INTRODUCTION AND CLASSIFICATION OF FUELS

1. INTRODUCTION AND CLASSIFICATION OF FUELS

A substance which produces heat is called a fuel. The heat may be produced either by combustion or by nuclear fission and fusion. Heat generated by the combustion of fuel is utilized either directly or is converted into mechanical or electrical energy.

Classification of fuels:

It was accepted to classify the fuel:

1- With respect to its state.

2- With respect to the method of its production.

With respect to the state fuels are divided into three groups:

a) Solid fuel (Wood, coal, peat, coke, etc).

b) Liquid fuel (Crude oil, tar, Mazut, …etc).

c) Gaseous fuels (natural gas, coke oven gas, blast furnace gas, producer gas).

Fuels with respect to the method of production are subdivided into two groups:

1- Natural fuel.

2- Manufactured fuel.

Only two kinds of natural fuels are used for metallurgical furnaces: the natural gas and crude oil (after treatment). As for manufactured fuel the following kinds are widely used:

1- Gaseous fuel (blast furnaces gas, coke oven gas, mixed blast furnace and coke oven gas, mixed natural and blast furnace gas).

2- Liquid fuels (Mazut, tar).

3- Solid fuels (coke, coal dust) coke is mainly used in blast furnace and cupola, coal dust is mainly used for furnaces of non-ferrous metallurgy. At present the solid fuels are substituted by gaseous fuel.
2. ORIGIN, COMPOSITION, CHARACTERISTICS AND SIGNIFICANCE OF CONSTITUENTS OF COAL

Origin of Coal:
Coal is a complex mixture of plant substances altered in varying degree by physical and chemical processes. These processes which changed plant substances into coal has taken million of years and has been accomplished by bacteria, heat and pressure inside the earth’s crust.

Composition of Coals:
Composition of coal is expressed in terms of its proximate and ultimate analysis. Proximate analysis of coal means determining the percentage of moisture, volatile matter, fixed carbon and ash. Proximate analysis with sulphur content and heating value of coal helps in deciding the mode of utilization of a particular coal.

A typical composition of different types of coals and some other fuels is given in the Table. 2.

The change in average composition from wood → peat → lignite → coals → anthrace (on dry ash free basis) is given in table 2.

Table 2: Composition change from wood to Anthracite

<table>
<thead>
<tr>
<th>Fuels</th>
<th>% Composition on dry ash free (daf) basis</th>
<th>Calorific value (daf), kcal/kg</th>
<th>Moisture at 60% R.H. and 40°C, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbon</td>
<td>Hydrogen</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Wood</td>
<td>50</td>
<td>6</td>
<td>0.5</td>
</tr>
<tr>
<td>Peat</td>
<td>57</td>
<td>5.7</td>
<td>2</td>
</tr>
<tr>
<td>Lignite</td>
<td>67</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>Sub-bituminous coal</td>
<td>77</td>
<td>5</td>
<td>1.8</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>83</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Semi-bituminous</td>
<td>90</td>
<td>4.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Anthracite</td>
<td>93</td>
<td>3</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Table 3 Typical composition of different types of coal.

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Proximate analysis, %</th>
<th>Ultimate Analysis, %</th>
<th>Calorific valve kcal/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture</td>
<td>Fixed carbon</td>
<td>Volatile matter</td>
</tr>
<tr>
<td>Peat</td>
<td>57</td>
<td>26</td>
<td>11</td>
</tr>
<tr>
<td>Lignite</td>
<td>35</td>
<td>28</td>
<td>31</td>
</tr>
</tbody>
</table>

**Bituminous coal:**

- Low volatile 3.5 16 72 8.5 79.5 4.5 4.5 1.5 1 9 7600 7900
- Medium volatile 3 24 62 11 77 5 5 1.5 0.5 11 7500 7700
- High volatile 8 36 49 7 68.5 5.5 16.5 1.5 1 7 6750 4700

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Proximate analysis, %</th>
<th>Ultimate Analysis, %</th>
<th>Calorific valve kcal/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub – bituminous</td>
<td>19</td>
<td>31</td>
<td>46</td>
</tr>
<tr>
<td>Semi-anthracite</td>
<td>3</td>
<td>8.5</td>
<td>79</td>
</tr>
<tr>
<td>Anthracite</td>
<td>2.5</td>
<td>3</td>
<td>87.5</td>
</tr>
<tr>
<td>Pine wood</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Oak wood, dry</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coke (by product oven)</td>
<td>1</td>
<td>1</td>
<td>87</td>
</tr>
<tr>
<td>Coke breeze (0-15 mm)</td>
<td>10</td>
<td>4</td>
<td>66</td>
</tr>
<tr>
<td>Charcoal</td>
<td>12</td>
<td>2</td>
<td>83</td>
</tr>
</tbody>
</table>

3. COMPOSITION OF SOLID AND LIQUID FUELS

For solid and liquid fuels both the technical composition on and the elementary chemical composition is determined. Technical analysis of the solid fuels consists of the determination of 1-moisture content (w) 2-ash content (A) volatile matters content which are the gaseous products of the fuel decomposition at high temperature and 4-Coke content (the solid remainder after heating the fuel sample at t=850°C without air). Besides the content of sulphur (S) and calorific value of fuel is determined while technical analysis of the solid fuels. For liquid fuels the viscosity temperature of solidification must be determined additionally.
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Due to the very complicated chemical composition of the solid and liquid fuels and a large number of the chemical combinations from which they consist of the chemical composition of solid and liquid fuels is carried out with respect to the chemical elements (elementary chemical analysis).

