Studies on the Variation in Coal Properties of Low Volatile Coking Coal after Beneficiation

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ABSTRACT

Coal is the main ingredient for the various industries like; Iron & steel industries, Power generation industries, Cement industries etc. and its calorific value is the back bone for the processing. The calorific value of coal depends on various factors on which ash content is the major one.Coking coal is an essential prerequisite for production of Iron & Steel through blast furnace route. Systematic R&D studies on the availability of desired quality coking coal from indigenous resources have become imperative to minimize the dependence on imported coals. The Low Volatile Coking Coal (LVCC) constitutes about 50% of the total coking coal reserves in India. These coals are characterized by high ash content and difficult in cleaning potential. This high ash content will be reduced by washability process. Washability analysis is the basis for nearly all coal preparation plant and it is carried out for the analysis of ash reduction in different specific gravity portion of coal and it's characterization defines how and which process can be applied for the certain quality of coal for specific separation

I. INTRODUCTION

The relative abundance of coal in India compared to other fossil fuels makes it a natural choice as the primary source of fuel, be it for steel making, power generation or for other uses. Total reserves of coal in the country are estimated to the order of 267 Billion Tons. Coking coal, which is merely 14% of the total deposits, is available mainly in Eastern part of India. Coking coal is an essential prerequisite for manufacture of Iron & Steel through blast furnace route. In India, the annual requirement of coking coal for various metallurgical purposes may be up to the tune of 35 million tones, out of which the availability from the indigenous sources is about 10 million tones only. The rest of the coking coal requirements are managed through imports from different countries.To meet the increased demand of coking coal concerted efforts have to be made to correct the imbalance between need and availability by increasing the production of coal of desired quality through better management of available resources of inferior grade. Low volatile coking coal (LVCC), though inferior in qualities but abundantly available in Eastern part of the country may be an immediate choice. The present production from LVCC is about 16 to 18 mt per year, and is primarily used for power generation. These coals, being of lower seams are likely to be more matured (Ro~1.30%) than the upper seams and consequently exhibit lower values of volatile matter. The country has a moderate reserve of such coal, amounting to about 50% of the total coking coal reserve. Proper utilization of these LVCC coals for metallurgical purpose after suitable may minimize improper utilization of scarce commodity coking coal.(Ref. Geological Survey of India (GSI) Report, Government of India 2009: Inventory of Indian Coal Resources.)

1.1 Definition of Coal:

Coal is a combustible compact black or dark-brown carbonaceous sedimentary rock formed from compaction of layers of partially decomposed vegetation and occurs in stratified sedimentary deposits.

1.2 Formation of coal:

Coal is formed by biological, physical and chemical processes, governed by temperature and pressure, over millions of years on plant remains, deposited in ancient shallow swamps. The degree of alteration (metamorphism), caused by these processes, during the temporal history of development determine their position or rank in the coalification series which commence at peat and extend through lignite to bituminous coal and finally anthracite. The relative amount of moisture, volatile matter, and fixed carbon content varies from one to the other end of the coalification series.

The moisture and volatile matter decrease with enhancement of rank while carbon content increases i.e., carbon content is lowest in peat and highest in anthracite.

1.3 Type / Grade:

Coal: It is classified into different types mainly on the basis of certain chemical (ash, moisture and volatile matters) and physical (caking index, coke type and swelling index) parameters. However, different modes of classifications are being followed in different countries mainly on the basis of prevalent industrial need. The Indian coal is broadly classified into two types – Coking and Non-Coking. The former constitute only a small part of the total coal resources of the country. These two are further subdivided as follows on the basis of certain physical and chemical parameter as per the requirement of the industry.

[1] Coking Coal
[2] Prime Coking **-** Mainly used for metallurgical purpose.
[3] Medium Coking **-** Mainly used in steel industry.
[4] Semi Coking **-** Mainly in cement, fertilizer and sponge iron industries.

Non Coking Coal: Non- coking coal comprises lion's share of Indian coal. Based on Useful Heat Value (UHV), it is classified into grades A to G for commercial use. A to C grades are considered as Superior and are used in cement, fertilizer and sponge iron industries. D to G grade, available in almost in all the coalfields, is considered as Inferior and is mostly used in power sector.

Lignite: Lignite is the youngest coal from geological perspective. It is a soft coal composed mainly of volatile matter and moisture content with low fixed carbon. It is commonly known as brown coal and is classified into grades A to C on the basis of Gross Calorific Value as per the requirement of the industries. It is considered as apt fuel for power generation especially due to its low ash content.
The common coals used in Indian industry are bituminous and sub-bituminous coal. The gradation of Indian coal based on its calorific value is as follows:

Grade	Calorific Value Range (in Kcal/kg)
A	**Exceeding 6200**
B	**5600 – 6200**
C	**4940 – 5600**
D	**4200 – 4940**
E	**3360 – 4200**
F	**2400 – 3360**
G	**1300 – 2400**

Normally D,E and F coal grades are available to Indian Industry.

1.4 Intrusion Of Ash Forming Material In Indian Coking Coal

Indian coking coal is drift originated coal. During the drifting process coal swamp are contacted with marine environment. Volcanic eruption zone & igneous zone.On this time various volcanic igneous and marine materials are mixed with the coal swamp and they affect the properties of Indian coal. Some coking coal gets contacted with sulfuric environment and some ironic environment. That creates different type of impurities in coal forming zone. These intrusions are mixed thoroughly with coal so difficult to wash some time.For the utilization coal should have certain properties. For the characterization of coal different analysis are carried out. The basic analysis for the separation of coal is based on specific gravity difference. For these purpose we concerned with particle size distribution not about particle size. For these analysis washability characteristics of coal is determined. That characterizes significance of particle size distribution and washing parameter like yield, ash, cut point density, NGM.

1.5 Objective:

Washability of coal is carried out for the analysis of ash reduction in different specific gravity portion of coal. Washabilty characterization defines how and which process can be applied for the certain quality of coal for specific separation. So the objective of washability is ash reduction with maximum utilizable coking coal.

1.6 Method For The Analysis

For the washabilty characterization Standard float and sink test is used. This is based on the specific gravity of coal. In different specific gravity portion have different density because of some heavy particle in coal. These heavy particle causes ash in coal. That is undesirable for use.

Washability characteristics of coal are generated from float/sink analysis of core samples, as mined samples, or from preparation plant feed samples. In addition to the float/sink analysis. Different steps in float and sink test:

[1] Sample Collection
[2] Sample Preparation For float and sink test.
[3] Different Density Media Preparation.
[4] Utilization of Media for the coal flotation.
[5] Ash determination in different density fraction of floated coal.
[6] Preparation of Washability Data.
[7] Graph of washability Data

Bulk sample Preparation:

The bulk sample should be spread on an impervious base, preferably under shelter. The sample should be dried and sieved in accordance with ASTM test Method.

1.7 Preparation Of Washability Data:

Run of mine coal comprises fragments of material which have density from the lower to highest in a continuous range. But the proportion of each varies. Those with low density have the lowest ash but the higher heat value and those with the highest density vice versa.Washability curve shows the relationship between ash content and the amount of float and sink produced at very particular relative density. Because the test is conducted under very controlled condition the result obtained relate to an almost perfect separation.From the sink & float masses together with the individual ash content of each relative fraction the washability data can be calculated. Different terms which used for the Data preparation are specific gravity, weight percentage, ash percentage, cumulative float weight and ash percentage, cumulative sink weight and ash percentage, characterize, NGM.

1.8 Washability Curve:

A curve or graph showing the results of a series of float-and-sink tests. A number of these curves are drawn to illustrate different conditions or variables, usually on the same axes, thus presenting the information on one sheet of paper. Washability curves are essential when designing a new coal or mineral washery. There are four main types of washability curves: characteristic ash curve, cumulative float curve, cumulative sink curve, and densimetric or specific gravity curve.

II. EXPERIMENTAL WORK:

The following experimental work was carried out.

