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REVIEW

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Importance of Coal Characteristics for Effective Utilization of Coal

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Abstract

Coal is a heterogeneous rock with complex characteristics. Composition varies even in centimeters. Origin influences the composition of coal deposits, both organic and inorganic materials. The concentration of vitrinite or inertinite is determined by the nature and origin of the coal during the formation. Fluctuation and rates of down-warping or up-warping influence the accumulation of inorganic materials. The rank of the coal is determined by the thermal treatment undergone by the coal deposits over the period. Internal Moisture content depends upon the rank of the coal. Surface moisture content is based on the size of mined and crushed coal. Beneficiation of coal is a process of reducing the inorganic materials.

Keywords: Coal; Beneficiation; Desulfurization; Hetereogeneous; Organic; Vitrinite

Introduction

Coal is a soft solid fuel extensively used in thermal plants, iron & steel plants, cement industries, and chemical industries apart from domestic purposes mainly in developing countries. Coal is generally classified as peat, lignite, sub-bituminous, bituminous, anthracite, and meta-anthracite. When used in industries it is classified as coking coal and thermal coal. Whereas thermal coal constitutes all types of coal, coking coal is bituminous coal with certain specific characteristics. Though coal is widespread all over the world, it is also transported through sea and rail routes to destinations of high demand. The utilization of coal depends on origin, composition, maturity, and level of impurities. It is the most abundant fossil fuel in the world. These aspects are explained below in detail.

Coal is formed by the accumulation of vegetable debris in a stagnant water body. Deposition of these vegetable matters mainly in vegetation-rich wetlands undergoes for a long period. Deposition of vegetable matter takes place in a basin that undergoes continuous down wrapping. Generally, coal formation takes place in different environmental conditions viz. Basin created by sand bars close to the sea, Stagnant water bodies or marshy lands and/or Fluvial deposits in grabben or half grabben regions (Nath, 2021).

The dead vegetable materials settled at the bottom of the stagnant water body undergo aerobic and anaerobic bacterial action and begin to transform through different coalification processes. In the first phase of coalification process, microorganisms as well as chemical reactions degrade the vegetable material. In the process, cellulose is substantially lost and the lignin chemical components are transformed into peat. There is a gradual decrease in the oxygen content leading to an increase in the carbon content. With the increase in the thickness of the load above, the water is squeezed out. In the second phase of coalification after deep burial, the coal is heated by geothermal energy or by regional metamorphism (Nath et al., 2022).

Coal undergoes chemical reactions and the proportion of aromatic carbon increases with maturity which is dependent on heat as well as time. Terrain undulation during coal formation is explained by variation in the thickness of coal seams, a mixture of shale/sandstones, and erosion in part or most of the coal basin indicating unconformities. At the time of accumulation if the sinking of the basin is faster than the level of deposition of vegetal matter, then the speed of water flow increases leading to erosion, transportation at high land, and deposition of these transported mineral matter in the basin. In case of a slow sinking rate of the basin, the accumulation of all vegetable matter in the basin is not possible thus leading to these materials being exposed to air and got degraded. In case of a low level of exposure or close to the surface of the water body, gel in some parts of vegetable matter gets oxidized leading to the formation of dull coals. If the vegetable matter is completely exposed, then it gets rotten and destroyed by oxidation.

Therefore, for the accumulation of the best coal formation, the level of sinking should be proportional to the level of deposition with a constant supply of vegetable matter. Though the coal resources of India (Fig. 1) are estimated to be 250bt, the economically viable reserve is only about 67bt (Nath, 2017; Krevelen, 1993).

