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Geochemical, Mineralogical, And Structural Characteristics Of Coal From The Gare Pelma Coalfield, Chhattisgarh, India

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Abstract: A variety of analytical methods are used in coal testing to assess the characteristics and makeup of coal. These tests are crucial for figuring out the quality, energy potential, and appropriateness of coal for different uses. In this study study we take four different grade of subbituminous coal samples are collected from Gare Pelma 4/2&3 Mines and we studied. It's moisture content, ash percentage, volatile matter content. We took four different grade samples of grade-17, grade-14, grade-12, grade-11, out of these four samples, sample number 04 has highest carbon percentage with highest Gross Calorific Value (GCV) -4070 Kcal/Kg, moisture% 5.00, ash% 37.86, volatile matter% 25.84 so this coal is considered as the best coal for power generation. The elemental composition also known as Ultimate analysis by SEM/EDAX and chemical structure of coal by XRD. Analytical techniques such as gross calorific value(GCV), proximate analysis (which measures moisture, volatile matter, ash, and fixed carbon) and ultimate analysis (which determines elemental composition like C, H, O, N, and S) help classify coal types and assess their energy potential and environmental impact. X-ray diffraction (XRD) is used to study the crystalline and amorphous phases in coal, particularly to identify mineral content and the degree of structural ordering in carbon-rich components. This study helps in optimizing the combustion efficiency, reduce emission and also ensure cost effective energy production. When we use this type of grading coal for the power generation, then we get less pollution and good environmental performance. The economic significance of coal, the challenges of switching to alternative energy sources, and the potential future of coal mining in the context of international efforts to combat climate change are also covered.

Keywords: Coal characterization; Geochemical analysis; Mineralogy; SEM; XRD; Gare Pelma Coalfield.

INTRODUCTION

Out of all the fossil fuels found on Earth, including coal, oil shales, and gas reserves, coal is the most prevalent. At the location where organic matter grew many millennia ago, there is a deposit of organic matter—the remains of deceased plants and animals—trapped in sedimentary rocks. When coals are burned, they often contain 10–30% inorganic material, which is composed of sand, quartz silt, and clay minerals. This adds to the metal emission burden. (Saikia et al., 2009;Singh et al., 2015 Dai et al., 2016). Coal has consistently held a leading place in China's energy consumption structure in recent years. As industrialization has progressed, the world's coal and electricity industries have brought about significant environmental issues in addition to providing energy power for the development of many nations. Statistics show that worldwide carbon emissions from fossil fuels hit a record level in 2024. Many industrial solid wastes, including coal gangue, fly ash, gasification slag, and desulfurization gypsum, will unavoidably be produced during the conversion of coal to electricity. These wastes are together referred to as coal electrical solid waste. For many years, coal has been the backbone of India's energy sector and the country's only significant source of electricity, accounting for more than half of the energy generated by thermal plants. Coal has the top spot in India. of the energy matrix at 50%, with hydropower coming in at 11.5% and wind, solar, and other renewable energy sources at 29%.

(Installed generation capacity, Ministry of Power, 2022). With more than 18% of the nation's total production, Chhattisgarh is the second-largest producer of coal in India. With an estimated 44,483 million tonnes in 12 coalfields spread over the districts of Raigarh, Surguja, Koriya, and Korba, the state holds 16% of India's total coal resources. In this research article we work on Coal from Gare Pelma Mines of Raigarh District Chhattisgarh and we are going to study four different grade of coal of GARE PELMA 4/2&3 MINES and compare them on the basis of their GCV, Proximate and Ultimate analysis and X-ray diffraction. Through this, XRD have been used to characterize the inorganic and organic matter of a coal sample collected from we can determine which type of coal is best suited for power generation. In coal chemistry, the microstructural characteristics of coal have been a hot topic. The chemical and structural characteristics of coals with varying degrees of metamorphism are significantly varied due to the composition of coal-forming materials and depositional settings, which influences the coals' propensity for spontaneous combustion and adsorption capacity. Thus, a comprehensive analysis of coal's microstructural properties is crucial for both the effective use of coal and the prevention and management of coal mine accidents.

Study Area and Geological Setting

Location of Gare Pelma 4/2&3 Mines Coalfield:

Gare Pelma 4/2&3 is a coal mine of the Gare area in the Mand Raigarh District, Chhattisgarh coal field supplies the coal into JPL Tamnar located in Dongamauha, Gharghoda, Raigarh. This mine spreads over an area of 10.58 square feet. Annual production of this mine is 6.25 Metric Tones Per Annum (MTPA). In this mine total four grade of coal is present Grade-11, Grade-12, Grade-14, Grade-17. Gare Pelma IV 2 and 3 The greatest professionals in the field selected mine, and we are sure of its exceptional quality. Gare Palma IV/4 Opencast Coal mine has an area of about 885.525 ha and situated in the Eastern part of Gare Palma Coalfield. It is a running mine having production capacity of 1MTPA [(OC-0.56+ UG-0.44 MTPA)] presently. Revised Mining Plan (including Mine Closure Plan) for Gare Palma IV/4 Coal Block (4th Revision) has been prepared based on geological report namely "Geological Note on Detailed Coal Exploration in Gare Palma IV/4 Block, Mand Raigarh Coalfield, Raigarh District., Chhattisgarh state", August 2018 prepared by South West Pinnacle Limited and "Geological Report on Detailed Coal Exploration in Gare Palma IV/4 & IV/5 (Integrated), Mand Raigarh Coalfield, Raigarh District., Chhattisgarh state" December 2017 prepared by South West Pinnacle Limited. It has been prepared based on the fresh exploration undertaken by M/s Hindalco Industries Limited

