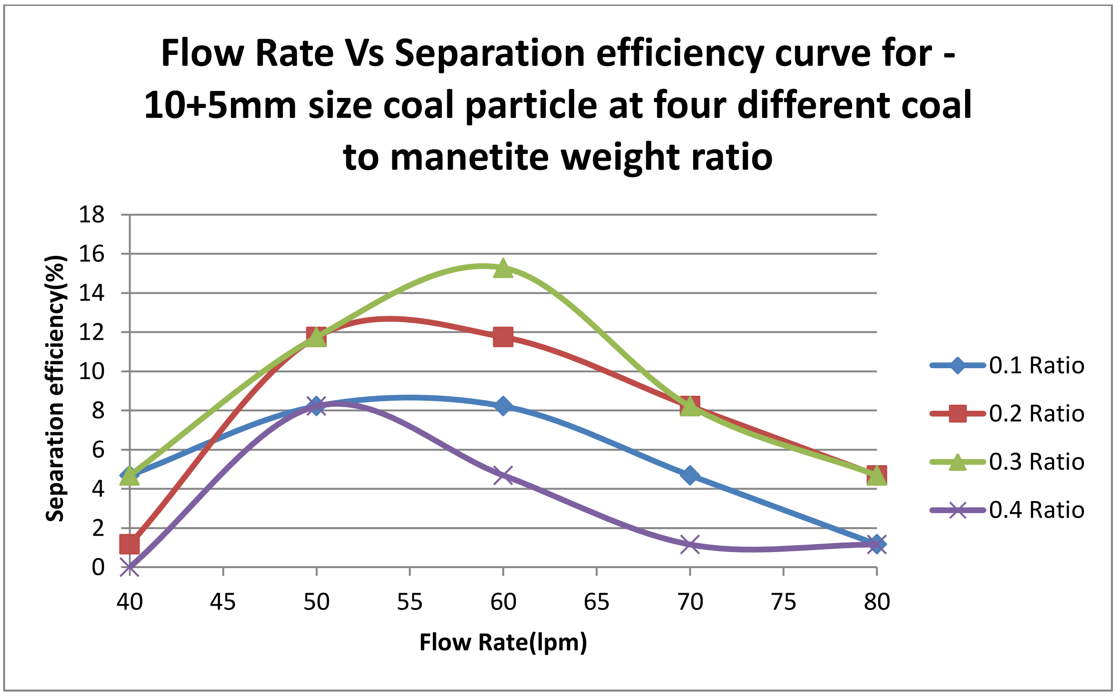

Figure.9: Flow rate vs Separation efficiency Curve for-10+5 mm Coal Particle at four different coal to magnetite weight Ratio.

