Geochemical characterisation of coal with special reference to thermal industries of Dhanpuri Open Cast Project, Sohagpur Coalfield, Madhya Pradesh, India

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Abstract - *Coal industry is very important for developing countries like India. India has a vast reservoir of coal in the world, come on the world's fifth-largest coal proved reserves including Lignites (Approx. 100 billion tonnes). Coal is a mixture of heterogeneous rock materials, including organic as well as inorganic contents in it, that's why the most advanced technology is used for its characterisation to meet as per the demand in thermal industries. In the thermal industry of India, coal grade is analysed by the Proximate analysis & Gross Calorific Value (GCV). The investigation area is Sohagpur coalfield of Gondwana group. Coal bearing formation of Sohagpur coalfield is Barakar formation. The average value of moisture% is 2.8, Ash% is 15.12, Volatile matter% is 26.71 & Fixed carbon% is 55.32 in coal samples. Relation of ash% in coal & its grade is inversely proportional to each other, that's why ash content should be lower for producer & consumers also. According to the joint work of XRD & FTIR, we know about the characteristics minerals, organic group & bonding present in coal. This study will unveil the reason of grade variation in coals, which will be helpful in thermal industries. The inorganic content (Minerals) & sulphur amount in coal tells us the allocthonous deposition in Mahanadi Basin of the Gondwana group. In this paper we are trying to know the reason in grade variation of coal, these studies can unveil to very minute details present in coal for gradevariation.*

Keywords: *Proximate analysis, Ultimate analysis, X-ray diffraction, Fourier transform infrared spectroscopy, Coal Characterisation*

I. INTRODUCTION

Coal is playing a very crucial role in developing countries like India because coal is very cheap & easy to use. India has a vast reservoir of coal. The Bulk of the coal produced in India is thermal coal. It provides 60% of the nation's electricity (Joonseok & Johannes, 2019). The present updated coal resource of India is about 315148.81 MT, out of which 313561.13MTcoal is reported to be contained by the Gondwana coalfields (Indian Coal and Lignite Resources-2017, Pg 1). The major coal-bearing formation of the Gondwana Basins is the Lower Permian Barakar Formation (Mukhopadhyay, 2018; Dutta, 2002).

Coal is a mixture of heterogeneous organic as well as inorganic materials & for this reason, many analytical techniques are used for its characterisation. This is a special type of rock that consists of organic carbonaceous matter include macerals & inorganic minerals. Mineral matter represents the mineralogical phase as well as other inorganic elements in coal. The quality & quantity of coal ash depends upon the rank & grade of coal. More ash in coal leads to more poorer quality of coal & for this cost of coal goes higher, which is a burden over the producer as well as on the consumers. This is the reason that coal quality should be identified through analysis for a better understanding of coal for thermal industries. This paper presents Proximate analysis, Ultimate analysis, X-Ray Diffraction analysis & Fourier Transform Infrared Spectroscopy Analysis data on investigated area i.e. Dhanpuri open cast project of Sohagpur coal field.

A. StudyArea

The coal mine of Dhanpuri Open Cast Project (OCP) is situated at border of Shadol & Anuppur district of Madhya Pradesh (India). The coalfield of Dhanpuri OCP is Sohagpur Coalfield. This comes under theSouth Eastern Coalfield (SECL) of Coal India Limited. The area is a graben structure of Son Valley Basin belt. The Dhanpuri OCP is surrounded by many coal mines including open cast as well as underground. The coal block is located at the latitude of 23°09'10.6"N & longitude 81°35’21.7”E.The Son River is about 6 km to the NNE direction from the coal mine.