Geological Framework: Early Carboniferous, Late Carboniferous-Early Permian, Middle Permian, Late Permian, Late Triassic, Early-Middle Jurassic, Early Cretaceous, Paleogene, and Neogene are the nine main coal-accumulating periods in China's geological history. Several coal-accumulating regions (CAA), such as North China, South China, Northwest China, Northeast China, the Qinghai–Tibet region, and the China offshore area, produced the coal during these times. The Late Carboniferous to Middle Permian of the North China CAA, the Late Permian of the South China CAA, the Late Triassic of the South China CAA, the Early-Middle Jurassic of the North and Northwest China CAA, and sequence stratigraphy, lithofacies paleogeography, and coal accumulation patterns of five major coal-accumulating periods were examined in this paper.

There are three ways to define the depositional environments of peat: (1) a narrow, internal approach that focuses on specific sites and conditions of precursor peat accumulations separate from the encasing sediments; (2) a broader approach that focuses on processes of adjacent (external) depositional sedimentary environment systems with general relations to peat environments but separate from the peat/coal composition; and (3) a more interdisciplinary holistic approach that integrates both narrow and broad approaches closer for a more comprehensive understanding of peat-to-coal depositional environments.

5. Materials and Methods

5.1 Coal Sampling and Preparation: Gare Pelma mines coal were the coal samples G17, G14, G11 and G12 utilized in the experiment. In order to avoid pollution and oxidation, these four fresh coal samples were gathered in accordance with the national standard Indian Standard 1350 PART-I and placed in collection bags. The Indian Standard 1350 PART-I standards were followed in the proximate and ultimate analyses of the samples G17, G14, G11 and G12 Prior to XRD, SEM and EDAX these samples underwent demineralization.

Powdering the Sample: An essential step in getting the material ready for diffraction tests is grinding it into a fine powder. This procedure guarantees that there are many crystals in the exposed volume of the sample, which is necessary for precise and repeatable diffraction data. In order to achieve uniform and consistent outcomes, the grinding process is designed to reduce the influences of particle size. Grinding might not be possible for soft, pliable materials. Cutting the material into uniform, smaller pieces may be required in these situations. This fine-grained state can be attained with specialized machinery such as cutting mills or knife mills.

Building a Specimen with a Flat Surface: The sample powder must be carefully converted into a specimen with an extraordinarily flat surface in order to satisfy the demanding requirements of diffractometry. In order to guarantee accurate and repeatable diffraction patterns, this procedure is essential. The broadening of diffraction lines, which can otherwise obfuscate genuine intensity measurements and result in incorrect data interpretation, is reduced on a flat surface.

Pressing and Compacting: The powder can be pressed into a mold to create a uniform and flat surface. This method ensures that the particles are evenly distributed and compacted, reducing the likelihood of surface irregularities.

Lapping and Polishing: Advanced techniques such as lapping and polishing can be used to further refine the surface. These methods involve the gradual removal of material to achieve a mirror-like finish, which is essential for high-resolution XRD measurements.

Using Sample Holders: Specialized sample holders designed to maintain a flat surface can be utilized. These holders often come with adjustable screws or clamps that help in pressing the powder into a flat configuration without introducing additional stresses or deformations.

Importance of fine Powder: To guarantee that the grains are oriented randomly, the sample needs to be ground into an extremely fine powder. The achievement of continuous diffraction rings, which are necessary for precise and repeatable intensity measurement, depends on this random orientation. The diffraction patterns become more consistent when the particles are randomly oriented and uniformly distributed, which lowers the data's variability.

As we all are aware about the heterogeneous nature of coal so to analyse the coal it is very important to perform the proper sampling method and for testing of coal we need a fine powder of coal so the proper preparation of coal sample is also required. For the sampling of coal from mines, wagons, rakes Indian standard 436 PART-I and for the preparation of coal sample preparation 436 PART-II.

Sample-01 **Sample-02**

Sample-03 **Sample-04**

5.2 Proximate Analysis

For Proximate analysis of coal we follow Indian Standard 1350 PART-I. Inherent Moisture(IM), Equilibrated Moisture(EM), Ash percentage and Volatile Matter content comes under proximate analysis.