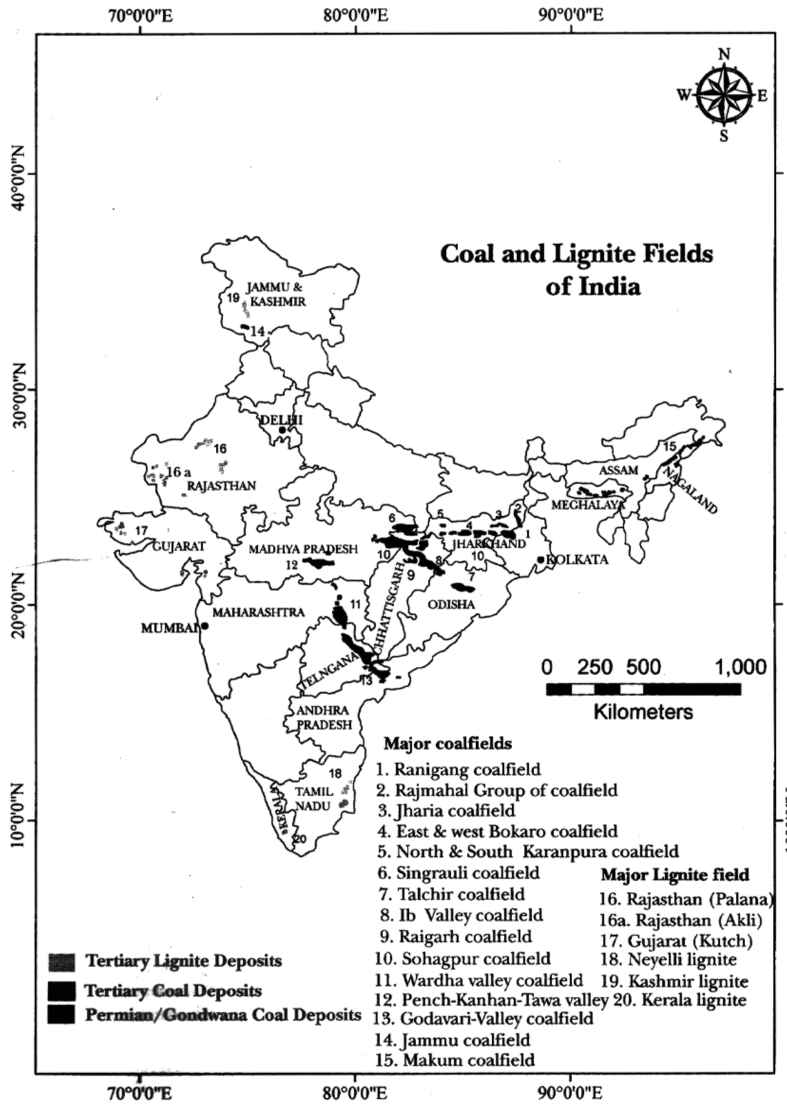

Fig. 1. Location of Tertiary and Gondwana coalfields of India

Composition

Depending upon the source, environmental conditions at the time of deposition, and influence of pressure & temperature, and time, every coal deposit or every seam has its own composition characteristics. Coal from one place to another place, even a few centimeters away, varies in the presence or absence of different organic components. As a result, coal exhibits different colors and other characteristics. In the field, coal is classified based on lithotypes, which are as follows: *Vitrain*- bright, black-colored, brittle particles with a conchoidal fracture, *Clarain*- brightly colored with semi-conchoidal fracture, *Durain*- dull, grainy texture, earthy luster with high hardness, and *Fusain*- a dull black appearance which is highly friable even with the hand.

This classification is used mainly for fieldwork during exploration. A more accurate study of composition can be obtained through microscopic analysis. The coal when looked through a microscope, three distinct types of particles known as macerals are identified.

Vitrinite- the most abundant maceral in the coal in most parts of coal deposits except some Gondwana coal basins. Its reflectance is higher than liptinite and lower than inertinite. In comparison with other maceral, vitrinite is rich in oxygen content. Most of the coal parameters are explained through vitrinite characteristics. The maturity of the coal is determined by the reflectance of vitrinite grains.

Liptinite- it is the least abundant maceral with a concentration hardly exceeding 20% in most of the coal. In comparison with other macerals, liptinite is rich in hydrogen content thus containing high volatile matter content. This maceral is derived from pores, pollen, resin, waxes, etc.

Inertinite- high concentration of this maceral occurs in most of the Gondwana coal basins. It is highly reflecting maceral with abundant cavities in its structure except for some sclerotinite. In comparison with other macerals, inertinite is rich in carbon content. There are two broad types of inertinite macerals viz. fusinite and semi-fusinite.