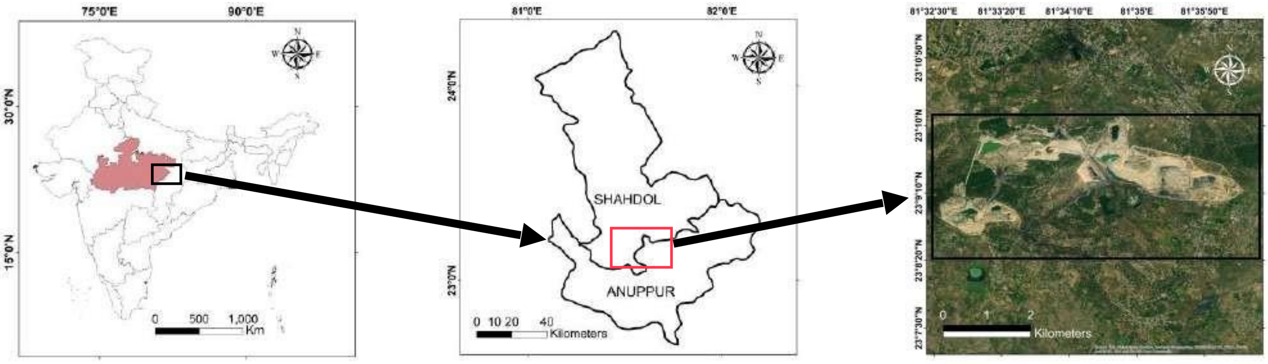

Figure No. 1 (near here) Location of investigated area in map

B. Geological Setting

The Sohagpur coalfield lies within one of the many Permian & Triassic extensional basins that occur in central and eastern India (Mitra, 1997). In general, these basins were formed during later part of mesozoic prior to the ultimate breakup from Gondwanaland into its component. Through the breakup and extension of these basins are generally broken into low angle inclined blocks by one or more normal faults.

In the Sohagpur coalfield, the strata strike generally

WNW-ESE and dip to the North at low angles(1-4 degrees) (Rao, 1983), although near the faults the dips may be much greater. The area is traversed by a number of faults. A major en-enchelon ENE-WSW trending fault with down throw towards the North runs through the middle part of the coalfield, along its southern boundary, and is named as Bamhani-Chilpa faults (Pareek, 1987). A major part of the Sohagpur Subbasin is covered by the Raniganj strata (Late Permian), whereas truncated wedges of Barren Measures (Early to Late Permian) occur in both sides of the Bamhani-Chilpa Fault, while rectilinear Barakar Formation outcrops in the upthrown side of the fault (Mukhopadhyay, 2018).

II. Material &Methods

A. Sample Collection

Coal samples have been collected from the Sohagpur coalfield of Madhya Pradesh in India. The samples were collected by the Pillar sampling method from the running coal seam. Every collected coal samples were put in Ziplock plastic bags & sealed immediately carefully to minimise oxidation & contamination. After collecting it, samples were crushed according to the mesh size required for analysis in laboratory.

B. Proximate & Ultimate Analysis

For general purpose proximate analysis is taken into consideration but it is very important for thermal industries. Proximate analysis include determination of moisture%, volatile matter%, fixed carbon% and ash% content following standards to measure it. This process is widely used for industrial purpose as well as grading of coals.

After crushing the samples & pulverised to less than -72 mesh size, coal samples is reduced to 0.5 kg by coning & quartering method. Moisture% (Inherent moisture & free moisture), Ash%, Volatile Matter%, & Fixed Carbon% is determined of the study area. The idea of sampling is to take a representative portion of the bulk sample originally brought to the laboratory (Chandra et.al 2000).

Moisture is found in coal through two types : (a) Free moisture (b) Inherent moisture. Free moisture can be happen in coal when it comes in contact with water in seam or either through the washery.

For moisture analysis in coal samples, 1 g of air dried coal(ground to pass through 212 micron IS sieve) isaken in silica dish & heated to a temperature at 108°±2°C in an oven. Loss in weight before and after heating of coal sample is taken as moisture content in coal. Water is present in the form of moisture in coal is inherent & free moisture. It may be physical or chemically bonded with coal that decomposes after heating 108°±2°C . For determination of inherent moisture in coal, the method adopted here is according to Chandra et.al (2000).