Determination of Inherent moisture(IM)

Take the air-dried coal sample (sample should pass through a 212-micron sieve).Mix thoroughly to ensure homogeneity.Weight exact 1 gm sample in an IM crucible.Now place the crucible in a preheated oven at 108 □ 2□C for 1:30 hrs .After 1:30hrs remove the crucible from and place the crucible with lid in a desiccator for 10-15 minutes to cool it down.Weight the sample again and note the weight loss. Now IM of the coal sample is calculated by following formula:

Inherent Moisture (%) =$W_2 - W_3 / W_4 * 100$

Where: W_1 = Weight of empty crucible

W_2 = Weight of empty crucible + sample

W_3 = Weight after oven dry

W_4 = Weight of sample

Determination of Ash percentage

Take the air-dried coal sample (sample should pass through a 212-micron sieve). Mix thoroughly to ensure homogeneity. Weight exact 1 gm sample in an ash crucible. Now place the sample in a non- heated Muffle furnace, switch on the furnace and let the temperature increased to 500□C ensure that the temperature remain constant (500□C) for 30 minute. After 30 minute let the temperature increased into 500□Cto 815□C and now this process continues for 1.30 hrs. After 1.30 hrs remove the sample and firstly keep it in a metal plate for 15 minutes when it gets cool enough place it in a desiccator for another 5-10 minutes. Now weight the sample again and note the final value. Now Ash% of the coal sample is calculated by following formula:

Ash (%) = $W_3 - W_1 / W_4 * 100$

Determination of Volatile matter content (VM)

Take the air-dried coal sample (sample should pass through a 212-micron sieve). Mix thoroughly to ensure homogeneity. Weight exact 1 gm sample in an ash crucible. Now place the sample in the Muffle furnace for 7 minutes at 900□C.After 7 minutes take out the sample from muffle furnace and keep it in a metal plate for few minutes until it gets cool down. Place the sample in desiccator for 10-15 minutes then by weighing the sample note the final weight. Now Volatile matter % of the coal sample is calculated by following formula:

Volatile matter % = $W_2 - W_3 / W_4 * 100 - IM$

Determination of Equilibrated moisture (EM)

Take the air-dried coal sample (sample should pass through a 212-micron sieve). Mix thoroughly to ensure homogeneity. Weight accurately 3gm of sample, add 20 ml DM water to the sample and boil it for 10 minutes in a Hot Plate with continuous stirring. Now filter the sample with the help of what man filter paper number-42. Now weigh accurately 1.5 gm of sample in a crucible and place it in Humidity Chamber (Temperature 40□C and Humidity60%) for 24 hours. Next day, take out the sample and crush with the help of a pistol and leave it for next 24 hrs. After 48 hrs take the first weight (either loss or gain of weight) and keep it in the chamber again for the next 24 hrs. After 72 hrs take the sample out and take the second weight then oven dry it for 2.00 hrs at 108 □ 2□C then take the third weight. Now EM of the coal sample is calculated by following formula:

Second wt.- final wt./ Second wt.- empty crucible wt.*100

Total moisture Analysis

Determination of Total moisture (TM)

Take 1kg of 12.5mm crushed sample and air dry it for 24 hrs. Now crush the air dried sample into 2.9mm and by taking 10 gm of this crushed sample place it in the oven for 2 hrs. After two hrs take out the sample and keep it in a desiccator for 10 minutes then note the final weight.

Now TM of the coal sample is calculated by following formula:

TM%=X+Y{1-X/100}

Where: X= Air dried wt. of sample

Y=Oven dried wt. of sample

Analysis of Gross Calorific Value

Determination of Gross Calorific Value(GCV) IS-1350 Part:

Take air dried and finely powdered (72mesh/212microne) coal sample. Weigh approx. 0.8-1.0gm of sample in the crucible. Place it in the bomb and Attach nichrome or ignition wire across the electrodes so it touches the sample. Seal the bomb tightly. Fill the bomb with pure oxygen to a pressure of 420 Psi using an oxygen filling unit. Fill the calorimeter bucket with a known volume of water (usually 2,000–3,000 mL, depending on the calorimeter design). Carefully place the charged bomb into the calorimeter bucket. Close the calorimeter lid and ensure thermometer/probe, stirrer, and ignition leads are connected. Start the stirrer and allow the system to reach a stable baseline temperature for about 3-4 minutes. Ignite the sample using the ignition system (usually an electric spark through the ignition wire).Combustion occurs rapidly; the temperature of water rises due to the heat released. Continue stirring and monitoring until the temperature reaches a maximum and stabilizes. Record the maximum temperature.