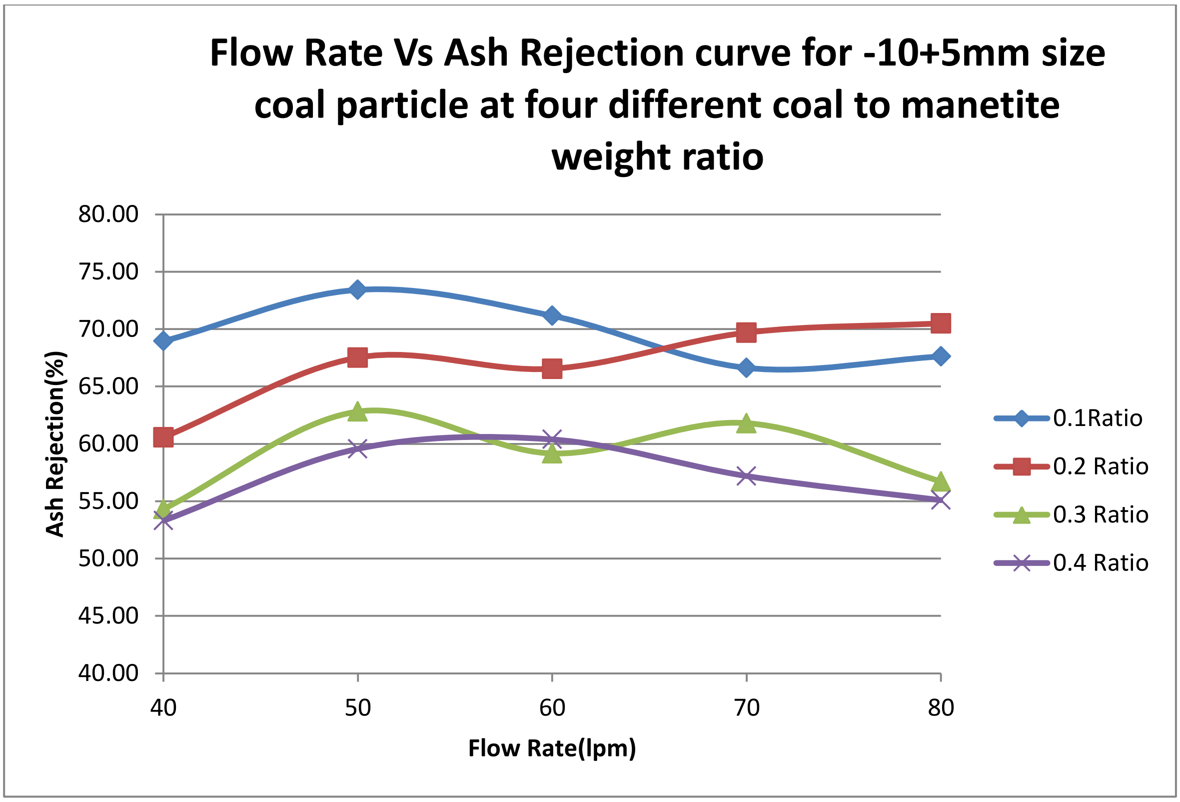

Figure.10: Flow rate vs Ash Rejection Curve for-10+5 mm Coal Particle at four different coal to magnetite weight Ratio.

