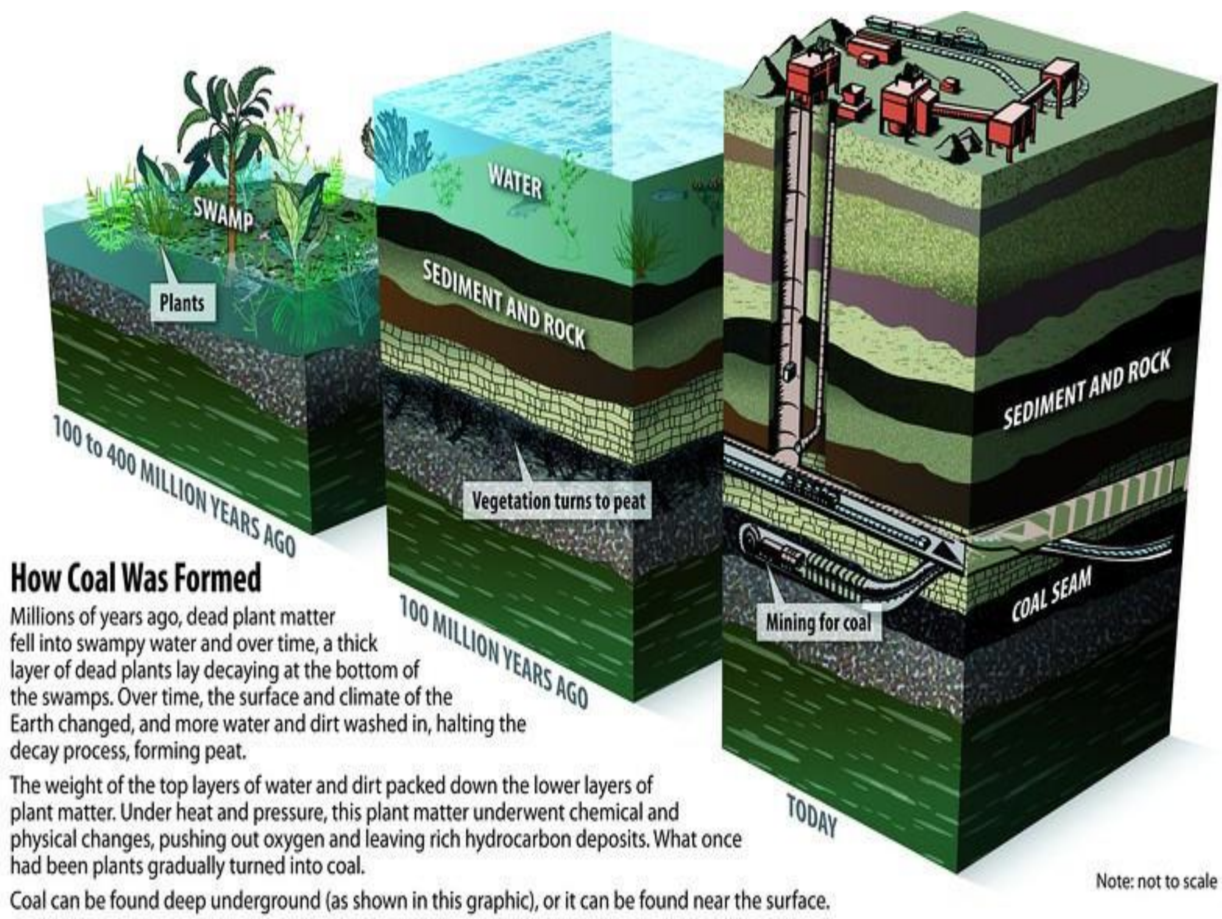
Coal

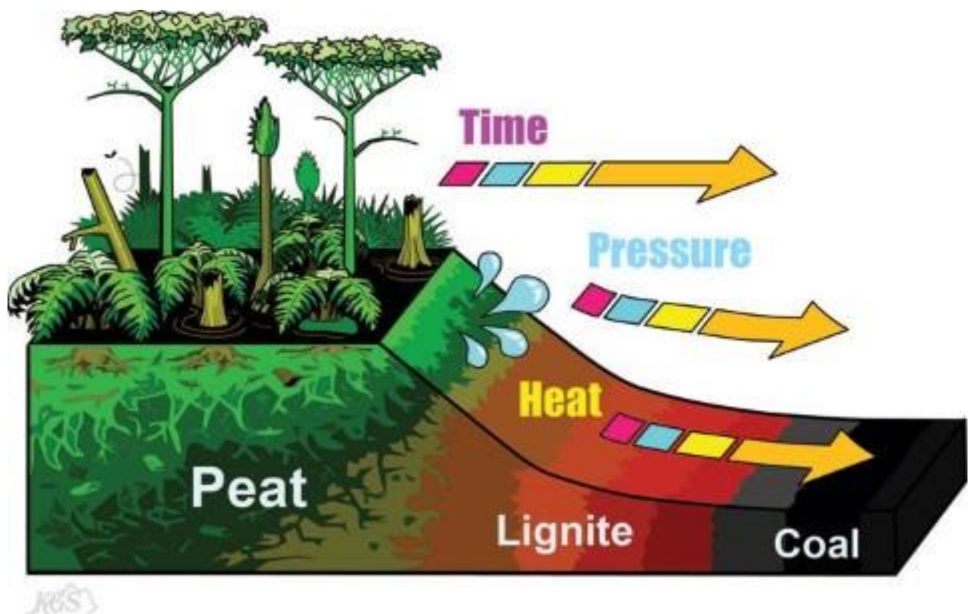
Coal, which has been a primary energy source for more than a century, began to form during the Carboniferous period, which took place between 360 and 290 million years ago. Plant matter accumulated in swamps and peat bogs, and after being buried and exposed to high heat and pressure — largely due to the shifting of tectonic plates — it was transformed into the coal that powered the industrial revolution and that the mining industry uses today.

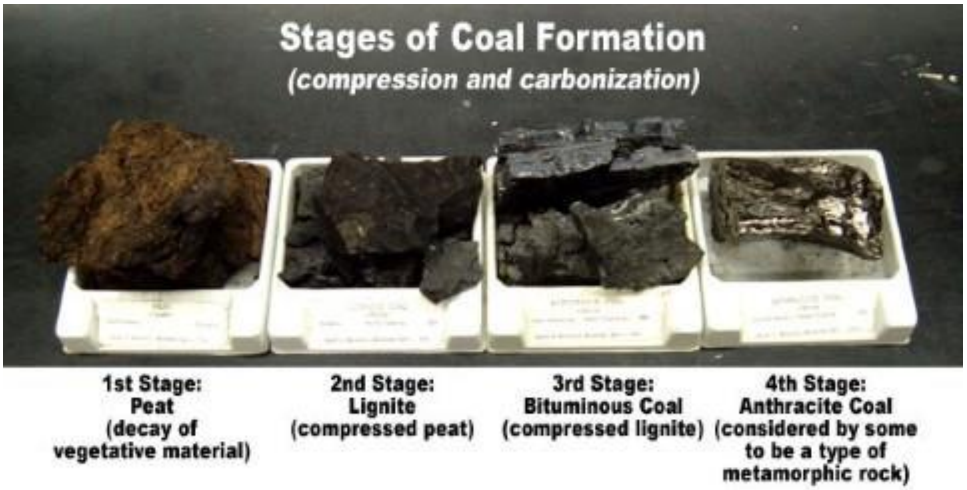


Coal types:

Coals are classified into three main ranks, or types: lignite, bituminous coal, and anthracite.These classifications are based on the amount of carbon, oxygen, and hydrogen present in the coal.Coals other constituents include hydrogen, oxygen, nitrogen, ash, and sulfur.Some of the undesirable chemical constituents include chlorine and sodium.

In the process of transformation (coalification), peat is altered to lignite, lignite is altered to sub-bituminous, sub-bituminous coal is altered to bituminous coal, and bituminous coal is altered to anthracite.





Low-rank coals

Peat

- First stage of transformation.
- Contains **less than 40 to 55 per cent carbon == more impurities.**
- Contains sufficient volatile matter and **lot of moisture** [more smoke and more pollution].
- Left to itself, it burns like **wood**, gives less heat, emits more smoke and leaves a **lot of ash.**

Lignite

- Lignite is the youngest type of coal. It is soft and ranges in color from black to shades of brown. As a result, it's sometimes called brown coal. Lignite is mainly used for electricity generation and accounts for 17 percent of the world's coal reserves.