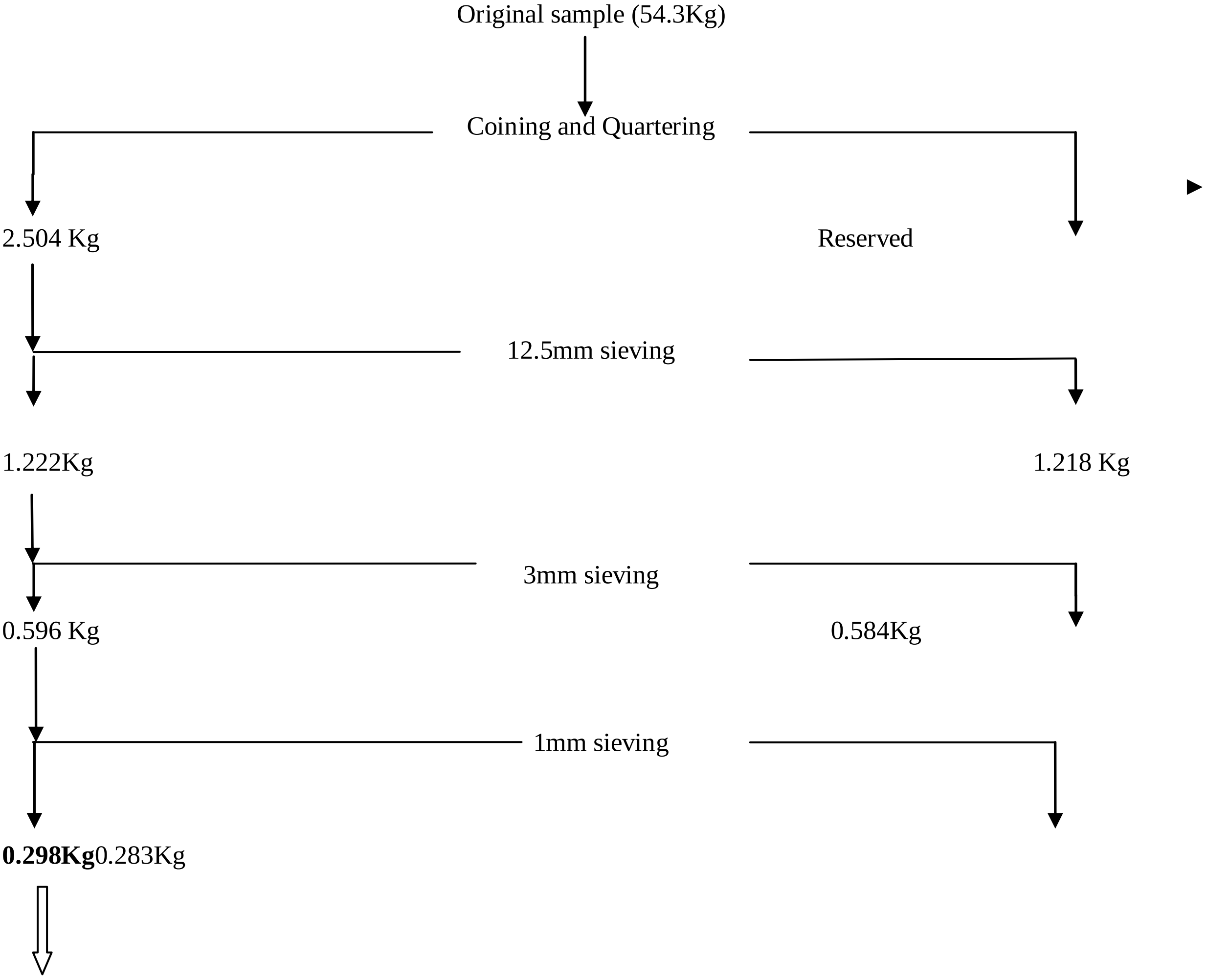
Coal is thoroughly investigated through various tests. Proximate test gives general overview of coal; Ultimate Analysis gives its elemental composition. HGI test gives idea about the hardness of coal, sink float test for different size fraction and analysis the ash.

2. Collection Of Coal Sample:

The coal samples were taken for the desired objective of project. Coal sample was taken from Ghanuadih coal mine. The coal sample was low volatile coking coal.

The coal sample was subject to Proximate analysis, Ultimate analysis, Gross CalorificValue, Free Swelling Index, Hardgrove grindability index, Specific Gravity, sink-float tests for categorization of sample.

SAMPLE CHARACTERIZATION



(-72 mesh) fine coal size occurs, when it pulverizes in pulverizers for proximate analysis of overall coal sample.

2.1. Proximate Analysis-

Determination of Moisture Content:-

About 1 gram of finely powdered (-212 µ) air dried coal sample was weighed in a silica crucible and was then placed inside an electronic hot air oven, maintained at 108±2˚C. The crucible with the coal sample was allowed to remain in the oven for 1 hours and was taken out with a pair of tongs cooled in a desiccator for about 15 minutes and then weighed. The loss in weight is reported as moisture (on percentage basis). The calculation is done as per the following:

% moisture (% M) = (Y-Z)/(Y-X)*100

Where, X=Wt. of crucible in grams

Y=Wt. of coal + Crucible in grams (Before heating)

Z= Wt. of coal + Crucible in grams (After heating)

Determination of Volatile Matter content (VM):-

About 1 gram of finely powdered (-212µ) air dried coal sample was weighed in a VM crucible and was then placed inside a muffle furnace maintained at 925˚C. The crucible was then covered with its lid. The heating was carried out for exactly 7 minutes, after which the crucible was removed, cooled in air and then in a desiccators and weighed again. The calculation is done as follows:

% volatile matter (% VM) = (Y-Z)/(Y-X)*100

Where, X=Wt. of crucible in grams

Y=Wt. of coal + Crucible in grams (Before heating)

Z= Wt. of coal + Crucible in grams (After heating)

Determination of Ash content (Ash)

About 1 gram of finely powdered (-212µ) air dried coal sample was weighed and taken in an empty silica crucible. Before that the crucibles were heated at 850˚C for about 1 hr. to remove any foreign particles in the crucible. The crucible along with the sample was put in a muffle furnace at 450˚C for about 30 minutes. After that the temperature of the furnace was raised to 850˚C and the sample was heated for about 1 hr. at that temperature.

The calculation is done as follows:
% Ash = (Z-X)/(Y-X)*100 Where,
X= Wt. of crucible in grams
Y=Wt. of coal + Crucible in grams (Before heating)
Z= Wt. of coal + Crucible in grams (After heating)

Estimation of Fixed Carbon (C)

The fixed carbon content of coal is given by the following formulae**- %FC = 100 – (%M+%VM+% Ash)**

2.2. Ultimate Analysis

Determination of total carbon, hydrogen, nitrogen, oxygen and sulphur percentages in coal comprises its ultimate analysis. Ultimate analysis give the elemental composition of coal i.e. carbon, hydrogen, nitrogen, sulphur and oxygen content of coal. Vario EL III CHNS analyser from Elementar Germany was used for determination of Carbon, Hydrogen, Nitrogen and Sulphur. Oxygen was calculated using the following relations:
O% = 100 – (C% + H% + N% + S + M +Ash %).

Procedure for Analysis

To start the analysis first of all the carousel from the Vario EL III was removed and the position of carousel hole was adjusted to zero. The main power of analyser was switched on, after a while the carousel of the analyser start moving and comes to original position i.e. zero. Now the carousel was placed at top at original position. Before performing the sample analysis the analyser is first run with few blank determination (No sample) and thereafter few samples of standard Sulfanilic acid (whose composition is known) is run to calibrate the analyser. It is to be ensured that calibration factor of the analyser should not be less than 90%.

To perform the ultimate analysis of coal, pre manufactured tin boat was weighed in precession digital balance. Few mg (say 4-5 mg) of Tungsten oxide, which acts as a catalyst, is mixed with approximately 10 mg of coal sample of -200 mesh size. The tin boat inside with tungsten oxide and coal samples was made to pellet with the help of pellet maker. Now the pellet is transferred to the slots provided in the Carousel (upper portions) of Vario EL III CHNS analyser. There are 79 slots in the analyser.Two types of gases namely helium and oxygen are used for the analysis. Helium is used as carrier gas and oxygen for combustion purpose. During the experiment helium gas flow is maintained at the rate of 200 ml/min and oxygen dosage is 90 sec for each sample. Before the gases come into contact with the pellet it is passed through drying agents. Vario EL III CHNS analyser consists of various parts and instrumentation which includes; oxidation tube, reduction tube and absorption columns for absorbing N_2, CO_2, water vapour, SO_2. In the oxidation tube there is ash finger. Oxidation tube is placed in the oxidation furnace the temperature of which goes to around 1150^{o}C. The product gas which is emitting from oxidation tube passes through reduction tube having temperature of 850^{0}C first and then these gases goes to absorption columns for absorbing N_2, CO_2, water vapour, SO_2. TCD detects the presence and quantity of these gases by measuring the peaks and the area under peaks. The quantity of gases absorbed under the peaks is converted in to the elemental composition i.e., N, C, H, and S in the instrument itself by way of a machine dedicated programme. The results are displayed in the computer attached to analyser machine after giving required commands. After completion of analysis the result was obtained by printing the result from the computer. Approximately one sample takes 15 min. for complete analysis.