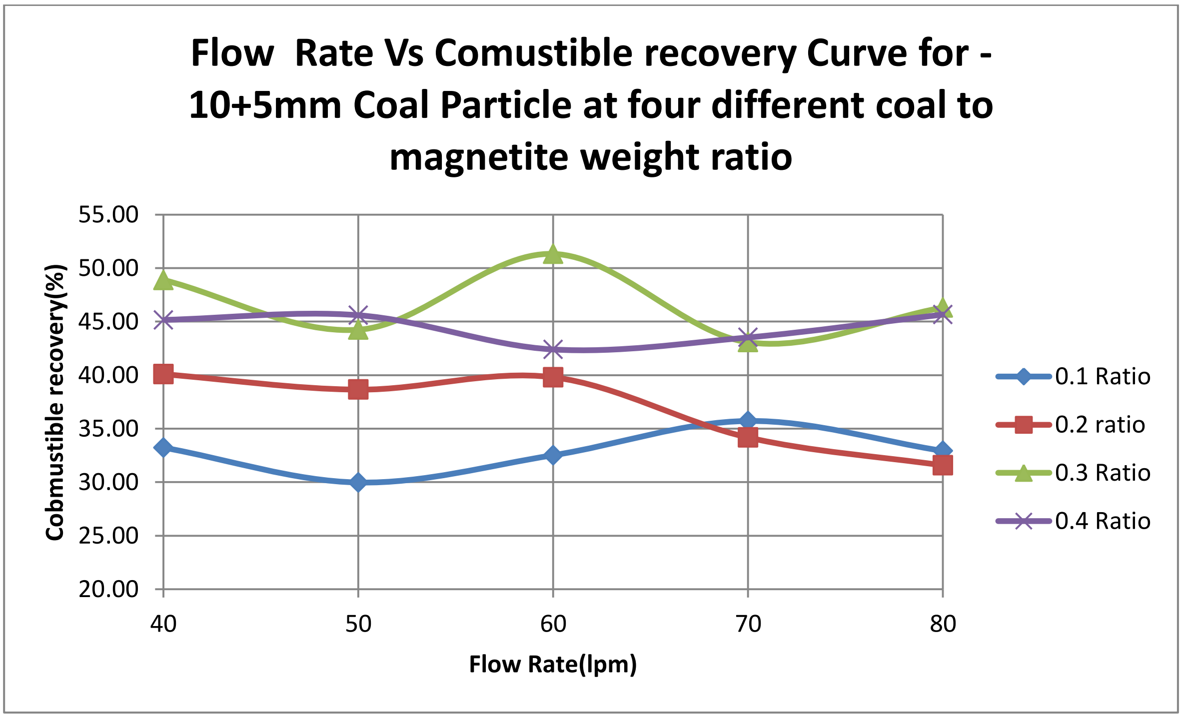

Figure.11: Flow rate vs Combustible Recovery Curve for-10+5 mm Coal Particle at four different coal to magnetite weight Ratio

5.4.2 FOR -4.75+1mm SIZE COAL PARTICLE

Table.12: Product reject ash data for coal size -4.75+1mm

Flow rates (lpm)	Coal to Magnetite weight ratio 0.2			Coal to Magnetite weight ratio 0.3		
	W_p (g)	A_c (%)	A_r (%)	W_p (g)	A_c (%)	A_r (%)
50	44.71	28	31	74.58	27	32
60	39.50	26	32	61.22	27	31
70				85.19	28	30

Table.13: Calculation for effect of parameters on feed coal of size -4.75+1mm

Flow rates (lpm)	Coal to Magnetite weight ratio 0.2					Coal to Magnetite weight ratio 0.3				
	Y_c (%)	E (%)	CR (%)	AR (%)	SE (%)	Y_c (%)	E (%)	CR (%)	AR (%)	SE (%)
50	44.71	1.164	44.90	55.81	0.71	49.72	4.69	50.58	52.61	3.19
60	39.50	8.22	40.70	63.74	4.44	40.81	4.69	41.51	61.10	2.61
70						56.79	1.16	57.03	43.87	0.9

5.4.3 FOR -12+10mm SIZE COAL PARTICLE

Table.14: Product Reject Ash data for coal size -12+10mm and 0.3 coal to magnetite weight ratio

Flow rates (lpm)	Coal to Magnetite weight ratio 0.3		
	W_p (g)	A_c (%)	A_r (%)
50	59.98	26	32
60	51.62	26	31
70	38.39	27	30

Table.15: Calculation for effect of parameters on feed coal of size -12+10mm

Flow rates (lpm)	Coal to Magnetite weight ratio 0.3				
	Y_c (%)	E (%)	CR (%)	AR (%)	SE (%)
50	39.98	8.22	41.19	63.30	4.49
60	34.41	8.22	35.46	68.42	3.88
70	25.59	4.69	26.03	75.61	1.64