- **Brown coal.**
- Lower grade coal.
- **40 to 55 per cent carbon.**
- Intermediate stage.
- Dark to black brown.
- Moisture content is high (over 35 per cent).
- It undergoes **SPONTANEOUS COMBUSTION** [Bad. Creates fire accidents in mines]

Bituminous Coal

Sub-bituminous coal is the result of millions of years of continued pressure and high temperatures on lignite. It burns cleaner than other types of coal, producing less greenhouse gas emissions due to its low sulfur content. Sub-bituminous coal is used in electricity generation and also in industrial processes. This coal type makes up 30 percent of the world's coal reserves.

- Soft coal; most widely available and used coal.
- Derives its name after a liquid called bitumen.
- **40 to 80 per cent carbon.**

- Moisture and volatile content (15 to 40 per cent)
- Dense, compact, and is usually of black colour.
- **Does not have traces of original vegetable material.**
- Calorific value is **very high** due to high proportion of carbon and low moisture.
- Used in production of **coke and gas**.

Anthracite Coal

- **Best quality**; hard coal.
- **80 to 95 per cent carbon**.
- Very little volatile matter.
- Negligibly small proportion of moisture.
- Semi-metallic lustre.
- **Ignites slowly** == less loss of heat == highly efficient.
- Ignites slowly and burns with a nice short **blue flame. [Complete combustion == Flame is BLUE == little or no pollutants. Example: LPG]**
- In India, it is found only in Jammu and Kashmir and that too in small quantity.

Fuel Characterization- Analysis of Coal

By Coal analysis quality or grade of coal is detrmined. It comprises of "proximate" and "ultimate".

(A) Proximate Analysis:

In the proximate analysis, moisture (M), Ash (A) and volatile matter (VM) are determined.

1. **% Moisture (%M)-** Moisture increases transportation, handling, storage cost. Moisture decreases the heat content per kg of power plant coal. Moisture increases heat loss due to evaporation and superheating of vapor

Moisture helps in binding the fines. Moisture helps in radiation heat transfer.

A known amount of coal (w_0 gm) is taken in a crucible and heated at 105°C for 1 hour. Moisture present in the coal is removed and the weight of the coal is taken(w_1 gm).

Hence, weight of moisture = weight loss = $w_0 - w_1$ gm

% Moisture (%M) = (weight loss/weight of sample) ×100

$$= 100 \times (w_0 - w_1) / w_0$$

2. **% Volatile Matter (% VM)-**

Volatile matter also contributes to the heating value of coal. Increase in percentage of volatile matter in coal proportionately increases flame length and helps in easier ignition of coal

Now the crucible is covered with a vented lid and it is heated at 950°C for 7 minutes. Due to absence of oxygen, coal does not burn and the volatile matter like H_2 , CH_4 , CO_2 present in the coal is removed. Now again the weight of coal is taken (w_2 gm).

Hence, weight of Volatile matter (VM) = weight loss = $w_1 - w_2$ gm

% VM = (weight loss due to VM/ weight of sample) ×100

$= 100 \times (w_1 - w_2) / w_0$

3. % Ash (% A)-

Ash is an impurity which will not burn. Ash content is important in design of furnace grate, combustion volume, pollution control equipment (ESP) and Ash handling plant. It increases transportation, handling, storage cost. Ash affects combustion efficiency and boiler efficiency. Itcauses clinkering and slagging problems in boiler

Now the lid of the crucible is removed and coal is burnt. Due to presence of sufficient oxygen coal burns and ash is formed . Weight of residue ie, ash (w_3 gm) is taken.

Weight of ash (A) = w_3 gm

% of Ash (%A) = (weight of ash /weight of sample)×100

$= (w_3 / w_0) \times 100$

4. % of Fixed Carbon (% FC)-

Fix carbon acts as a main heat generator during burning. It gives a rough estimate of heating value of coal

Fixed carbon (FC) is obtained from the following equation:

FC= 100 – (%M + %A + %VM)

Road map of Proximate Analysis

$$\text{Coal Sample } (w_0 \text{ gm}) \xrightarrow[\boxed{-\ \text{Moisture}}]{\boxed{105^{\circ}\text{C / 1 Hour}}} \text{Sample } (w_1 \text{ gm})$$