Maturity

After the deposition of organic matter, the peat is buried leading to pressure from overburdened materials and heat from geothermal gradient or regional metamorphism and occasionally from contact metamorphism. Due to pressure from overburden materials, water is squeezed out of coal. A slow and continuous supply of heat leads to the realignment of elements. In the initial stages, organic materials are enriched in aliphatic components. On maturity, these components gradually change to aromatic by enrichment of carbon and release of hydrogen, oxygen, etc. With the increase in rank, coal gradually attain a completely aromatic nature in the anthracite. With the increase in maturity, the inherent moisture content of coal decreases gradually from close to 90% in peat, 45% in lignite, 10% in sub-bituminous coal, and less than 2% in bituminous coal of coking quality. Then the moisture content slightly increases up to 3% in. anthracite due to the perfect alignment of aromatic carbon leading to more internal cavities.

Coal also becomes harder with an increase in rank. Low-rank coals are sticky owing to high inherent moisture content and lack of well-packed organic compounds. Similarly, with an increase in rank, the calorific value also increases in the trend is not completely linear. Depending upon the constituents of coal the calorific value changes. The calorific value increases from less than 20MJ/kg in lignite to around 33MJ/ kg in sub-bituminous coal. Further, the increase in calorific value is small as in bituminous coal it is around 36 MJ/kg and remains more or less constant with an increase in rank. Also, with an increase in rank, the coal attains its maximum level from the bituminous stage. The variation is more at this stage which is likely to be based on volatile matter content and variation in composition of the coal. The reflectance of vitrinite increases from 0.21% in lignite to more than 5% in anthracite. As per the ICCP-94 classification, coal with a mean reflectance of less than 0.5% are called low-rank coals.

Impurities

Coal is intimately associated with different impurities viz. clay, silica, sulphides, carbonates, and other silicates. Clay is the most prominent impurity found in all the coal deposits in varying proportions. It ranges from as low as less than one percent in Indonesian coals to more than 50 percent in Indian coals. Though sulphides are found greater than two percent in many coal deposits of the world, their concentration is less than 0.5 in Indian coal. Carbonates and other silicates are mostly found in minor quantities.

Impact of Coal Characteristics on Utilization

Moisture

Thermal power generation- Coals of various ranks are utilized depending on availability and demand. High-rank coals can be transported to distant places on demand. Low-rank coals such as lignite cannot be transported to distant places and are used locally as pithead mines. This is because the inherent moisture content of lignite is more than 40% and is not very solid after mining. They disintegrate and form slurry in case of rain. The inherent moisture content of sub-bituminous coal reaches up to 15% and bituminous coal is less than 7%. Crushing increases the surface area of the coal, and on washing there is an increase in surface moisture of the coal. If the total moisture content is very high then the coal needs to be pre heated before injection. Anthracite contains inherent moisture of less than 3%. They give smokeless heat, but resources are restricted to a few places.

Iron & steel industry- The inherent moisture content of coking coal used in iron & steel industries is less than 2%. As these coals are valuable, they are transported only to the iron & steel industries.

Ash
All coal-based industries are concerned with the presence of mineral matter content. On burning mineral matter in the coal gets oxidized and forms ash. Major problems with mineral matter are as follows

Lowering thermal value- With the increase in the percentage of mineral matter content, the thermal value of coal decreases.

Transportation of dead-weight materials- As a non-combustible material, the mineral matter present in the coal is unwanted. To obtain unit thermal values, more coal is needed and thus increases transportation costs.

Coal handling- In iron & steel plants coal is crushed to below 3mm size and in thermal power plants coal is crushed to below 200-micron size. To generate a unit of thermal value, more quantity of coal is crushed with increased ash in the coal. This causes more energy consumption and wear & tear on crushing and transportation materials and as mineral particles are harder and may damage the crushing equipment. With mechanized mining practices for coal extraction, large pieces of stones are mined along with coal. As these hard materials resist crushing, they remain oversized and do not pass through the screen easily. Therefore, they are re-circulated repeatedly for size reduction.

Thermal power generation- Coal with ash up to 70% is effectively utilized in thermal power generation (in fluidized bed combustion). Ash and sulfur play very crucial roles in combustion efficiency and environment-related problems. Apart from the composition of coal, inorganic particles also control carbon burnouts and flame stability. In thermal power plants, presence of mineral matter creates enormous problems that are detailed below.

Size of power plant- For high ash coal, to generate unit thermal value, more coal is burnt. Therefore, the boiler size, pathway, economizer, coal handling, and ash handling equipment are to be in large sizes leading to more space and investment.