Determination of Oxygen: It is deduced indirectly as follows.
% of oxygen in coal = 100 – (% of C +H+N+S+Moisture+Ash %)

Fig .1: Vario EL III CHNS analyser

Relationship Between Ultimate Analysis and Proximate Analysis		
%C	=	0.97FC+ 0.7(VM - 0.1A) - M(0.6-0.01M)
%H	=	0.036FC + 0.086 (VM -0.1xA) - 0.0035*M*2* (1-0.02M)
%N2	=	2.10 -0.020 VM
where		
FC	=	% of fixed carbon
A	=	% of ash
VM	=	% of volatile matter
M	=	% of moisture

Note: The above equation is valid for coal containing greater than 15% Moisture content.

2.3 HGI (HardgroveGrindability Index) of Coal:-The grindability of Coal is a measure of the ease with which it can be ground fine enough for Use a pulverized fuel, & it also shows the physical properties of coal like hardness, tenacity and fracture. There is a fixed relationship between Grind ability and rank of coal in the natural series from brown coal to lignite & anthracite. Coals easier to grind have 14 to 30 percent volatile matter. Coals with higher volatile matter are more difficult to grind. However Petrography & mineral constituents influence grindability. The Hardgrove Index of coal is affected by its moisture content and hence on the humidity of the atmosphere in which the test is carried out.

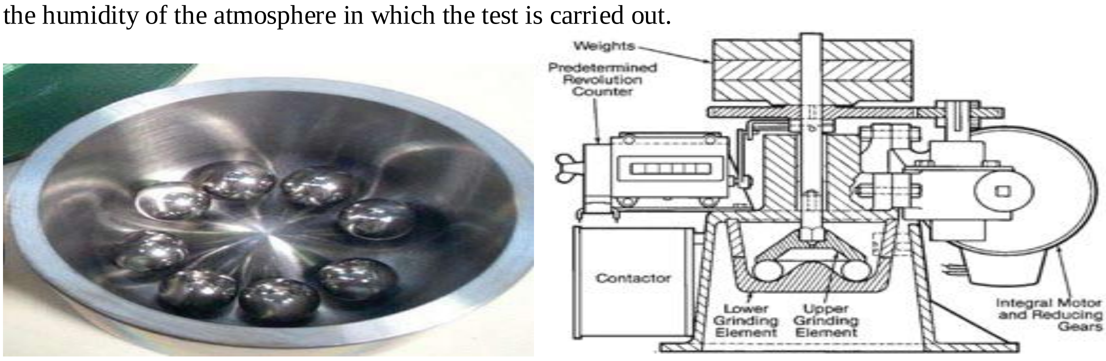


Figure 2 Cross section of HGI test apparatus

Experimental Procedure:

1 kg of coal **sample** was taken and crushed to pass through 4.75mm sieve. The resulting Sample was put in two sieves of 32 mesh sieve (upper sieve) and 16 mesh size (lower Sieve). Sieve the material for 2 minutes until the entire material pass through 32 mesh sieve. 150 grams of the coal sample passing through

30mesh sieve retaining on 16 mesh size sieve was collected for HGI test. Three coal samples of 50 gm. are prepared for HGI test. The 50gm Sample was taken in a ball mill along with 8 iron balls having diameter of one inch. The mouth of the ball mill was closed and it was set to rotate for about 60 revolutions, after 60 rotations, the machine was stopped. The sample left in the ball mill was then collected along with any powdered substance sticking to the surface of the machine with the help of a brush. This sample was then put in a sieve of 200mesh size and was shaken for about 10 minutes. After sieving for about 5 minutes, the sample which passes through 75µ Size was Collected and weighed on the balance.

Calculation- The hard groove grind ability index of coal is calculated using the following formula.
HGI = 13 + 6.93 W, Where
W = weight of the test sample passing through 200 mesh size sieve after grinding.

2.4 Calorific Value

Calorific value determination of coal sample was done in Bomb Calorimeter. In this a known amount fuel is burnt and heat liberated was absorbed in water to increase its temperature. The rise in temperature of water is determined and water equivalent of bomb is taken into account and from this heat of combustion is determined. The empty weight of crucible of bomb calorimeter was weighed and the balance was tarred. Now coal, diesel and coal oil mixture sample was taken in the crucible and weighed. Burette of two liters which was attached to the calorimeter was allowed to fill and after filling, the bottom tap was open and water was collected in the calorimeter bucket. Crucible was put in the bomb assembly and the two terminals in the bomb assembly were joined by platinum wire. Now the lid was tightened. The bomb was filled by oxygen up to a pressure of 410 psi. The bomb is placed in the bucket filled with water and electrical terminal is inserted in the bomb. The lid is put on machine and current is supplied. Due to flow of current the platinum wire ignites and the sample catches fire. After 8 minutes the result was displayed and it was printed by printer attached to it.

2.5 Free Swelling Index (Fsi):

For the determination of Free swelling index the method specified in IS (Indian Standard) 1353: 1993 was used. One gram of coal was taken in a standard silica crucible with lid. After that it was lightly tapped for 10 to 12 times on the table to level the surface. Covered silica crucible was placed in free swelling furnace for 4 minutes. It is essential that apparatus be adjusted to give proper temperature in the crucible in the specified time i.e. 800 +10°C in the first 1.5 minutes and 820 +/- 5°C in the next 2.5 minutes from the start of the tests. The crucible was removed from the furnace and allows cooling. The coke bottom obtained was compared with standard profile, numbered from 1 to 9.

FSI ≥ 1.0, Semi Coking coal **-** Mainly used in cement, fertilizer and sponge iron industries.
≥ 2.5, Medium Coking coal**-** Mainly used in steel industry.
≥ 3.5, Prime Cokingg **-** Mainly used for metallurgical purpose.

(Ref. O.P.GUPTA., 1990, Fuels, Furnaces and Refractory, 1st edition, Khanna Publication, Delhi.)

2.6 Determination Of Specific Gravity Of Different Samples: The specific gravity of the coal samples is largely affected by the particle size distribution of the coal. This is because the void space between the coal particles is lesser if the size of the coal particle is small, whereas the void space is more in the bigger coal particle size. So the packing density is much more affected by particle size distribution of the coal.

PROCEDURE: A specific gravity meter of 25 ml was taken and cleaned & dried well so as no moisture left in it. Now the weight of the empty specific gravity meter was taken. Then it is filled fully with water and its weight was taken. After this it is again dried fully and now the specific gravity meter filled fully with kerosene oil and its weight was taken. Then it is again cleaned, dried and approximately 50% filled with coal and weight was taken. Now it is partially filled with kerosene oil and cap was loosed and shakes well so as to dissolve the coal fully in the kerosene oil. After dissolving the specific gravity meter was filled fully with kerosene oil and cap was closed. The outer surface was of the specific gravity meter was cleaned with cotton and then its weight was taken.

Calculation:
Weight of empty specific gravity meter bottle = w1
Weight of empty specific gravity meter bottle + full water = w2
Weight of empty specific gravity meter bottle + full kerosene = w3
Weight of empty specific gravity meter bottle + 50% filled with coal sample = w4
Weight of empty specific gravity meter bottle + 50% filled with coal sample +50% filled with kerosene oil = w5

Specific gravity = [(w4 - w1) * (w3 - w1)] / [{ (w3-w1) – (w5-w4) } * (w2 - w1)]
Specific gravity of various samples is shown in Table in chapter 4.

2.7 Calculating Washability Data (Tromp,1937.)

There are many ways washability data can be manipulated to show results of combining the various screen and gravity fractions. These mathematic manipulations involve nothing more than multiplication, division, and an understanding of weighted averages. There is no difficulty in calculating the washability data in a usable form.

Plotting Washability Data: As the full value of the washability data cannot be interpreted until the data has been plotted on graph paper. There are two types of graph paper that can be used, rectangular coordinate graph paper and a combination of semi-log and rectangular coordinate graph paper. Plotting on rectangular coordinate paper is most common because rectangular coordinate paper is easy to obtain, but the combination semi log and rectangular coordinate gives results that can be read accurately and easier (Keller., et al 1948.) The latter type of graph paper can be home made by pasting a sheet of semi.log paper beside a sheet of rectangular coordinate paper or it can be especially printed. Rectangular coordinate paper must be used in conjunction with semi.-log paper since the specific gravity curves must be plotted on rectangular graph paper.
There are five washability curves plotted on this chart. They are:
Cum. floats – Ash curve, cum. Sinks – Ash curve & Washability Characteristic curve or Instantaneous Ash curve. The representation of the above said curves are as follows:
Curve 1 – Total floats – Ash curve
Curve 2 – Total Sinks – Ash curve
Curve 3 – Characteristic curve
Curve 4 – Yield curve
Curve 5 – NGM curve

[1] The specific gravity curve is a plot of the cumulative float weight percent against the specific gravity.
[2] The cumulative float curve is a plot showing the cumulative float weight percent plotted against the cumulative float ash percent.
[3] The cumulative sink curve is a plot of the cumulative sink weight percent against the cumulative sink ash percent.
[4] The elementary ash curve is drawn by plotting Ordinate “Z” against the direct percent of ash.