Ash is come by the complete combustion of inorganic mineral matter of coal. The formation of mineral matter in coal is occur by two methods. First one is inherent mineral matter and second one is adventitious or epigenetic mineral matter which is deposited in gap like cleat, fissure, cleavage and cracks developed in coal. For ash percentage in coal, 1gm of air dried coal (ground to pass through 212 micron IS sieve) is taken in a dish made up of silica. The dish containing coal should be in very thin layer and heated in muffle furnace. First the temperature is raised to 500°C in 30 minutes and then again raised to 815°±10°C in another 30 to 60 minutes. Temperature is maintained for another 60 minutes. After that the dish is taken out and cooled. Loss in weight before and after heating of coal is

Sample	M	A	VM	FC*	C	H	N	O	S	H/C	O/C	GCV(Kcal/gm)
A1	3.52	13.7	32.62	50.08	64.11	4.45	0.59	15.3	1.76	0.8	0.1	5537
A2	1.95	12.5	15.98	69.55	63.38	4.79	0.65	11.4	1.10	0.8	0.1	5638
B3	2.34	20.6	29.60	47.45	59.13	4.1	0.57	14.4	1.21	0.8	0.2	4791
C1	3.41	13.7	28.65	54.21	65.36	4.2	0.54	26.7	0.56	0.9	0.3	5798

*by the difference

Table 1 (near here) Proximate analysis, ultimate analysis result & gross calorific value of coal samples

calculated and expressed as Ash% incoal.

For Volatile matter in coal, 1 g of air dried coal(ground to pass through 212 micron IS sieve) is taken into a crucible with a lid & placed in muffle furnace which have already temperature of 900°±10°C for a period of 7 minutes. Loss in weight is then calculated before and after heating. Data is expressed in form of percentage of the coal samples. But this data is also contain the % of moisture, so that it should be deducted from the total percentage of volatile matter & then it is expressed as true volatile matter% in coal samples.

For ultimate analysis, samples were analysed by the CHNOS-Euro EA Elemental Analyzer.

C. X-Ray Diffraction Analysis

Coal samples from the open cast mine of Dhanpuri were taken for investigation. Analysis done by the Rigaku Miniflex 600 Desktop X-Ray Diffraction System at room temperature. Coal samples analysed are in powder form of -72 mesh size. First coal samples were placed in sample holder tray that makes a very thin layer of sample due to it's square shape groove. That sample holder then placed inside the tube of X-ray diffraction analyser.

D. Fourier Transform Infrared Spectroscopy Analysis

This analysis is done by the Nicolet iS5. The samples are being prepared by K-Br method. Sample mixes with the KBr for making pellets & then pressed by the 8 Ton hydraulic pressure. After that the sample placed in the compartment of sample holder. Infrared Rays of the analyser passes from the sample and then graphs is plotted between the transmittance & wave numbers of that sample. To provide adequate characterisation of a mineral by infrared spectroscopy the spectrum recorded in the range of 4000-400 cm-1.

III. Results and Discussion

A. Proximate Analysis

The proximate analysis of coal from table no. 2 revealed the variation of value among the samples. Moisture% ranges from 1.95-3.52, Ash% ranges from 12.50-20.60, Volatile Matter% ranges from 15.98-32.62 and Fixed Carbon% content is calculated

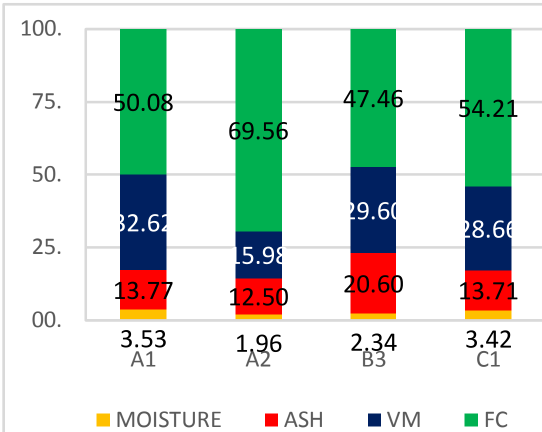

Fig. 2 (near here) Tabular representation of Proximate analysis for coal samples in percentage

by subtraction the sum of moisture, volatile matter, and ash contents from 100, ranges from 47.45-69.55. Less ash contents of these coals shows the coal are of steel grade & washery grade if coking property is present in coal samples. Gross Calorific value of coal samples is from Grade G9 to G6.