Calculations

A. Temperature Rise $\Delta T = T_{max} - T_{initial}$

B. Gross Calorific Value (GCV)

GCV= (W+w). ΔT-e/m

Where: W = Water equivalent of the calorimeter (J/°C)

w = Mass of water in the bucket (g)

ΔT = Temperature rise (°C)

e = Correction factor (acid correction, fuse wire, etc., in J)

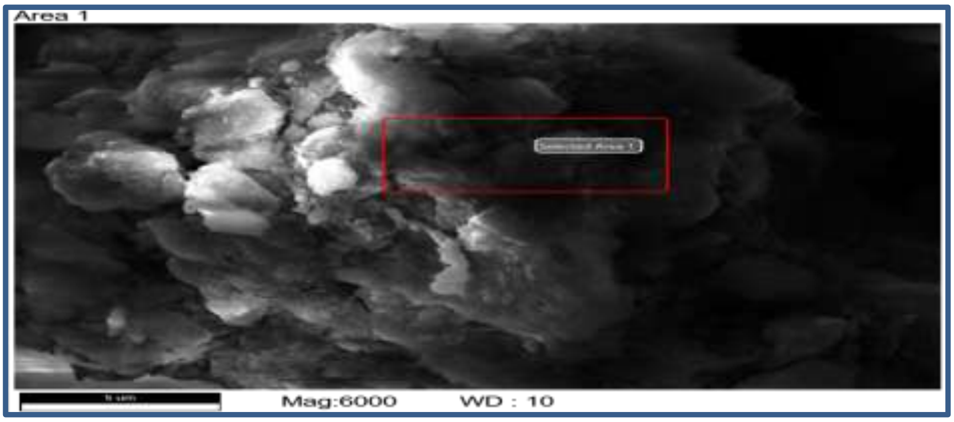
m = Mass of the sample (g)

Table No 01 Result of Coal Samples

SAMPLE ID	IM%	ASH%	VM%	FC%	TM%	EM%	GCV(Kcal/Kg)	GRADE
SAMPLE-01	2.90	61.24	17.20	18.66	10.12	4.40	2269	G-17
SAMPLE-02	4.43	49.19	20.65	25.73	11.78	5.50	3245	G-14
SAMPLE-03	5.00	37.86	25.84	31.30	13.65	6.09	4070	G-11
SAMPLE-04	4.05	23.41	23.99	48.55	12.68	5.57	3770	G-12

5.3 Ultimate Analysis

EDAX for sample -01 of Area 1



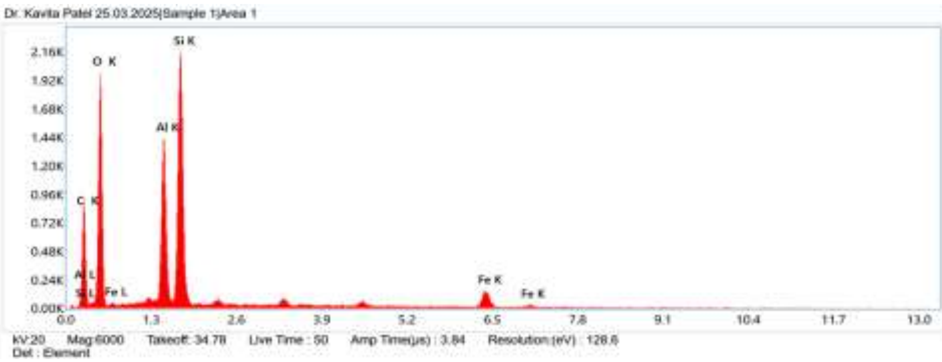
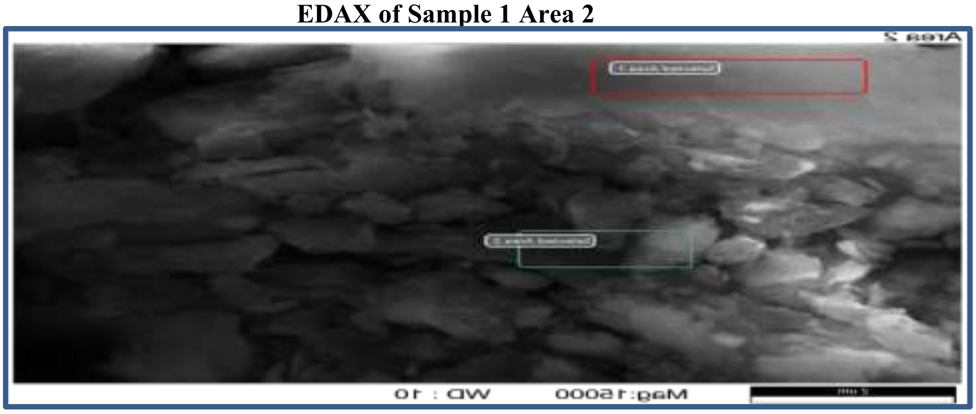