Ordinate “Z” =A+B/2
in which,
A = the cumulative weight percent of the float material down to but notincluding the specific gravity fraction.
B = the weight percent of the material in the gravity fraction.
5. The ±0.1specific gravity distribution curve is drawn by plotting the cumulative float weight percent, against the corresponding specific gravities. If the wash ability study includes material that has a gravity higher than 1.90 the ± 0.10% values are calculated slightly different.

2.8 Float & Sink Analysis
‘Heavy liquids’ used in laboratory:
- **Zinc Chloride**
- **Bromoform**
- **CTC (Carbon Tetra Chloride)**

Float & Sink analysis: Procedure
[1] Correct densities in series of containers (test with hydrometer).
[2] Place sample in container (start at lowest or highest relative density depending on sample).
[3] Remove floats, remove sinks.
[4] Remove dense liquids from floats and sinks – filtering and/or washing.
[5] Dry samples.
[6] Weigh and analyses samples.
[7] Calculate washability and plot curves

The specific gravity at which a coal is to be cleaned is determined from the washability data and economic considerations. The ease of washing at this specific gravity may be judged from the amount of near gravity material (ngm) present in the coal. The amount of this material is defined as the percentage of the coal that will float in a range within plus minus 0.10 specific gravity of the separation value. The presence of ngm causes misplacements of sinks in floats and floats in sinks. The larger the amount of ngm, the more difficult the cleaning operation, and vice versa. The following table shows the estimate of coal washing problem from the amount of near-gravity material.

Degree of separation difficulty according to B.M.Bird

Amount of ngm %		Degree of difficulty	Comments
Greater than	**Less than**		
0	7	simple	Almost any process, high tonnages
7	10	Moderately difficult	Efficient process, high tonnages
10	15	Difficult	Efficient process, good operation, medium tonnages
15	20	Very difficult	Efficient process, expert operation,low tonnages
20	25	Exceedingly difficult	Very efficient process, expert operation, low tonnages
25	-	Formidable	Limited to a few exceptionally efficient processes, expert operation, low tonnages

(Ref. Bird, B. M., 1931, Interpretation of Float-and-sink Data, Proceedings of the Third International Conference on Bituminous Coal, Pittsburgh. Vol. 2)

2.9 Washability Characteristics

The raw coal contains impurities after its primary sizing operations. It contains the minerals matter with which it was associated underground and some other materials getting mined up during handling. But these should not be operation by which coal is cleaned is known as coal cleaning. The properties which are used in coal cleaning are specific gravity, shape and size of the particles, friction, resilience, surface tension etc. Cleaning process generally depends upon differences in density between clean coal and its impurities. They suitably remove the free dirt but not the inherent dirt. The extent of removal of free dirt on the amenability of a coal to improvement in quality is more commonly known as the "washability" of coal and is more commonly indicated by the "float and sink" analysis of coal. These washability investigations are conducted before average proposal for installation of a coal washery is considered.

(Ref. James G. Speight, Mercel Dekker, 1994, The Chemistry and Technology of coal . 1st edition.D.V. SubbaRao, Coal Its Beneficiation, M.K. Publications, 2003.

Tsai, S. C., "Fundamental of Coal Beneficiation and Utilization", Elsevier, Amsterdam, 1982)

III. RESULTS AND DISCUSSION

This chapter presents the results obtained from the experiment carried out during the course of study, related discussions are presented. Experimental results obtained from characterizations study, size analysis, proximate analysis, ultimate analysis, gross calorific value (GCV), HGI, free swelling index (FSI), Specific gravity, washability analysis tests in the forms of tables.

3.1 Characteristics Of Feed Coal

Table 3.1: Proximate Analysis

ASH(%)	MOISTURE (%)	VOLATILE MATTER (%)	FIXED CARBON (%)
35.13	0.37	17.56	46.94

Table 3.2: Ultimate Analysis

CARBON (%)	HYDROGEN (%)	NITROGEN (%)	SULPHER (%)	OXYGEN (%)
54.50	3.62	1.09	0.37	4.92

GROSS CALORIFIC VALUE = 5169.30 kcal/kg

HARDGROVE GRINDIABILITY INDEX =87.08

FREE SWELLING INDEX= 1

3.2 Size Analysis

Table 3.3: Size Analysis Of Each Size Fraction Of Rom Coal

SIZE(MM)	WEIGHT (%)	CUMMULATIVE PASSING	CUMMULATIVE RETAINING
50.8	11.52	-	11.52
-50.8+38	12.04	88.48	23.56
-38+25.4	13.70	76.44	37.26
-25.4+19	8.44	62.74	45.70
-19+12.6	10.07	54.30	55.77
-12.6+6.3	12.11	44.23	67.88
-6.3+3.2	7.37	32.12	75.25
>3.2	24.75	24.75	-

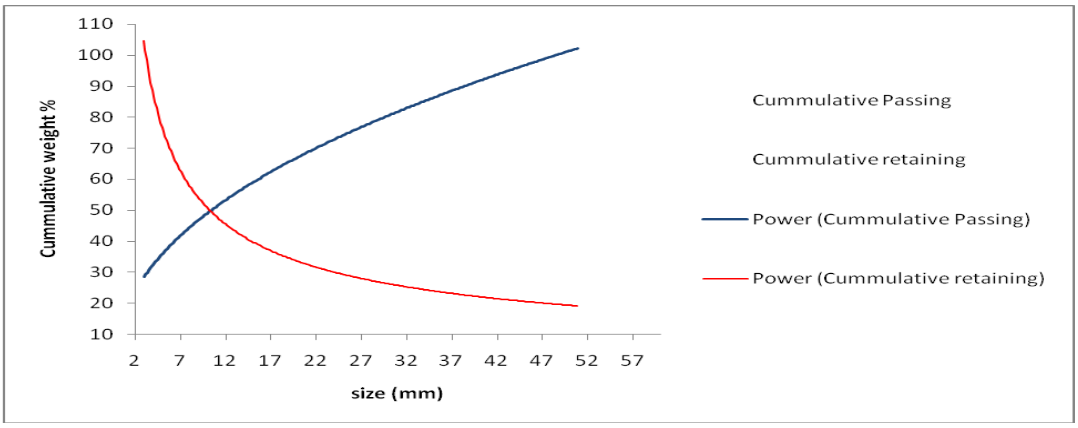


Fig.3 Size analysis of each size fraction of rom coal

Table 3.4: Size analysis of each size fraction of rom coal

d_{50}	10mm
d_{90}	39mm
d_{10}	48mm

3.3: Screening And Size Wise –Proximate, Ultimate, Gcv, Hgi, Fsi & Specific Gravity Analysis

Table3.5: Proximate Analysis

SIZE (mm)	ASH (%)	MOISTURE (%)	VM (%)	FC (%)
50.8	31.03	0.21	17.32	51.44
-50.8+38	35.49	0.29	17.64	46.58
-38+25.4	33.54	0.19	17.37	48.90

-25.4+19	37.47	0.18	17.43	44.92
-19+12.6	36.39	0.13	17.61	45.47
-12.6+6.3	35.87	0.33	17.32	46.48
-6.3+3.2	35.05	0.35	17.23	52.63
>3.2	30.12	0.39	18.46	51.03

Table 3.6: Ultimate Analysis

SIZE (mm)	CARBON (%)	HYDROGEN (%)	NITROGEN (%)	SULPHER (%)	OXYGEN (%)
50.8	59.55	3.36	1.06	0.42	4.37
-50.8+38	54.38	3.52	1.07	0.37	4.88
-38+25.4	56.09	3.58	1.04	0.50	5.06
-25.4+19	53.23	3.47	1.10	0.39	4.16
-19+12.6	53.00	3.65	1.06	0.28	5.49
-12.6+6.3	49.89	4.30	1.02	0.86	7.73
-6.3+3.2	54.67	3.56	1.06	0.42	4.89
>3.2	59.95	3.76	1.24	0.78	3.76

Table 3.7: Gross Calorific Value:

SIZE(mm)	GCV(KCAL/KG)
50.8	5707.9
-50.8+38	5275.8
-38+25.4	5388.7
-25.4+19	5086.1
-19+12.6	5163.3
-12.6+6.3	5214.3
-6.3+3.2	5228.0
>3.2	5652.4

Table 3.8: Hardgrove Grindability Index:

SIZE(mm)	HGI
50.8	88.26
-50.8+38	84.17
-38+25.4	96.16
-25.4+19	79.94
-19+12.6	83.82
-12.6+6.3	89.50
-6.3+3.2	81.74
>3.2	119.37

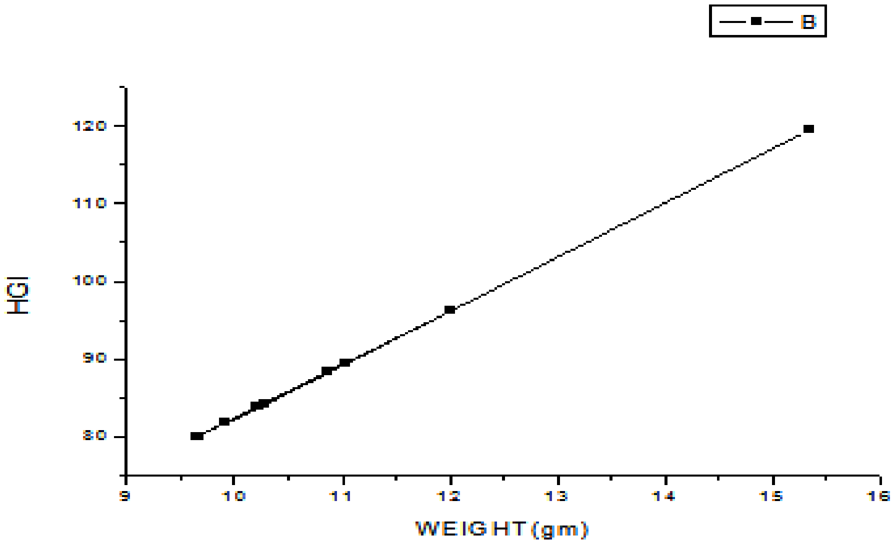


Fig. 4 Hardgrove Grindability Index

Table 3.9: Free Swelling Index:

SIZE(mm)	**FSI**
50.8	1
-50.8+38	1
-38+25.4	1
-25.4+19	1
-19+12.6	1
-12.6+6.3	1
-6.3+3.2	1
>3.2	1.5

Table 3.10: Specific Gravity Of Rom Coal

SIZE	**SPECIFIC GRAVITY**
-200#	1.5123

Table 3.11: Specific Gravity Of Each Size Fraction Of Rom Coal

SIZE(mm)	**SPECIFIC GRAVITY**
50.8	**1.7059**
-50.8+38	**1.6328**
-38+25.4	**1.5953**
-25.4+19	**1.5804**
-19+12.6	**1.5514**
-12.6+6.3	**1.5311**
-6.3+3.2	**1.5283**
>3.2	**1.5047**

3.4 Washability Characteristic Of Low Volatile Coking Coal:

Table 3.12: Washability Characteristic For Size Fraction -6.3+3.2 mm

Sp. Gravity	Wt.%	Ash%	Cumulative Float Wt.%	Cumulative Float Ash%	Cumulative Sink Wt.%	Cumulative Sink Ash.%	ngm	Z
<1.3	1.44	5.45	1.44	5.45	100	32.8	10.85	0.72
1.3-1.4	9.41	10.76	10.85	10.05	98.56	33.19	32.09	6.14
1.4-1.5	22.68	20.24	33.53	16.94	89.15	35.56	50.88	22.19
1.5-1.6	28.20	28.37	61.73	22.16	66.47	40.79	39.19	47.63
1.6-1.7	10.99	35.27	72.72	25.83	38.27	49.94	38.27	67.22
>1.7	27.28	55.86	100	32.8	27.28	55.86	35	86.36

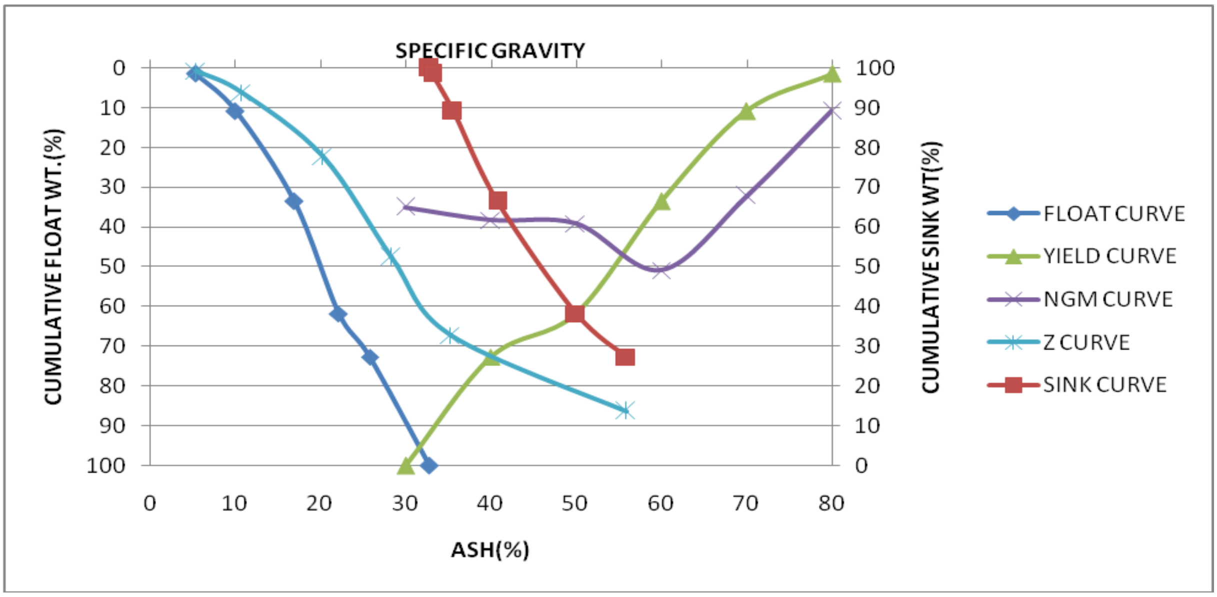


Fig.5 washability characteristic for size fraction -6.3+3.2 mm

Acc (%)	Ycc (%)	CDcc/m	NGMcc/m (%)	Am (%)	Ym (%)	CDm/r	NGMm/r (%)	Ar (%)	Yr (%)
17	**34**	**1.4**	**51**	**31.41**	**44**	**1.63**	**35**	**60**	**22**

Table 3.13: Washability Characteristic For Size Fraction -12.6+6.3 mm

Sp. Gravity	Wt.%	Ash%	Cumulative Float Wt.%	Cumulative Float Ash%	Cumulative Sink Wt.%	Cumulative Sink Ash. %	NGM	Z
<1.3	0.75	4.93	0.75	4.93	100	33.71	6.65	0.37
1.3-1.4	5.90	11.77	6.65	10.99	99.25	33.93	30.62	3.7
1.4-1.5	24.72	20.24	31.37	18.28	93.35	35.33	60.33	19.01
1.5-1.6	35.61	30.78	66.98	24.92	68.63	40.77	46.81	49.17
1.6-1.7	11.20	39.78	78.18	27.05	33.02	51.54	33.02	72.58
>1.7	21.82	57.58	100	33.71	21.82	57.58	24	89.09