B. Ultimate Analysis

Ultimate analysis coal reveals the elemental distribution in among coal samples. Carbon percentage in coal samples ranges from 59 to 65%, Hydrogen ranges from 4.1 to 4.79%, Nitrogen ranges in 0.5%, oxygen ranges from 29 to 34% &

Sulphur ranges from 0.5 to 1.7%. Sulphur content in coal samples are ranging from 0.54 to 1.76% that is also favours the allocthonous deposition of coal in basin.

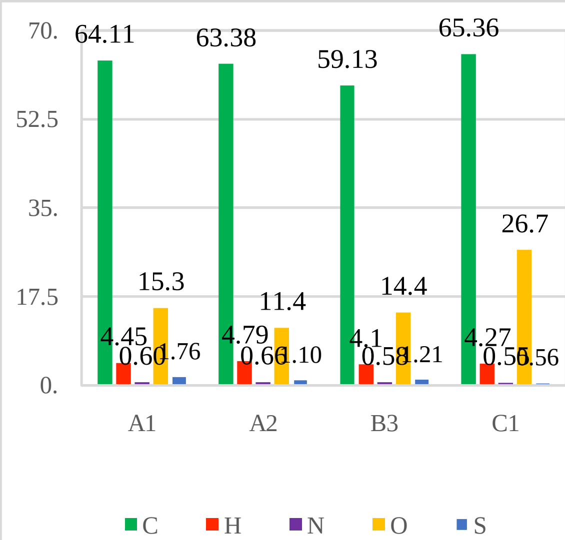

Fig. 3 (near here) Tabular representation of Ultimate analysis for coal samples in percentage

C. X-Ray Diffraction(XRD)

X-ray diffraction analysis of coal samples, graph were plotted by the Origin software. In graph different peak shows the different minerals presence in coal samples. Graph is plotted between the Intensity (A.U. = Arbitrary Unit) on Y-axis & 2theta degree (2θ) values on X-axis. According to XRD data, mineral phase identified by the XRD were Quartz, Kaolinite, Feldspathoid, Anatase(Rutile), Aditionally, peaks of Iron Oxide, Birnessite, Graphite, Beryllium Bis(Hypophosphate), Sodalite,Cr-Oxide, Cossaite, Caesium-Element), Si-Carbide, Millosevichite, Spodumene(Pyroxene), Al-Phosphate, Muscovite, Spangolite were also detected incoal samples. There are few minerals which were reported in coal samples of SECL. Mineral groups present in samples are Native elements, Phosphates, Silicates, Oxides & Sulphates etc. This is the main contribution for mineral matter in form of ash in coals.

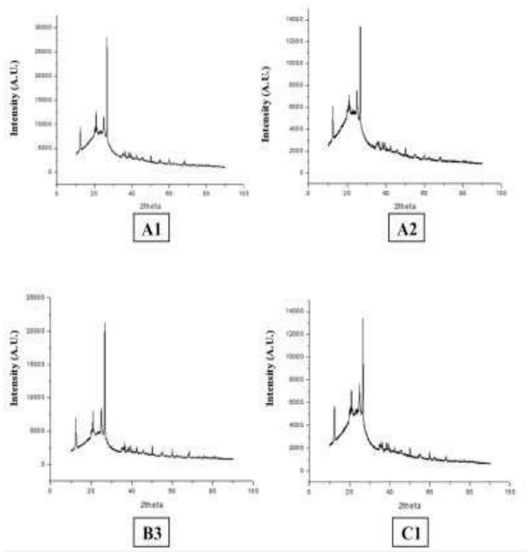

Fig. 4 Graphical representation of X-ray diffraction for all coal samples

Mode of formations of these samples in coal are :

1. Terrigenous detrital minerals
2. Authigenic minerals
3. Diagenetica lterations
4. Plant origin materials

D. Fourier Transform Infrared Spectroscopy (FTIR)

For all the coal samples FTIR figure showed different absorption band for aliphatic group. Different absorption band in graph shows the different characteristics of functional group present in coal samples.