Table No. 2 Elemental composition of sample -01 area -01

Element	Weight %
C K	46.4
O K	38.8
Al K	5.0
Si K	7.5
Fe K	2.3

EDAX of Sample 1 Area 2



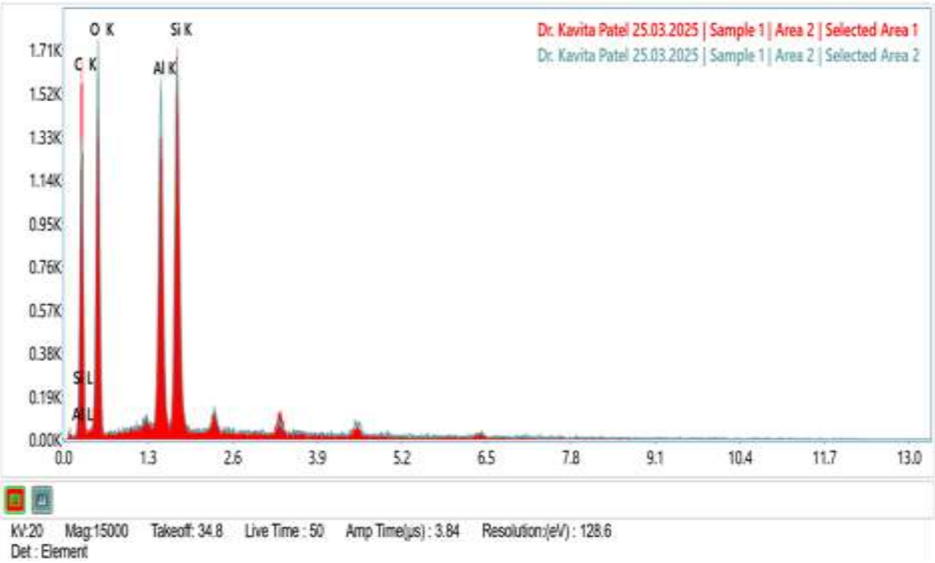
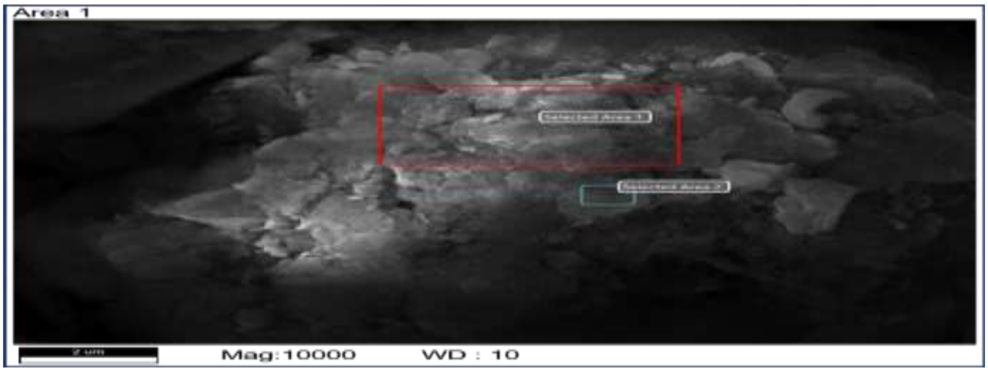


Table No. 3 Elemental composition of sample -01 area-02

Element	Weight %
Sample 1 | Area 2 |	
C K	55.4
O K	34.8
Al K	4.7
Si K	5.0

Observations: Carbon(C) is major component, oxygen(O_2) is present in the form of minerals and wate, presence of aluminium(Al) and silicon(Si) is observed may contribute to aluminosilicates like Kaolinite($Al_2Si_2O_5(OH)_5$) contribute to Ash content. Some amount of iron(Fe) is also present.

EDAX for sample -02



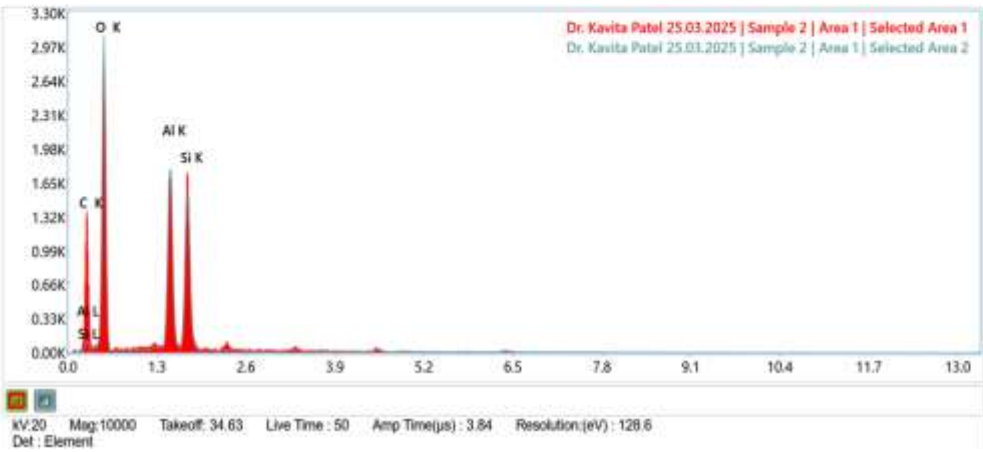


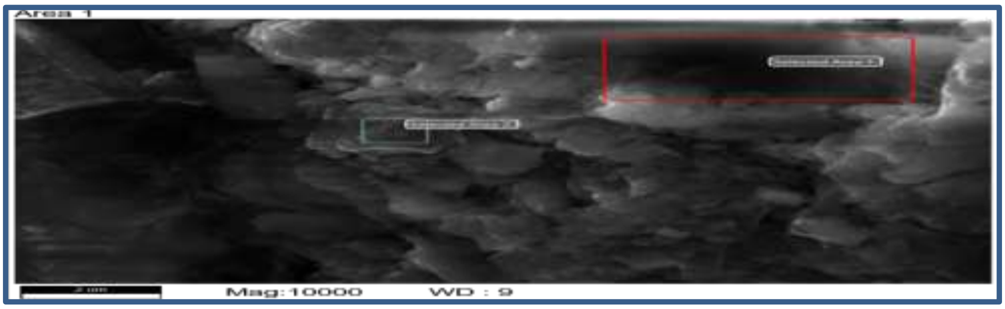
Table No 4 Elemental composition of sample -02 area -01 and 02