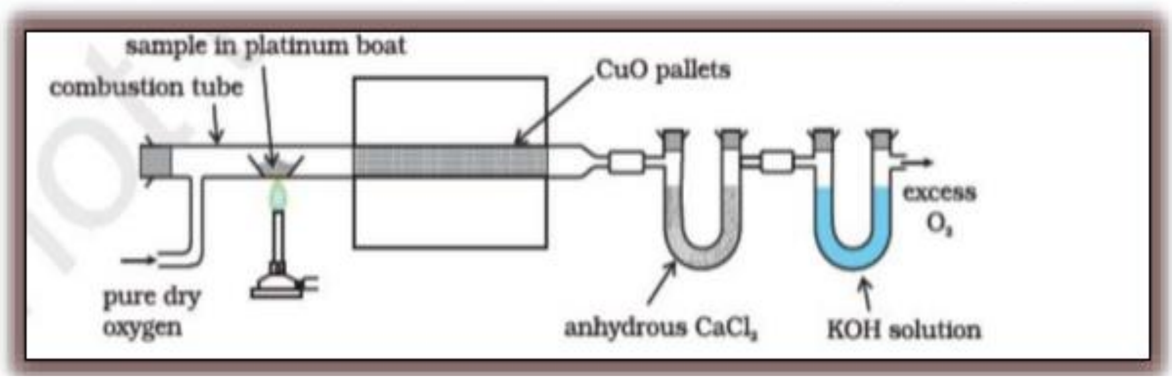
$$\xrightarrow[\boxed{-\ \text{Volatile Matter}}]{\boxed{\text{Crucible covered withVented Lid / } 950^{\circ}\text{C / 7 minutes}}} \text{Sample (} w_2 \text{ gm)}$$

$$\xrightarrow{\boxed{\text{Burning}}} \text{Ash (} w_3 \text{ gm)}$$

(B) Ultimate Analysis –

The ultimate analysis indicates the various elemental chemical constituents in coal such as carbon, hydrogen, oxygen, sulfur, nitrogen etc.
This analysis is useful in determining the quantity of air required for combustion and volume and composition of combustion gases. This information is required for calculation of flame temperature and flue gas duct design. It involve following steps:

1. Determination of Carbon and Hydrogen-



A known amount of coal (w_0 gm) is taken and it is burnt. The gases are passed in anhydrous $CaCl_2$ tube (absorbs water) and then in KOH tube(absorbs CO_2).

$$CaCl_2 + H_2O \longrightarrow CaCl_2.H_2O$$

$$2KOH + CO_2 \longrightarrow K_2CO_3 + H_2O$$

Due to this factor weight of both tubes increases.

Hence,

Weight of H_2O = w_{H2O} = Incease in the weight of $CaCl_2$ tube

Weight of CO_2 = w_{CO2} = Incease in the weight of KOH tube

Hence , w_{H2O} gm water is present in w_0 gm coal.

Now, Combustion of H_2 takes place as follows

$$\underset{\boxed{2\text{ gm}}}{H_2} + \tfrac{1}{2} O_2 \longrightarrow \underset{\boxed{18\text{ gm}}}{H_2O}$$

As

18 gm water is formed from 2 gm H_2.

Therefore, w_{H2O} gm water will be formed from = $(2/18) \times w_{H2O}$ gm H_2

As

w_0 gm coal contains = $(2/18) \times w_{H2O}$ gm H_2

Therefore, 100 gm coal will contain = $(2/18) \times (w_{H2O}/w_0) \times 100$ gm H_2

Hence

$$\boxed{\%\,H = (2/18) \times (w_{H2O}/w_0) \times 100}$$

Similarly, combustion of Carbon takes place as follows

$$\underset{\boxed{12\text{ gm}}}{C} + O_2 \longrightarrow \underset{\boxed{44\text{ gm}}}{CO_2}$$

It can be derived

$$\% C = (12/44) \times (w_{CO2} / w_0) \times 100$$

2. % of Nitrogen –

% of nirogen in the coal sample is detrmined by Kjeldahl Method. Its steps include digestion, distillation, and titration.

.**a. Digestion:** A known amount of coal sample (w_0 gm) is heated in the presence of sulphuric acid. The acid breaks down the coal via oxidation and reduced nitrogen in the form of ammonium sulphate is liberated