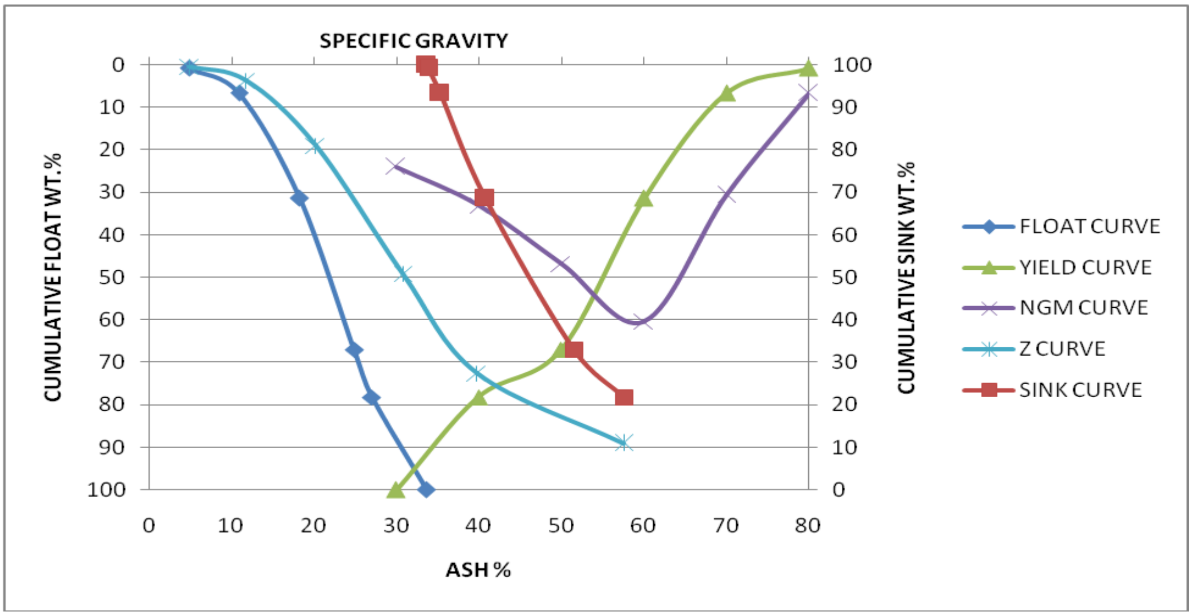


Fig.6 washability characteristic for size fraction -12.6+6.3 mm

Acc (%)	Ycc (%)	CDcc/m	NGMcc/m (%)	Am (%)	Ym (%)	CDm/r	NGMm/r (%)	Ar (%)	Yr (%)
17	**26**	**1.38**	**55**	**31.49**	**53**	**1.62**	**31**	**60**	**21**

Table 3.14: Washability Characteristic For Size Fraction -19+12.6 mm

Sp. Gravity	Wt.%	Ash%	Cumulative Float Wt.%	Cumulative FloatAsh%	Cumulative Sink Wt.%	Cumulative Sink Ash.%	NGM	Z
<1.4	4.15	13.11	4.15	13.11	100	34.64	24.6	2.07
1.4-1.5	20.45	19.83	24.6	19.69	95.85	35.97	60.72	14.37
1.5-1.6	40.27	29.02	64.87	25.1	75.4	39.84	48.32	44.74
1.6-1.7	8.05	37.64	72.92	26.48	35.13	52.25	35.13	68.89
>1.7	27.08	56.6	100	34.64	27.08	56.6	25	86.46

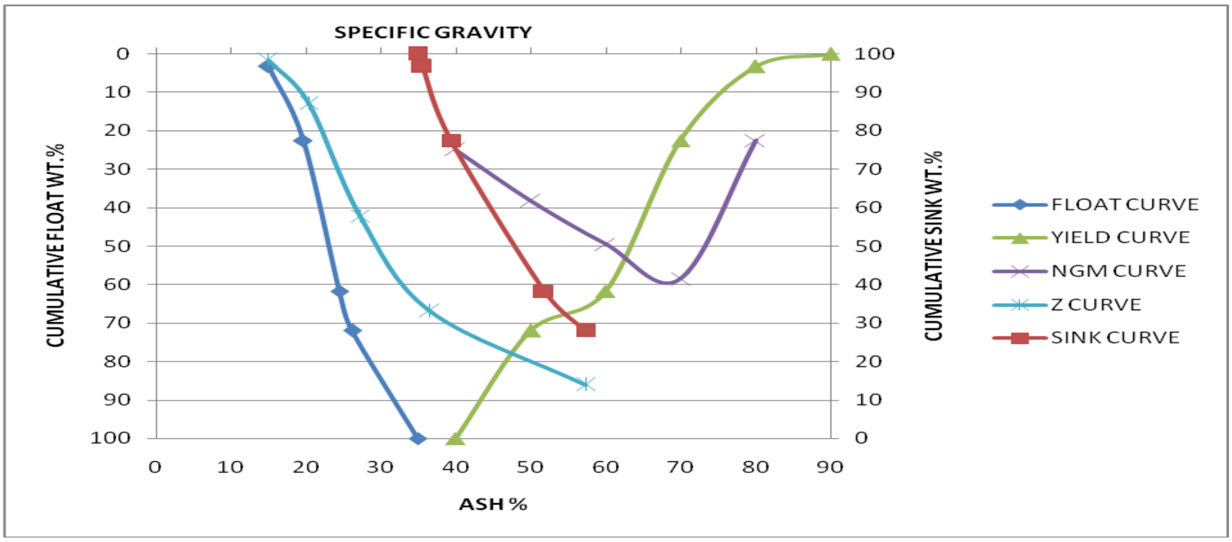


Fig.7 washability characteristic for size fraction -19+12.6

Acc (%)	Ycc (%)	CDcc/m	NGMcc/m (%)	Am (%)	Ym (%)	CDm/r	NGMm/r (%)	Ar (%)	Yr (%)
17	**13**	**1.35**	**40**	**29.11**	**64**	**1.62**	**33**	**60**	**23**

Table3.14: Washability Characteristic For Size Fraction -25.4+19mm

Sp. Gravity	Wt.%	Ash%	Cumulative Float Wt.%	Cumulative Float Ash%	Cumulativ e Sink Wt.%	Cumulative Sink Ash.%	NGM	Z
<1.4	3.28	14.98	3.28	14.98	100	34.88	22.51	1.64
1.4-1.5	19.23	20.37	22.51	19.58	96.72	35.55	58.46	12.89
1.5-1.6	39.23	27.23	61.74	24.44	77.49	39.33	49.54	42.12
1.6-1.7	10.31	36.57	72.05	26.18	38.26	51.72	38.26	66.89
>1.7	27.95	57.32	100	34.88	27.95	57.32	27	86.02

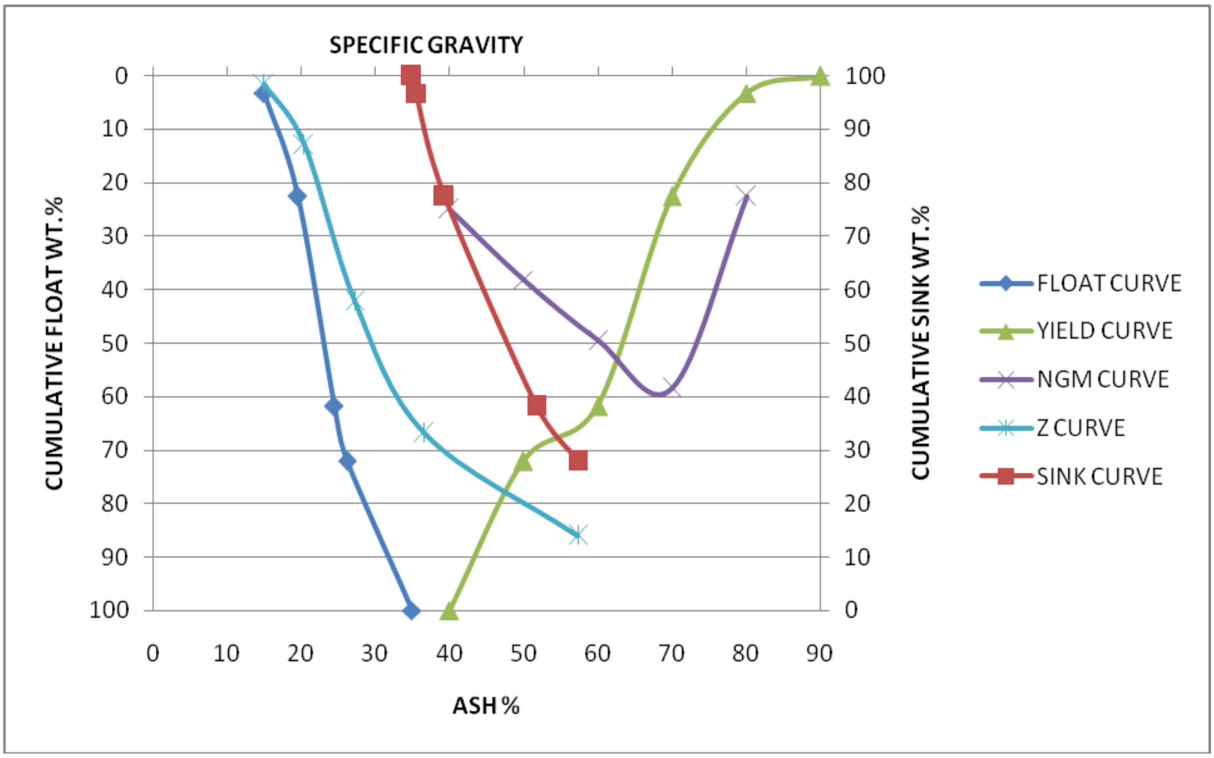


Fig.8 washability characteristic for size fraction -25.4+19mm

Acc (%)	Ycc (%)	CDcc/m	NGMcc/m (%)	Am (%)	Ym (%)	CDm/r	NGMm/r (%)	Ar (%)	Yr (%)
17	**10**	**1.34**	**40**	**28.45**	**66**	**1.62**	**36**	**60**	**24**