Element	Weight %
Sample 2 | Area 1 | Selected Area 1	
C K	47.2
O K	43.8
Al K	4.6
Si K	4.4
Sample 2 | Area 2 | Selected Area 2	
C K	13.5
O K	61.3
Al K	13.3
Si K	11.9

Observation

Highest peak of oxygen observed shows highest percentage of oxygen(O_2), carbon is prominent other than that aluminium(Al) and silicon(Si) also present indicates presents of aluminosilicate ($Al_2Si_2O_5(OH)_5$)s, iron (Fe)is not present.

EDAX for sample-03



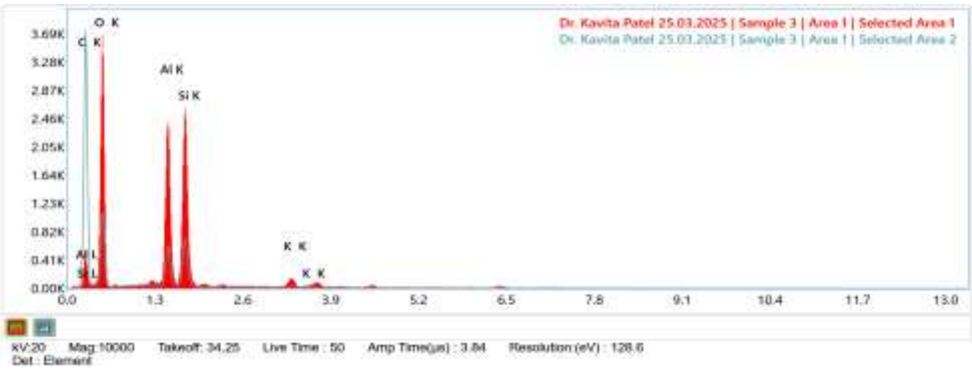


Table-04 Elemental composition of sample -03 area -01 and 02

Observation: Carbon percentage is highest among all the sample other than that aluminium (Al) and silicon(Si) is present presence of potassium is observed, iron(Fe) is not showing any peak.
EDAX for sample-04

Element	Weight %
Sample 3 | Area 1 | Selected Area	
C K	29.6
O K	52.6
Al K	8.3
Si K	8.7
K K	0.7
Sample 3 | Area 1 | Selected Area 2	
C K	73.7
O K	23.5
Al K	1.3
Si K	1.5

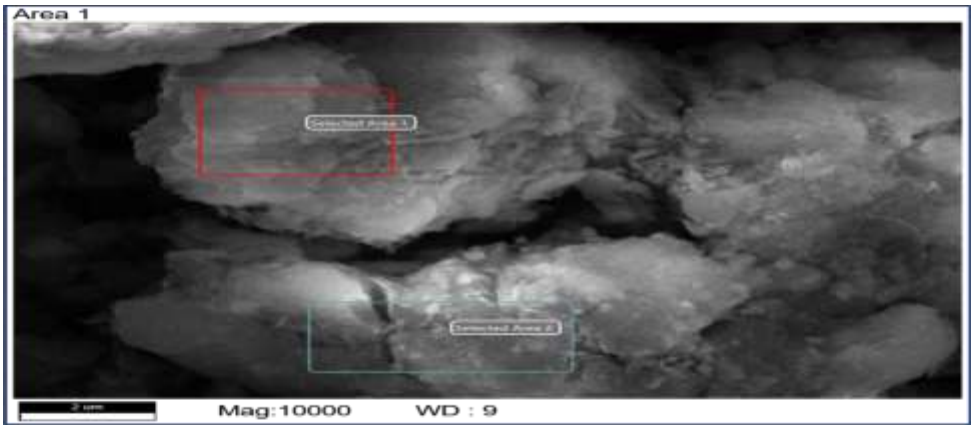
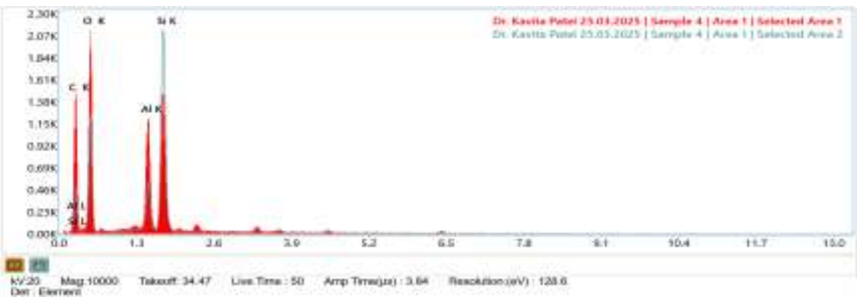


Table-05 Elemental composition of sample -04 area -01 and 02



Observation

Highest peak Oxygen (O_2) is observed, Carbon is prominent, aluminum(Al) and silicon (Si) is present, iron is not present.