Band Region	Functional group assignment
3600-3200	-OH stretching vibration
3080-3035	Aromatic nucleus CH stretching vibration
2975-2955	Aliphatic CH_3 asymmetric stretching vibration
2925-2919	Aliphatic CH_2 asymmetric stretching vibration
2863	Aliphatic CH_3 symmetric stretching vibration
2848	Aliphatic CH_2 symmetric stretching vibration
2400-2000	Inorganic Carbonyl Compounds
1745-1730	Aliphatic (grease, acid, ketone, aldehyde) (C=O)
1721-1695	Aromatic (carbonyl/carboxyl groups) (C=O)
1650-1630	C=O, highly conjugated
1615-1585	Aromatic nucleus (C=C)
1590-1560	Carboxylic group in salt from COO
1435	Aliphatic CH_2 and CH_3 bending vibration
1380	Symmetric deformation $-CH_2-$ (bending)
1097	Si-O-Si asymmetric stretching vibration
1032	Si-O Stretching of clay mineral
794	Si-O Symmetric
880-860	Aromatic nucleus (CH), one adjacent H deformation
776-730	Aromatic nucleus (CH), three to four adjacent H deformations
463	Amorphous silica Si-O-Si band

Table 2 (near here) Band assignments derived from FTIR spectra (D. Wu et al., 2012; Davis et al., 1981; Painter et al., 1985; Katara et al., 2013; Hlavay et al., 1978; Coates, 1977; Farmer, 1974;Clarence, 1974; Russell, 1987)

By comparing the result of frequency after the literature survey, FTIR shows the presence of strong aliphatic absorption (v-CH, -CH2 & -CH3) in coal samples. Other organic group including -OH, C=C, C-O, C-OH, O=C=O, C-O-C are also present in coal samples. Presence of Kaolinite, Feldspathoid, Quartz, Montmorillonite etc in coal samples can also be confirmed by absorption band showing in graph. Absorption band in 3454 wave number(cm-1) shows the presence of OH group that might be from the Kaolinite mineral of coal. Absorption band of 2923 &1622 wave number(cm-1) shows the presence of organic carbon & organic matter in coal samples.

Here below will discuss about key points functional group present in coal samples.

Sample No. A1 : In this coal sample of we found from the figure no. 5 that the transmittance occur at the wave numbers of 3690, 3618, 3419 is a sign of OH stretching vibration, that due to occurrence of

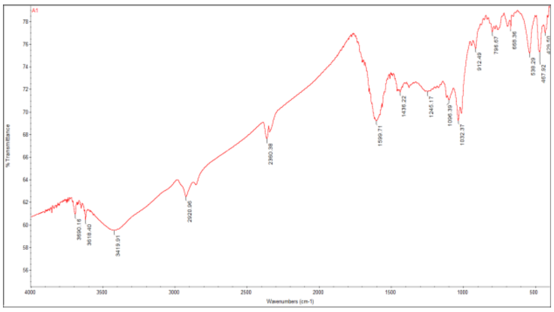

Fig 5 (near here) Graphical representation of FTIR for A-1 sample

Montmorillonite mineral of coal sample (Summer, 1995). Absorbance in 2920 is due to Aliphatic CH_2 asymmetric stretching vibration. 2360 absorbance is due to presence of carbonyl compounds in coal & that should be Carbon dioxide. Absorption in 1097 & 796 band is showing the presence of Quartz, 467 is sign of Felspar present in coal samples.