Ash disposal- Due to mineral matter content fly ash and bottom ash are generated. In high ash coal, these materials are produced in large quantities. In India, more than 100Mt of fly ash is produced every year from around 300Mt of coal burnt in thermal power plants. Fly ash is used as fill for dykes, embankments and mine fill and construction materials in building industries. In India, only around 15% of fly ash produced is utilized and the remaining quantum gets added to old stock, leading to a huge amount of land acquisition in thermal power plant adjoining areas.

Environmental problem- Dumped fly ash in the land causes environmental problems such as loss of fertile land, deforestation, and filling of pores in the soils. From the fly ash disposal site, toxic inorganic elements are leached due to rainwater. This causes contamination to running water and groundwater. Due to the high quantum of fly ash generated, the efficiency of the electrostatic precipitator that collects fly ash decreases. This leads to the release of fly ash in the air causing air pollution.

Iron & steel industry- In the iron and steel-making process, with the rank and composition of the coal meeting the specification of making coke, the other most important parameter to be taken into consideration is the impurity level of coal. It is desirable to have an ash level below 10%. But in India, the level is maintained at 17% owing to the quality of coal available. With the increase in ash content of the coal, more limestone is needed to remove silicon and other materials as slag during the operation. The presence of sulfur equally creates problems in the blast furnace operation and needs to be reduced.

Rank
Thermal power generation- Rank plays an important role in the power generation. Generally, a power plant is constructed to utilize particular coalfield or a few. In case of disturbance in the supply of the chosen coalfields, coals from other places are sourced. Then, the coal must have a similar rank to the used one. While low-rank coal burns quickly with a large quantity of volatile matter, high-rank coal burns at a later stage with a high calorific value. If there is a change in the supplied coal from the previous one, then the plants have to be modified to make efficient power generation. If coal of

two different ranks is blended and charged in the furnace, maintaining flame stability becomes a difficult task. To keep proper flame stability, oil is substituted in many power plants that use coals with high ash content. Similarly, carbon burnout will be uneven leading to the high carbon content in the fly ash.

Iron & steel industry- Coal rank range of 1.0 to 1.4 mean vitrinite reflectance gives good quality of coke provided ash and reactive concentration is well within the permissible range. Coal is generally blended with other coals to obtain consistent coke quality. At the same time, coal producers to make good profit include very low or very high ranks with good quality coking coals. In a country like India where these blended imported coals are again blended with locally available coal, attention should carefully be given to maintaining the coal quality.

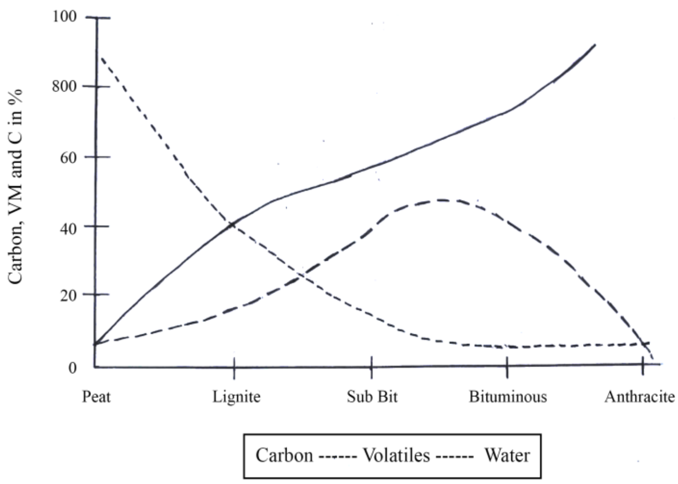

Fig. 2. A trend of Carbon, Volatiles and Water in coal with an increase in rank.

Composition
Thermal power generation- Maceral composition is also of great importance in thermal power plants. The vitrinite maceral initially fuses to the plastic stage with the release of volatile matter and energy. Once the volatile matters are released, it forms char particles which release energy more or less at a constant rate. The energy release can be predicted and flame stability can be maintained in vitrinite rich coals. Inertinite does not fuse and on combustion, it breaks into several smaller particles. Breaking of the particle leads to the quick release of energy and generates more surface area. Flame stability cannot be predicted for inertinite grains leading to oil supplementation to maintain it.