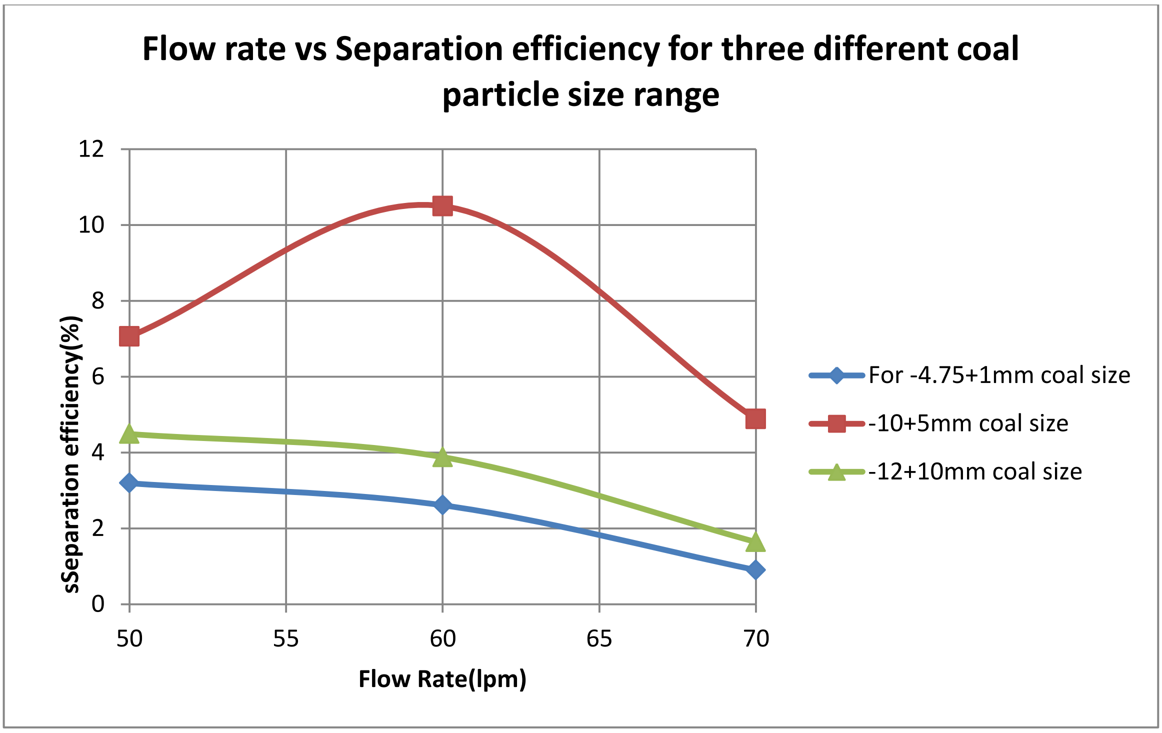

Figure.12: Flow Rate vs Separation Efficiency for Three different Coal Particle size range.