- **6. Results**

6.1 Proximate and Ultimate Analysis Results

Results of Proximate Analysis

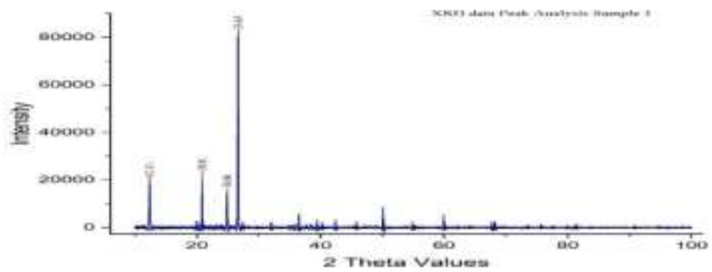
In table number-02 the results of proximate analysis is shown and it is clearly visible that sample number-03 has highest Gross Calorific Value(4070kcal/kg) and Volatile Matter content (25.84%) and lowest Ash percentage on the other hand sample number-01 has lowest Gross Calorific Value (2269 Kcal/Kg) and Volatile Matter content(17.20%).

6.2 Mineralogical Characteristics (XRD)

XRD graph for sample -01

Table-08 miller indices of sample 01

Element	Weight %
Sample 4 | Area 1 | Selected Area 1	
C K	53.3
O K	39.1
Al K	3.6
Si K	4.0
Sample 4 | Area 1 | Selected Area 2	
C K	44.2
O K	41.0
Al K	3.1
Si K	11.7



2 θ	d- spacing (Å)	Miller indices
12.34	7.17	[001]
20.84	4.24	[110]
24.87	3.58	[100]
26.60	3.35	[002]

Observation

We found most intense peak at 26.63° 2θ which is characteristic of the [002] plane of hexagonal graphite and d- spacing is 3.34 Å. Peak at12.31° 2 θ observed common for clay mineral anther peaks 20.81° and 24.86° peak shows the presence of amorphous carbon.

XRD graph for sample-02

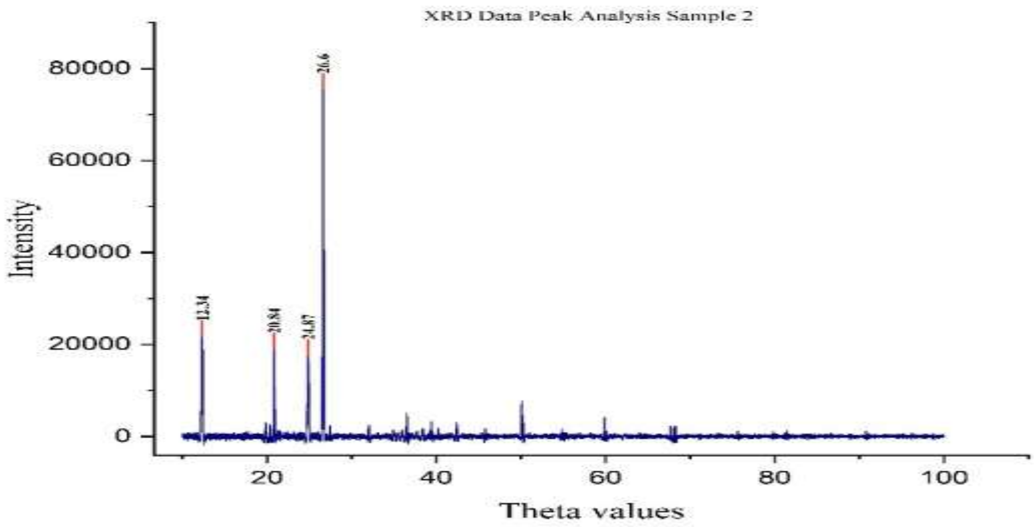


Table-09 miller indices of sample 02

2 θ	d- spacing (Å)	Miller indices
12.34	7.17	[001]
20.84	4.24	[110]
24.87	3.58	[100]
26.60	3.35	[002]

Observation

We found most intense peak at 26.60° 2θ which is characteristic of the [002] plane of hexagonal graphite and d- spacing is 3.35 Å. Peak at12.34° 2θ observed common for clay mineral anther peaks 20.84° and 24.87° peak shows the presence of amorphous carbon.