Table 3.15: Washability Characteristic For Size Fraction -38+25.4mm

Sp. Gravity	Wt.%	Ash%	Cumulative Float Wt.%	Cumulative Float Ash%	Cumulative Sink Wt.%	Cumulative Sink Ash. %	NGM	Z
<1.4	2.44	16.51	2.44	16.51	100	35.28	20.22	1.22
1.4-1.5	17.78	20.69	20.22	20.18	97.56	35.75	55.7	11.33
1.5-1.6	37.92	27.31	58.14	24.83	79.78	39.11	51.18	39.18
1.6-1.7	13.26	35.03	71.4	26.72	41.86	49.81	41.86	64.77
>1.7	28.60	56.66	100	35.28	28.6	56.66	30	85.7

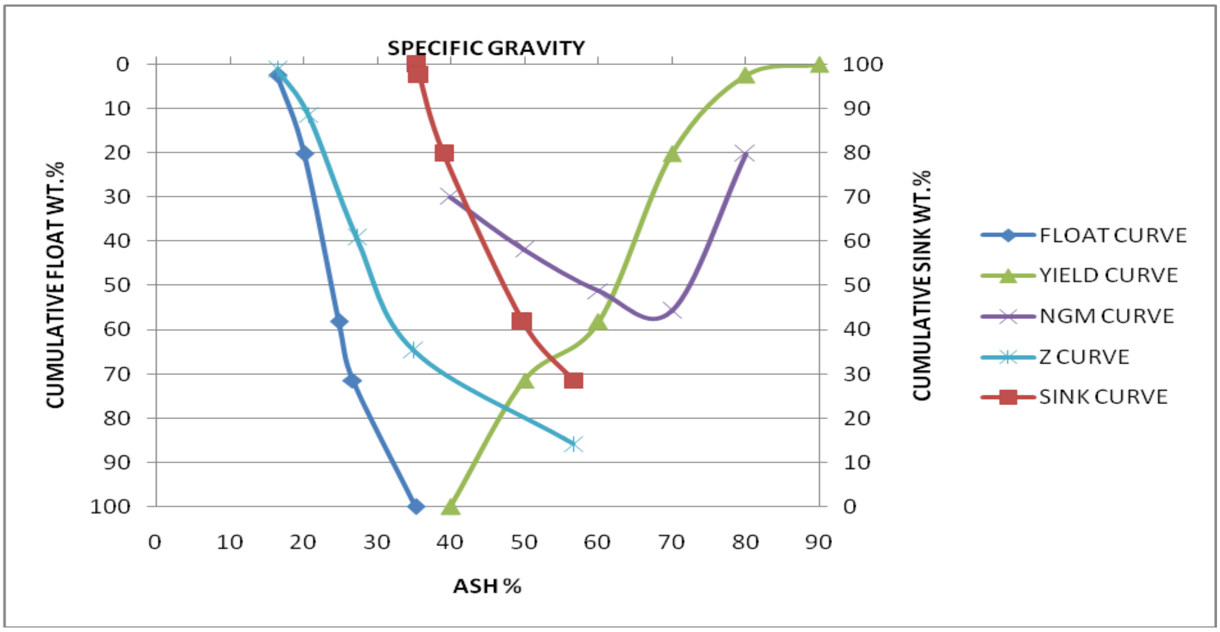


Fig.9 washability characteristic for size fraction -38+25.4mm

Acc (%)	Ycc (%)	CDcc/m	NGMcc/m (%)	Am (%)	Ym (%)	CDm/r	NGMm/r (%)	Ar (%)	Yr (%)
17	**6**	**1.32**	**26**	**28.82**	**71**	**1.62**	**39**	**60**	**23**

Table 3.16: Washability Characteristic For Size Fraction -50.8+38mm

Sp. Gravity	Wt.%	Ash%	Cumulative Float Wt.%	Cumulative Float Ash%	Cumulative Sink Wt.%	Cumulative Sink Ash. %	NGM	Z
1.4-1.5	10.43	18.41	10.43	18.41	100	37.24	48.35	5.21
1.5-1.6	37.92	28.18	48.35	26.07	89.57	39.43	65.78	29.39
1.6-1.7	27.86	38.68	76.21	30.68	51.65	47.69	51.65	62.28
>1.7	23.79	58.26	100	37.24	23.79	58.26	42	88.1

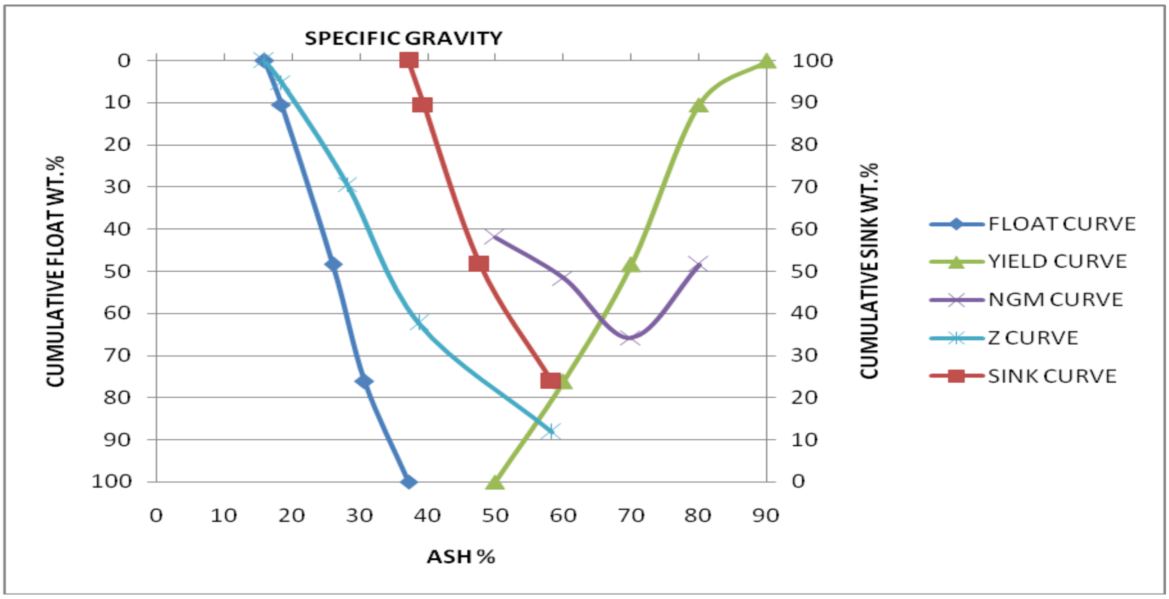


Fig.10 washability characteristic for size fraction -50.8+38mm

Acc (%)	**Ycc (%)**	**CDcc/m**	**NGMcc/m (%)**	**Am (%)**	**Ym (%)**	**CDm/r**	**NGMm/r (%)**	**Ar (%)**	**Yr (%)**
17	**7**	**1.37**	**35**	**33.32**	**74**	**1.62**	**47**	**60**	**19**

Table :3.17 Washability Characteristic For Size Fraction +50.8mm

Sp. Gravity	Wt.%	Ash%	Cumulative Float Wt.%	Cumulative Float Ash%	Cumulative Sink Wt.%	Cumulative Sink Ash. %	NGM	Z
1.4-1.5	8.01	20.51	8.01	20.51	100	45.85	33.05	4
1.5-1.6	25.04	29.67	33.05	27.44	91.99	48.06	39.27	20.53
1.6-1.7	14.23	37.48	47.28	30.46	66.95	54.94	66.95	40.16
>1.7	52.72	59.66	100	45.85	52.72	59.66	48	73.64

