***Keywords*: property, analytical methods, coal carbonization, caking, swelling**

1.3.1 Definitions and properties of solid fuels

Coal varies widely in composition and properties and they are used in different conditions. Coal characteristics are determined by various kinds of analytical and testing data, which are of scientific, technical and commercial interest. Following are the definitions of some coal characterization and analysis.

Ultimate and Proximate analysis of coal

Ultimate analysis is the elemental analysis which determines the percentage composition of carbon, hydrogen, oxygen, nitrogen and sulfur by weight. These elemental compositions are of pure fuel only, which is free of moisture and inorganic compounds.

Proximate analysis reports moisture, volatile matter, ash and fixed carbon content of a fuel by percentage weight, as defined by ASTM D 121. Moisture is the amount of water obtained from the fuel by heating at a specific condition according to the standard method, without making any chemical change to the fuel. Volatile matter consists of gases and vapors driven off during pyrolysis under specified condition minus moisture. fixed carbon is the nonvolatile fraction of coal. and ash is the inorganic residue remaining after combustion. Proximate analysis is the most often used analysis for characterization of coals.

Gross and Net calorific value → The amount of energy produced by the complete combustion of a fuel material (KJ/Kg)

When coal is heated at high temperature in presence of air, heat liberated per unit weight of fuel is called heating value or calorific value of that fuel. Calorific value can be determined either at constant volume or constant pressure. Gross calorific value at constant volume is the amount of heat liberated by combusting unit weight of coal at constant volume in an atmosphere of water

vapour saturated oxygen, the original fuel and final products of combustion should be at 25°C and the water obtained by this process should be in liquid state.

Gross calorific value at constant pressure is similar to that of constant volume, only difference is that, the combustion occurs at constant pressure.

Net calorific value at constant volume is the amount of heat liberated by combusting unit weight of coal at constant volume in an atmosphere of water vapour saturated oxygen, the original fuel and final products of combustion should be at 25°C and the water obtained by this process should be in vapour state. Net calorific value at constant pressure is that, the combustion occurs at constant pressure, not constant volume.

Gross calorific value is also called higher heating value as it is higher than net calorific value. The reason for this is, while determining net calorific value, the water remains in vapour state, hence the heat of condensation is not taken in consideration, which is rather a part of gross calorific value where water obtained is in liquid phase.

Ash content

Ash in coal, which is the remains when coal is burnt, is one of the materials of interest. Ash is derived from the mineral matter content of coal. The inorganic materials which were actually the part of the plant structures, constitute the 'inherent' mineral matter of coal, whereas, the 'extraneous' mineral matter is that which was introduced probably as air-borne dusts or water-borne silts at the later stage of coalification. Mineral matter of coal predominantly consists of kaolinite, pyrite and calcite and upon combustion; results in the oxides of silicons and metals, such as, aluminium, iron and calcium. These oxides are the essential part of ash. When coal burns, shales and other hydrated materials, which are also the constituents of mineral matter of

coal, decompose and lose their water of hydration and also emit carbon dioxide, sulfur dioxide gases. As there is a loss in weight, so, amount of ash of coal is always less than its mineral matter content.

Moisture content

Moisture of coal may also become inherent or extraneous. Inherent moisture is the moisture associated with coal inherently, which cannot be removed by only air drying, it can be removed when coal is heated above 100°C. Extraneous moisture can be removed by air drying of coal.

Volatile matter

Volatile matter is the volatile part of coal when coal undergoes thermal decomposition. The volatile part of organic mass of coal is the main constituent of it. The moisture content of coal is not included in it. But volatile matter of may contain water, when hydrogen and oxygen of coal produce water at high temperature of decomposition. The water of hydration, which is liberated during decomposition, is also a part of volatile matter. It is observed that, as the maturity of coal increases, volatile matter decreases. Fixed carbon is the non volatile part of organic mass after decomposition. Ash is not included in it. Fixed carbon should not be confused with the total carbon of coal. In anthracite, the values of fixed carbon and total carbon are almost equal, whereas, for other coals, fixed carbon is less than total carbon.

The major elements present in coal are carbon, hydrogen, oxygen, sulfur and phosphorous. There are different methods to determine their content.

Lignite or brown coal: Brown or Black color woody substances with high moisture contents

Bituminous coal: Black in color, easily ignites, and burns with flame and smoke.

Anthracite: Black color and lustrous, difficult to ignite and burns without flame.

In 1837, Regnault first classified the coal based on chemical composition in five categories on the basis of total oxygen and nitrogen percentage using the ultimate analysis of coal.

In 1844, Walter R. Johnson, divided them according to the ratio of fixed carbon to the volatile matter which is defined as Fuel ratio. P Frazer (1887) used the fuel ratio to classify the various coals and it was tabulated as

Coal	Fuel Ratio
Dry anthracite	100-12
Semi anthracite	12-8
Sub-bituminous	8-5
Bituminous	5-0

The different types of coal are usually classified by rank which depends upon the degree of transformation from the original source (i.e., decayed plants) and is therefore a measure of a coal's age. As the process of progressive transformation took place, the heating value and the fixed carbon content of the coal increased and the amount of volatile matter in the coal decreased. The method of ranking coals used in the United States and Canada was developed by the American Society for Testing and Materials (ASTM) and is based on a number of parameters obtained by various prescribed tests.

The following table (Table 1) discusses about different grades of Indian coal, their characteristics and uses.

Table 1. General Classification of Indian Coals (IS : 770-1964)

Type	Name	Symbol	V.M/% at 900±15°C Unit coal basis	Gross Calorific value kcal/kg	Chief uses
Anthracite	Anthracite	A_1	3-10	8330 - 8670	gasification, producers, domestic and where intense heating and no smoke are required.
	Semi anthracite	A_2	10-15	8440 - 8780	,,
Bituminous	Low volatile (caking)	B_1	15-20	8670 - 8890	carbonization for the productions of metallurgical coke
	Medium volatile (caking)	B_2	20-32	8440-8780	,,
	High volatile (caking)	B_3	over 32	8280-8610	coking coals, gasification
	High volatile (semi caking)	B_4	over 32	8000-8440	Long-flame heating
	High volatile (non caking)	B_5	over 32	7500-8060	Steam raising, gasification, long flame heating
Sub-bituninous	Non caking	B_6	over 32	6940-7500	Steam raising, Gasification
Lignites or Brown coal	Normal lignite	L_1	45-55	6110-6940	Steam raising, briquetting gasification
	Canneloid lignite	L_2	55-65	6940-7500	,,

Analysis of coal is also reported in terms of some arbitrary basis. These are,

1) Run-of-mine (ROM)

When the coal directly obtained from a mine is analysed by elemental or proximate analysis, the data are called run-of-mine.

2) As-received

After extraction from mine, coal is transported to the receiver. The analysis data obtained at this point is called as-received.

3) Air-dried

When analytical data are collected after air drying the coal at a standard condition of 40°C and 60% relative humidity, the data are called at air-dried basis.

4) Dry

When the effect of moisture content is removed from the analytical data, then that is said as dry basis.

5) Dry and ash-free (d.a.f)

When the data are reported excluding the effect of ash content, then it is said d.a.f basis.

6) Dry and mineral matter free (d.m.m.f)

When effects of both moisture and mineral matter are removed from the analytical data, then it is reported as d.m.m.f basis. This is the data of pure coal only.

7) Moist-mineral-matter-free

This is the basis where the effect of mineral matter is excluded, only pure coal and moisture are taken to report the data.