XRD graph for sample-03

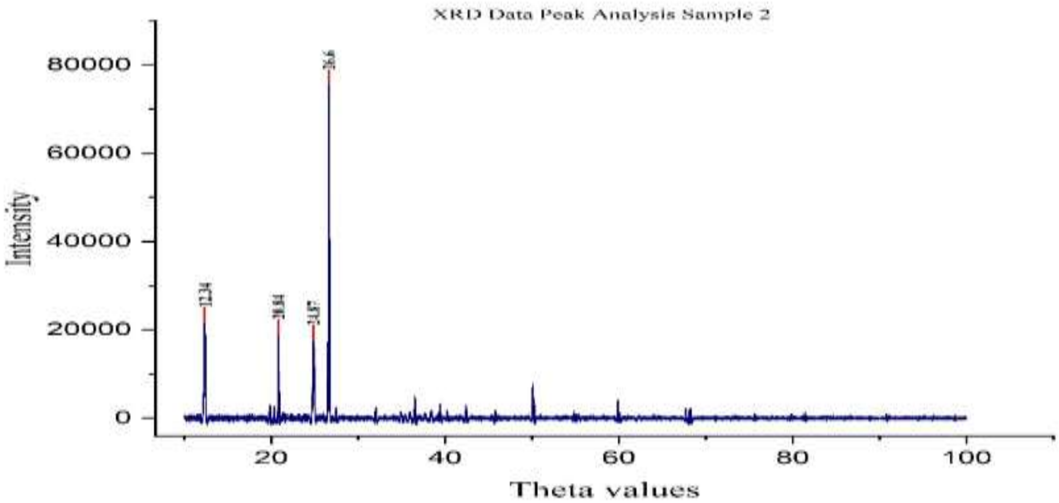


Table-10 Miller indices of sample 03

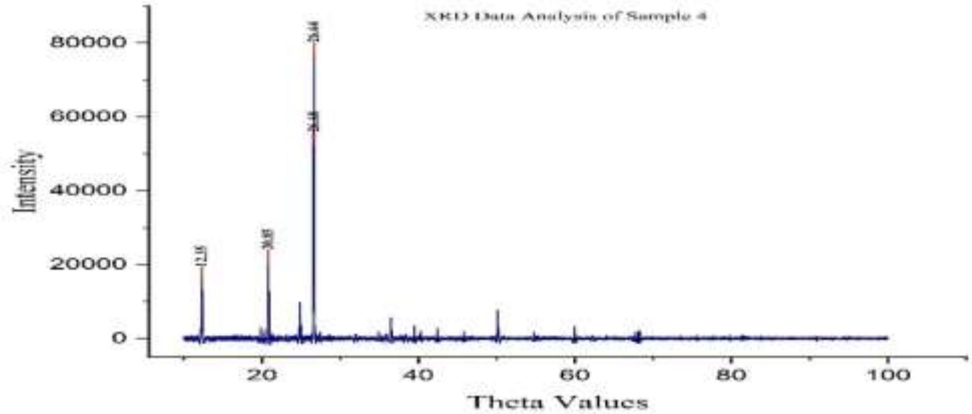
2 θ	d- spacing (Å)	Miller indices
12.34	7.17	[001]
20.84	4.26	[101]
24.85	3.58	[100]
26.62	3.34	[002]

Observation

We found most intense peak at 26.62° 2θ which is characteristic of the [002] plane of hexagonal graphite and d- spacing is 3.34 Å. Peak at12.34° 2θ observed common for clay mineral anther peaks 20.84° and 24.85° peak shows the presence of amorphous carbon.

XRD graph for sample-04

Table-11 Miller indices of sample-04



2 θ	d- spacing (Å)	Miller indices
12.35	7.16	[001]
20.85	4.26	[100]
24.66	3.61	[100]
26.64	3.34	[002]

Observation

We found most intense peak at 26.64° 2θ which is characteristic of the [002] plane of hexagonal graphite and d- spacing is 3.34 Å. Peak at12.35° 2θ observed common for clay mineral anther peaks 20.85° and 24.66° peak shows the presence of amorphous carbon.

Conclusions

The proximate analysis of coal analysis shows that sample no. 03 has highest gross calorific value 4070 and sample number 01 has lowest Gross Calorific Value 2269 ultimate analysis by EDAX shows that the same sample contain higher percentage of carbon 73.7% and sample number 01 contain 46.4 thus we can say that sample number 03 is the best coal for power generation. By XRD analysis the chemical structure of coal is determined which suggest crystalline as well as amorphous structure of coal. Carbon percentage is highest among all the sample other than that aluminum (Al) and silicon(Si) is present presence of potassium is observed, iron(Fe) is not showing any peak. the results of proximate analysis is shown and it is clearly visible that sample number- 03 has highest Gross Calorific Value(4070kcal/kg) and Volatile Matter content (25.84%) and lowest Ash percentage on the other hand sample number-01 has lowest Gross Calorific Value (2269 Kcal/Kg) and Volatile Matter content (17.20%). The rapid growth of renewable energy capacity and the impending wave of LNG export capacity could change the market, making the future of coal mining questionable. However, in the light of global attempts to fight climate change, the economic importance of coal and the necessity of socioeconomic, safety, and health considerations continue to be crucial.

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