$$\text{Coal (N)} + H_2SO_4 \rightarrow (NH_4)_2SO_4$$

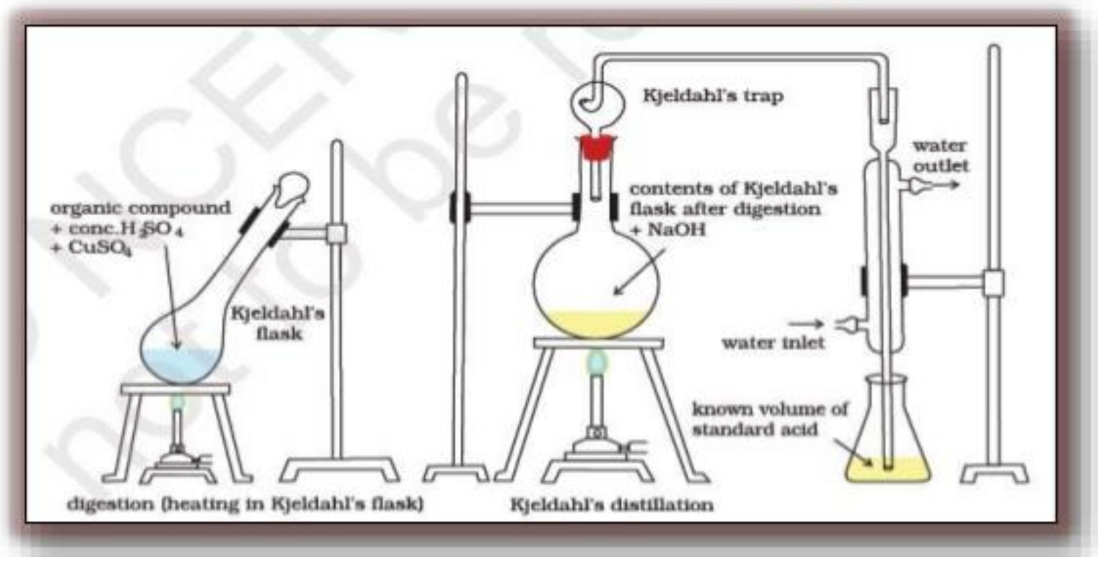
b. Distillation: The distillation of the solution now takes place and a small quantity of sodium hydroxide is added to convert the ammonium salt to ammonia. The distilled vapors are then trapped in a special trapping solution of HCl (hydrochloric acid) and water.

$$(NH_4)_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O + 2NH_3$$
$$NH_3 + HCl \rightarrow NH_4Cl$$

c. Titration: The amount of ammonia or the amount of nitrogen present in the sample is then determined by back titration. As the ammonia dissolves in the acid trapping solution some of the HCl is neutralized. The acid that is left behind can be back titrated with a standard solution of a base such as NaOH or other bases $B(OH)_2$.

$$B(OH)_2 + H_2O + Na_2CO_3 \rightarrow NaHCO_3 + CO_2 + H_2O$$

Determination of Nitrogen



Calculation – % Nitrogen (N) is determined by the following formula:

$$\% N = (1.4 \ N V)/ w_0$$

Where,

N = Normality of acid utilized with NH_3

V = Volume of acid utilized with NH_3

W_0 = Weight of coal sample

3. % of Sulphur-

Effect of sulfur content:

- Affects clinkering and slagging tendencies
- Corrodes chimney and other equipment
- Limits flue gas exit temperature

% Sulphur is detrmined by burning coal sothat sulphur present in the coal forms H_2SO_4. It is then treated with $BaCl_2$ so white precipitated of $BaSO_4$ is formed. It weighed.

Weight of $BaSO_4$ = w_{BaSO4} gm

$$\underset{\boxed{32\ gm}}{S} + 4\,O^{2-} \longrightarrow SO_4^{2-} \xrightarrow{\boxed{BaCl_2}} \underset{\boxed{233\ gm}}{BaSO_4}$$

As in % of Hydrogen

$$\boxed{\%\ S = (32/233) \times (w_{BaSO4} / w_0) \times 100}$$

$$\text{Percentage of sulphur} = \frac{32 \times \text{wt. of } BaSO_4 \times 100}{233 \times \text{wt. of organic compound}}$$

4. **% Ash (% S) -** It is determined by Proximate Analysis.
5. **% Fixed Carbon (% FC)-**

$$\boxed{\%\ FC = 100 - (\%\ C + \%\ H + \%\ N + \%\ S + \%\ Ash)}$$

Additional Facts –

1. O_2 is present in air 23% w/w ie, 100 gm air contains 23 gm O_2.
2. O_2 is present in air 21% v/wvie, 100 litre air contains 21 litre O_2.
3. Molar mass of air is 28.97 ie, 28.97 gm air occupies 22.4 litre volume at NTP.

On the basis of above facts following formula can be derived :

1. Weight of required air = (100 / 23) x weight of Net O_2 gm
2. Volume of required air = (100 / 21) x volume of Net O_2 litre
3. Volume of required air in litre

   = (22.4 / 28.97) x weight of required air in gm