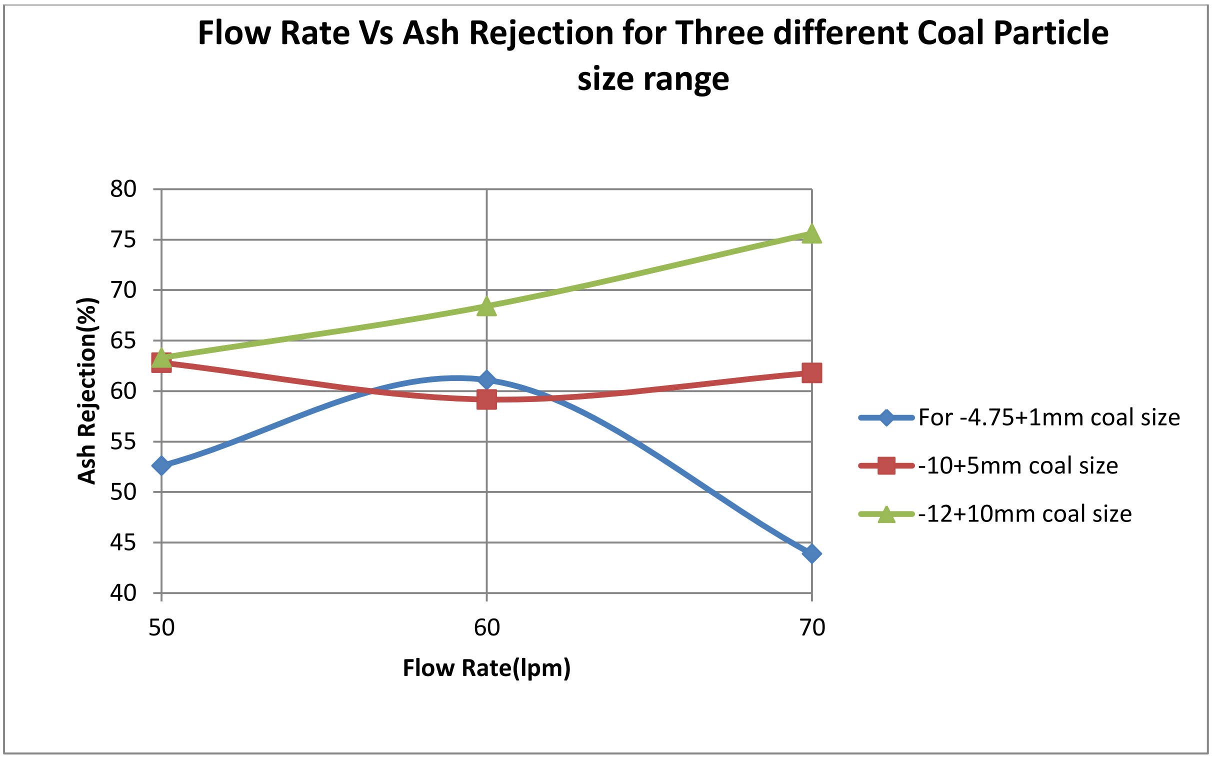

Figure.13: Flow Rate vs Ash Rejection for Three different Coal Particle size range.

5.5 DISCUSSIONS

The proximate analysis of the coal sample shows that the used coal sample is of uniform composition. The average ash percentage was found to be 28.33% and average fixed carbon content was found to be 32.66%.

From the washability curve we could see that the increment curve does not have any sharp cut like "L" shape which suggested that the coal is difficult to clean. From the washability data we can conclude that maximum float yield of 28.73% is obtained at specific gravity 1.6, hence if we clean the coal in a medium of specific gravity 1.6 we can have maximum float yield of 57.35% with ash percentage 18.03.

The bed expansion and density of bed at different flow rate data gives us an idea that the bed density decreases with increase in flow rate and for 500g of magnetite particle bed density of 1.3-2 g/cm^3 is achievable within 40-100lpm flow rate range.

Experiments show that the coal cleaning efficiency depends on various parameter like flow rate and coal to magnetite weight ratio which affects the gas solid two phase flow. Experiments were performed with three different size fraction of Basundhara coal and their coal cleaning efficiency can be summarized as follows.

5.5.1 Effect of particle size

5.5.1.1 -10+5mm size range

Experiments show that the maximum coal enrichment 15.28% of coal is achieved at 0.3 coal to magnetite weight ratio and at 60lpm air flow rate and the minimum coal enrichment is seen at 0.4 coal to magnetite weight ratio and at 40lpm flow rate. It was observed during the experiment that at 0.4 coal to magnetite weight ratio after 12-15s after the stratification starts the bed defluidized may be because of the reason that the minimum fluidization velocity of 200g of coal particle is more than velocity at 40lpm. It is observed from the graph of flow rate vs AR (refer Figure.10) at different ratio is that AR is maximum 73.42% at 0.1 coal to magnetite weight ratio and 50lpm flow rate. The AR value lies in the range of 50% to 73%. From the flow rate vs CR at different ratio (refer Figure.11) it is observed that the maximum CR achieved is 51% at 0.3 coal to magnetite weight ratio and 60lpm flow rate.

5.5.1.2 -4.75+1mm Coal

For finding out the effect of coal particle size experiments were conducted at optimum flow rate and optimum ratio i.e. at 60lpm flow rate and 0.3 coal to magnetite weight ratio for this size range. The maximum separation efficiency achieved for this particle range is 4.44% at

0.2 coal to magnetite weight ratio and 60lpm flow rate. The maximum 63.74% AR and 57.03% CR value are achieved for this particle range. Such low separation efficiency may be because of the misplacement of small size particle in the fluidized bed.