Sample No. A2 : Here in this coal sample of A2 also shows the absorption band in 3691, 3618 & 3395 that is sign of OH stretching band of Montmorillonite mineral in coal. Difference in sample no. A1 to A2 is due to % Transmittance difference of 20-30%. Additional absorption in A2 at band of 1009, 939 & 686 which is due to presence different functional group in coal samples.

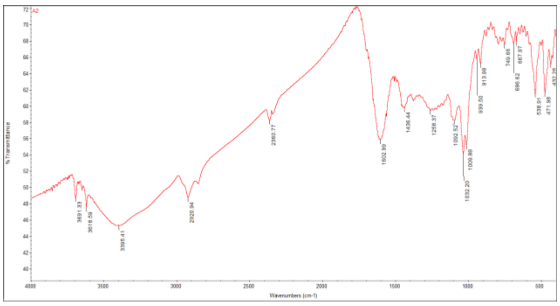

Fig 6 (near here) Graphical representation of FTIR for A-2 sample

Sample No. B3 : Here OH absorption band in range of 3700-3350 is sign of Montmorillonite mineral in coal. The GCV of B3 is also less comparatively to other coal samples of Dhanpuri OCP. So inorganic matter should be high in this sample. Absorption in 1032,

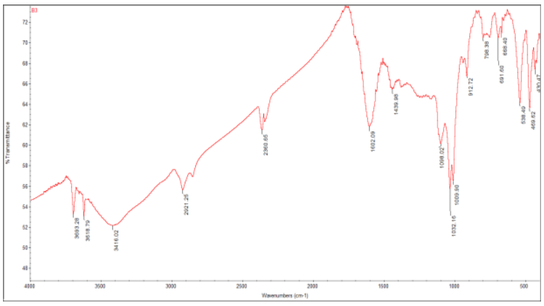

Fig 7 (near here) Graphical representation of FTIR for B-3 sample

1009, 912, 798, 691, 668, 538,469, 430 band confirms the presence of asymmetric & symmetric silica that should be Quartz & other clay minerals. It's all lower the GCV value and increases the ash content in coal.

Sample No. C1 : This sample shows the absorption band in 3853 which is for the first time among all coal samples. Rest all the absorptions are almost same as in rest of coal samples.

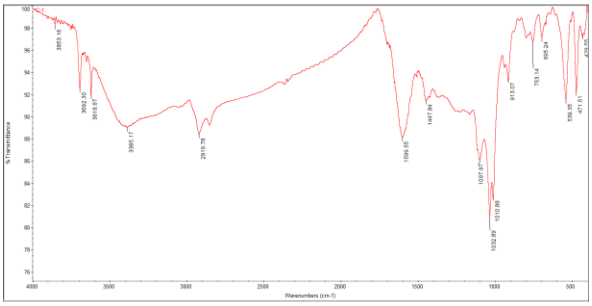

Fig8 (near here) Graphical representation of FTIR for C-1 sample

IV. Conclusion

Coal of Dhanpuri open cast project is suitable for thermal grade coal ranges from G9-G6 grade of coal according to ministry of coal, Government of India. The coals are also suitable for steel grade-I to Washery grade-I if coking properties present due to it's ash content. In the coal samples we can see that the sample B3 has a lesser gross calorific value (GCV) than other coal samples, also can be correlated to a high O/C ratio relatively among other coal samples. H/C ratio decreases with the degree of coalification & can be seen in coal samples of B3 that is lesser. Coal is a bituminous rank of coal. The minerals found in coals are because of the allochthonous nature of coal & sulphur range in coal samples also proves it. XRD & FTIR graph shows the presence of an aliphatic group as well as the presence of inorganic content of coal which plays an important role to determine the rank & grade of coal. This inorganic content is biggest reason for lowering the grade of coal & will lead to burden over producers & consumers in costing of coal, which is required to be cut for profitable extraction. This inorganic matter should be removed after mining through the beneficiation (washing) of coal, so that in transportation from mining areas to site of thermal industries it will be less burden.

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