Iron & steel industry- The application of coal mainly in the iron and steel industry is based on the composition of the coal and its rank. Coal with less than 55% of reactive maceral (vitrinite and some semi-fusinite) cannot form the metallurgical coke. Coals with high inertinite maceral are either beneficiated to increase the reactive maceral level for effective utilization of coal or sold as cheap thermal coal.

Coal Quality Improvement
The quality of coal can be improved by various methods depending on the economy and technology available. Though rank can be improved, thermal treatment is unfeasible. Composition of coal to a lesser extent though possible by coal beneficiation, is not the main criterion of beneficiation. Coal quality is improved mainly by reduction of mineral matter contents (Nath, 2017, 2021, 2022, 2023)

Coal Beneficiation
Coal is beneficiated or cleaned or washed for reduction of unwanted mineral contents which is associated with coal seams and also inclusion during mining practice. For coal produced from mechanized open cast mines, there is a pronounced degree of contamination in the coal, which deteriorates the quality of coal. Coal is beneficiated by various methods depending upon the nature of the association of mineral matter with coal. A dry beneficiation method such as a rotary breaker is used for the removal of large stone particles and reduction of ash level to some extent. Different types of jigs are commonly used for beneficiation of coal with wide ranges. Heavy medium bath type separation is practiced for large-sized coal particles. Cyclones are efficient for the relatively small size of particles. Floatation is undertaken for fine coal particles less than 0.5mm.

Desulfurisation

Desulfurization techniques are classified as physical, chemical, thermal, or biological. Such techniques are extensively applied for coal desulfurization before combustion. Most of the research work on coal desulfurization has been focused on pyritic sulfur removal, which represents at least half of the total sulfur content in coal. Organic sulfur is more difficult to remove by conventional processes since it is firmly bonded to organic units.

Physical treatment includes magnetic separation or the use of hydrocyclones and mainly removes inorganic sulfur. Chemical treatment involves the use of strong acids, bases, or salts. It is usually applied at elevated temperatures, varying between 200 and 300°C for the elimination of organic sulfur. Leaching with sodium carbonate, sodium hydroxide or potassium hydroxide is also effective, achieving 90% removal of both inorganic and organic sulfur. Thermal treatment techniques involve mainly pyrolysis or the use of airstream mixtures. Both techniques operate at high temperatures (350- 500°C), and are considered quite complicated and the degree of desulfurization depends on several parameters such as temperature, particle size, air-streaming/gas composition, coal rank, heating rate, and type of reactor used. Biological desulfurization is a well-established laboratory technique that uses bacterial cultures (thermophilic or mesophilic bacteria) to oxidize pyrite and therefore remove sulphur from coal.

Table 1. General coal properties for different rank of coal and their industrial use.

<table>
<tr><th colspan="6">Types, uses and properties of coal</th></tr>
<tr><td rowspan="3">Coal Types</td><td colspan="2">Low-rank coal</td><td colspan="3">Hard coal</td></tr>
<tr><td rowspan="2">Lignite</td><td rowspan="2">Sub bituminous coal</td><td colspan="2">Bituminous coal</td><td>Anthracite</td></tr>
<tr><td>Thermal coal</td><td>Metallurgical coal</td><td rowspan="2">Smokeless fuel</td></tr>
<tr><td>Use</td><td>Power generation</td><td>Power, cement and chemical industries</td><td colspan="2">Iron & steel industry</td></tr>
<tr><td>Properties</td><td colspan="5">▼ Increase in calorific value, carbon, hardness
Decrease in moisture, oxygen, volatile matter</td></tr>
</table>

Conclusion

Understanding the coal characteristics is very important for the proper utilization of coal. Origin, composition, maturity, moisture contents, and presence and nature of impurities are the basic things to understand the coal characteristics. There are many more coal analyses and techniques for efficient utilization and predictable output, but they involve huge investments and the latest technologies. Coal is a highly heterogeneous material and there is a great variation from one point to another even a few centimeters away in a single coal seam of a mine. However, the overall picture can be attained using proper sampling methods. Above-mentioned characterizations one can predict the properties and problems of a given coal. Further, there are very few power plants (except some pithead thermal power plants) and iron & steel industries getting coal from a single dedicated source. The multiplicity of supply sources further adds to the problem of inconsistency in the quality of coal. This leads to either modification of plant design or procurement of proper supply at high cost. In the absence of proper blending facilities, it is not operationally feasible for the plants to homogenize the feed coal to obtain the desired results.

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