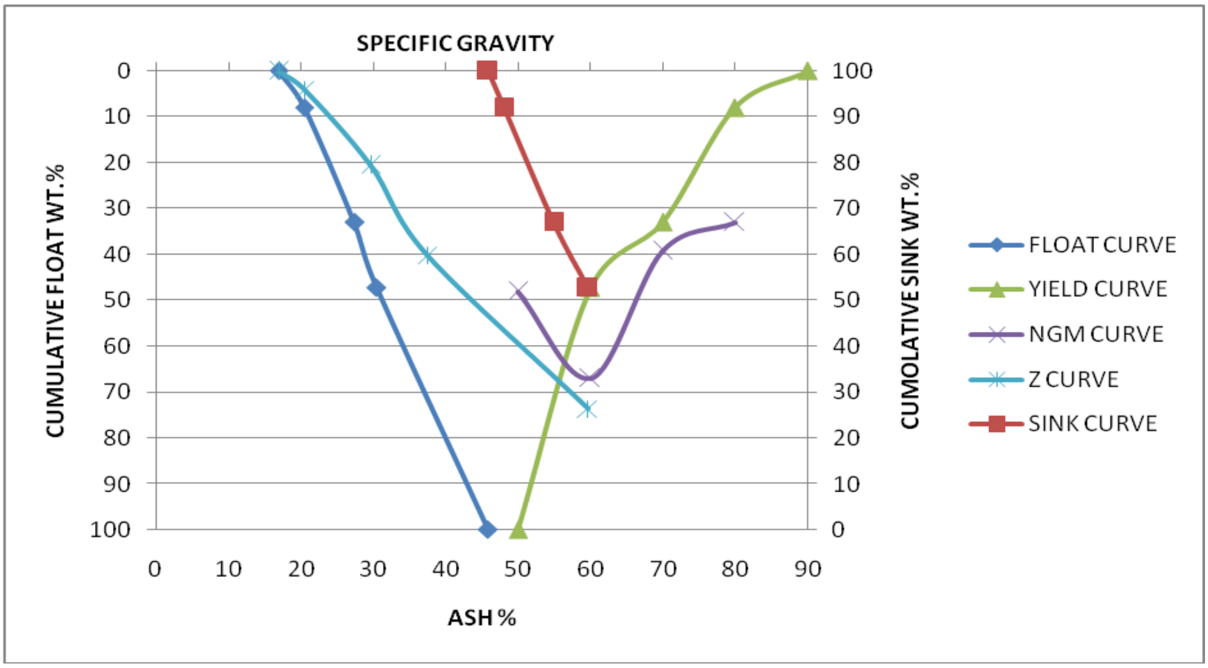


Fig.11 washability Characteristic For Size Fraction +50.8mm

Acc (%)	**Ycc (%)**	**CDcc/m**	**NGMcc/m (%)**	**Am (%)**	**Ym (%)**	**CDm/r**	**NGMm/r (%)**	**Ar (%)**	**Yr (%)**
18	**3**	**1.35**	**23**	**30.70**	**44**	**1.60**	**67**	**60**	**53**

3.5 Discussions: On the basis of experimental results the following discussion are made;

- From **float and sink** test of the coal sample, size of (-6.3 + 3.2mm), it was found that from the Table 4.11 the ash at lowest specific gravity (1.2) was 5.45 % and at highest specific gravity (>1.7) the ash % of coal was 55.86 %.
  From the Fig. 4.3, it was observed that the optimum specific gravity of separation is 1.4 with total float yield 34% at cumulative ash % of 17 i.e. on beneficiation of the coal in a medium of specific gravity 1.4 , 34 wt. % of coal having 17 % ash was obtained. From the washability data and curves, Characteristic ash% of clean coal is 24%, Characteristic ash% of reject coal is 46%, Characteristic ash% of middling coal is between 24% and 46% and near gravity material of clean coal is 51%. If the near gravity material is very high, it may be regarded as difficult to wash category coals.
- From the Table 4.12 of the coal sample size of (-12.6+6.3mm), it was observed that the ash at lowest specific gravity (1.2) was4.93% ash and at highest specific gravity (>1.7), the ash % of coal was 57.58 %.

From the Fig 4.4, it can be seenthat the optimum specific gravity of separation is 1.38 with total float yield 26% at cumulative ash % of 17 i.e. on beneficiation of the coal in a medium of specific gravity 1.38,26% wt. of coal having 17 % ash is achievable. From the washability data and curves, Characteristic ash% of clean coal is 23%, Characteristic ash % of reject coal is 49%, Characteristic ash % of middling coal is between 23% and 49% and Near gravity material of clean coal is 55%.

- From the Table 4.13 of the coal sample size of (-19+12.6mm),it was found that the ash at lowest specific gravity (1.3) was13.11% ash and at highest specific gravity (>1.7), the ash % of coal was 56.60 %.
  From the Fig 4.5 , it can be depictedthat the optimum specific gravity of separation is 1.35 with total float yield 13% at cumulative ash % of 17 i.e. on beneficiation of the coal in a medium of specific gravity 1.35, only13 wt. % of coal having 17 % ash could be obtained. From the washability data and curves, Characteristic ash% of clean coal is 20%, Characteristic ash % of reject coal is 46%, Characteristic ash % of middling coal is between 20% and 46% and Near gravity material of clean coal is 40%.
- From the Table 4.14 of the coal sample size of (-25.4+19mm), it was observed that the ash at lowest specific gravity (1.3) was14.98% ash and at highest specific gravity (>1.7), the ash % of coal was 57.32 %.
  It was It may be observed from Fig 4.6, that the optimum specific gravity of separation is 1.34 with total float yield 10% at cumulative ash % of coal having 17 % ash. From the washability data and curves, Characteristic ash% of clean coal is 19%, Characteristic ash % of reject coal is 45%, Characteristic ash % of middling coal is between 19% and 45% and Near gravity material of clean coal is 40%.
- From the Table 4.15 of the coal sample size of (-38+25.4mm), it was found that the ash at lowest specific gravity (1.3) was16.51% ash and at highest specific gravity (>1.7), the ash % of coal was 56.66 %.
  It was observed from the Fig 4.7 that the optimum specific gravity of separation is 1.32 with total float yield 6% at cumulative ash %of coal having 17 % ash. From the washability data and curves, Characteristic ash% of clean coal is 19%, Characteristic ash % of reject coal is 46%, Characteristic ash % of middling coal is between 19% and 46% and Near gravity material of clean coal is 26%.
- From the Table 4.16 of the coal sample size of (-50.8+38mm), it was found that the ash at lowest specific gravity (1.4) was18.41% ash and at highest specific gravity (>1.7), the ash % of coal was 58.26 %.
  It was observed from the Fig 4.8 that the optimum specific gravity of separation is 1.37 with total float yield 7% at17 % cumulative ash %. From the washability data and curves, Characteristic ash% of clean coal is 20%, Characteristic ash % of reject coal is 51%, Characteristic ash % of middling coal is between 19% and 46% and Near gravity material of clean coal is 35%.
- From the Table 4.17 of the coal sample size of (+50.8) it was found that the ash at lowest specific gravity (1.4) was20.51% ash and at highest specific gravity (>1.7), the ash % of coal was 59.66 %.
  From the Fig4.9, it was observed that the optimum specific gravity of separation is 1.35 with total float yield 3% at18 % cumulative ash. From the washability data and curves, Characteristic ash% of clean coal is 23%, Characteristic ash % of reject coal is 49%, Characteristic ash % of middling coal is between 23% and 49% and Near gravity material of clean coal is 23%.

IV. CONCLUSION

From the experimental result and subsequent discussion the following conclusion are drawn.

- Large size fractions of coal contains very high ash% so small size fraction of coal was used for the washing purpose because it contain comparatively low ash% as it is observed in washability data such as size fraction from +50.8mm contain high ash% as compare to small size fraction from -6.3+3.2mm as very low ash%.
- Generally, washability of low volatile medium coking coal can be improved by crushing it to lower size. Most of the washaries wash the LVMC coal up to a size of -13mm but on further grinding it to lower sizes of around -3mm increases the yield further. Difficult washability characteristics of LVMC coal is due to fine dissemination of mineral particles with macerals and ash% of marketable product which can further be improved by making coal blendable with prime coking coal, so that this coal can be used in various steel plants.
- On the basis of results obtained by conducting different experiments and considering different aspects of beneficiation, a complete cost-benefit analysis is necessary prior to taking decision of washing these coals. Crushing at lower size involves increased cost of size reduction, cost of beneficiation and the handling cost of materials although there is increase in the yield of the beneficiated coal.
- From the washability analysis, crushing of coal to less than ½ inch is economical.
- From the washability data it is observed that for coal crushed to 1/8 -1/4 inch at 17% ash the yield is 34 % at 1.4 cut gravity.
- Washing at 17% ash, NGM is very high. It indicates difficult washing. So there is need for blending LVMC (after beneficiation) with prime coking coal.

- The clean coal can be used as a blend constituent for coke making in steel plants and the middling's can be used in power plants.
- Utilization of LVMC coals after suitable beneficiation can reduce the import of coking coal, thereby saving considerable amount of foreign exchange.

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