5.5.1.3 -12+10mm Coal

For this particle range the maximum separation efficiency achieved is 4.49% at 0.3 coal to magnetite weight ratio and 50lpm flow rate. The maximum AR and CR value achieved for this size range is 75.61% and 41.19%. The CR and AR value is close to the AR and CR value obtained for -10+5mm particle range.

It is observed that the maximum separation efficiency of 10% is achieved for coal size range -10+5mm.And the separation efficiency in the size range of -12+10mm and -4.75+1mm is less as compared to -10+5mm size coal particle. From the flow rate vs AR curve for three different size range of particle (refer Figure: 13) it is observed that maximum ash rejection is achieved for -12+10mm particle size range. The AR value is minimum for -4.75+1mm size range. In the small size particle range misplacement of small sized particle is more because of back mixing in the fluidized bed. The reason behind such low enrichment of coal may be due to the adherence of magnetite medium particle on the surface of coal which directly contributes to the ash in the cleaned coal.

5.5.2 Effect of flow rate

Experiments were carried out for five different flow rates i.e. 40lpm, 50lpm, 60lpm, 70lpm and 80lpm.The stratification of coal particles in the bed strongly depends on the flow rates. For Basundhara coal it is observed that the % enrichment increase with increase in flow rate and maximum in between 50-60lpm and decreasing sharply at 70-80lpm flow rate. The variation may be because of the reason that at low flow rates the bed expansion is less and the bed density is very high, higher than the optimum separation density. From the washability data it is observed that the maximum separation density was around 1.6g/c.m^3 and between 50-60lpm flow rate the bed density lies in between 1.7-1.5g/cm^3 so it can be concluded that because of stable bed and optimum separation density in between 50-60lpm maximum enrichment is observed. And at high flow rates the probability of misplacement of heavier coal particle because at this flow rate the bed started behave like a spouted bed with more agitation inside the bed which may results in low enrichment value.

5.5.3 Effect of Coal to Magnetite weight ratio

This is one of the important parameter affecting the separation efficiency. Experiments were carried out at four different coal to magnetite weight ratio i.e. 0.1, 0.2, 0.3and 0.4for -10+5mm coal size particle. It is observed that separation efficiency and enrichment percentage is more in the ratio 0.2 and 0.3 as compared to ratio at0.1 and 0.4. This may be because of the reason that at ratio 0.4 the amount of feed coal is more which results in poor fluidization in the bed resulting in poor separation efficiency. At 0.4 coal to magnetite weight ratio it was also observed that at some flow rate the coal particle remains defluidized which results in poor separation.

CHAPTER-6

CONCLUSION

The effect of coal particle size and process parameter such as flow rate and coal to magnetite weight ratio on coal cleaning efficiency has been studied in a 10c.m outer diameter and 120c.m height fluidized bed. It is observed that maximum separation occurring for particle range -10+5mm and least separation occurring for particle range-4.75+1mm. The optimum condition of separation is different for different size range of particle. For -10+5mm range the optimum condition of separation is 0.4 coal to magnetite weight ratio at 60lpm flow rate and for -4.75to1mm particle range it is 0.2 ratio and 50lpm air flow rate. It can be concluded from the study that for maximum separation a constant air flow rate is required for a stable bed of optimum separation density where the misplacement effect of finer coal particle and heavier coal will be less. ADMFB is effective in cleaning coarse size coal particle in the range -12+5mm.For cleaning finer coal with high efficiency some modification in the bed should be made to achieve a stable fluidized bed. Coal cleaning using bed material of different size for high ash coal can be studied as a future work to this project. This method has potential for the use of presently discarded high ash coal beneficiation for various process applications in thermal power plant sponge iron units and coke ovens.

CHAPTER-7

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