Elementary analysis consists of the determination of the main elements carbon (C) hydrogen (H) Oxygen (O) nitrogen (N) sulphur (S) and the content of moisture (W) and ash (A).

On the base of the elementary chemical analysis of solid and liquid fuels the following kind of fuel mass are distinguished:

1- Organic mass (O).
2- Combustible mass (C).
3- Dry fuel (D) and
4-“as” received moist fuel (2). The composition of each fuel mass is shown in table (1).

<table>
<thead>
<tr>
<th>Index</th>
<th>C</th>
<th>H</th>
<th>O</th>
<th>N</th>
<th>S</th>
<th>A</th>
<th>W</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Organic mass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>C</td>
<td>Combustible mass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>A</td>
<td>Dry fuel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Z</td>
<td>Or received moist fuel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

The composition of each mass in percentage by weight may be expressed as follow:

1- Organic mass

\[ C^O + H^O + O^O + N^O = 100\% \]  \hspace{1cm} (1)

2- Combustible mass

\[ C^C + H^C + D^C + N^C + S^C = 100\% \]  \hspace{1cm} (2)

3- Dry fuel

\[ C^d + H^d + O^d + N^d + S^d - A^d = 100\% \]  \hspace{1cm} (3)

4- As received fuel:

\[ C^r + H^r + N^r + D^r + S^r + A^r + W^r = 100\% \]  \hspace{1cm} (4)

The content of any element given for the one fuel mass may calculated for the other mass if the conversion factor for these two masses known:

1- Organic mass into combustible mass

\[ K_{o-c} = \frac{100 - S^c}{100} \]
2-Orga1nic mass into dry mass

\[ K_{o-d} = \frac{100 - (S^d + A^d)}{100} \]

3-Orga1nic mass into as received fuel

4-Combustible mass into organic mass

\[ K = \frac{100 - (S' + A' + W')}{100} \] (7)

\[ K_{c-o} = \frac{100 - A'}{100} \] (8)

5-Combustible mass into organic mass

\[ K_{c-d} = \frac{100 - A^a}{100} \] (9)

6-Combustible mass into as – received fuel

\[ K_{c-r} = \frac{100 - (A' + W')}{100} \] (10)

7-Dry mass into organic mass

\[ K_{d-o} = \frac{100}{100 - (S^d + A^d)} \] (11)

8-Dry mass into combustable mass

\[ K_{d-c} = \frac{100}{100 - A^d} \] (12)

9-Dry mass into as – received fuel

\[ K_{d-r} = \frac{100 - W'}{100} \] (13)

10-As – received fuel into organic mass

\[ K_{r-o} = \frac{100}{100 - (S' + A' + W')} \] (14)

11-As – received fuel into combustible mass

\[ K_{r-c} = \frac{100}{100 - (A' + W')} \] (15)

12-As – received fuel into dry mass

\[ K_{r-d} = \frac{100}{100 - W'} \] (16)
Taking into account the conversion factor any fuel mass can be converted into the others by multiplying each component of a given mass by its conversion factor for example:

\[ X^o = X^c K_{c-o} = X^c \frac{100}{100 - S^c} \]

\[ X^c = x^o K_{o-c} = X^o \frac{100 - S^c}{100} \]

etc.

By the way \( K_{c-o} = \frac{1}{K_{o-c}} \)

\[ K_{r-d} = \frac{1}{K_{d-r}} \] and so on.

**Significance of the Constituents of Coal:**

**Moisture:** In general high moisture content in coal is undesirable because:
- It reduces the calorific value of the fuel.
- It increases the consumption of the coal for the heating purposes.
- It lengthens the time of heating.
- We pay for it when the coal is purchased and transported.

But there are certain specific cases where moisture is deliberately added or is desirable to some extent e.g.
- Dust nuisance is checked while loading, unloading, transporting and charging coal into the oven when it is wet.
- Moisture undergoes endothermic decomposition which reduces the temperature of the hot coal bed (either when burning it on grate or during the manufacture of producer gas) thereby eliminating its fusion and clinker formation which otherwise would have blocked the passage of air.
- Sometimes, water is sprayed on the coal dust charged in the coke oven. This apart form checking dust nuisance during coal charging helps in protecting the methane and other hydrocarbons present in the coke oven gas from cracking in presence of hot coke and other oven walls because, it undergoes endothermic decomposition to reduce the temperature of the coke oven gas as well as that of the coke mass thereby eliminating its fusion (called graphitization).

**Volatile matter:**
Certain gases like CO, CO$_2$, CH$_4$, H$_2$, N$_2$, O$_2$, hydrocarbons etc. are present in the coal which comes out during its heating. These are called the volatile matter of the coal.

The coal with higher volatile matter content:
- Ignites easily i.e. it has lower ignition temperature.
- Burns with long smoky yellow flame.
- Has lower calorific value.
- Will give more quantity of coke oven gas when it is heated in absence of air.
- Will require larger furnace volume for its combustion.
- Has a higher tendency of catching fire (due to low temperature exothermic oxidation) when stored in open space.

**Fixed Carbon:**
It is the pure carbon present in the coal. Higher the fixed carbon content of the coal, higher will be its calorific value.

In anthracites, the volatile matter is very small and the values of fixed carbon and total carbon are almost equal. In other coals, fixed carbon is less than total carbon. The carbon content is determined by Libel’s method by completely burning the coal in a current of pure oxygen and finding the amount of resultant carbon dioxide. The carbon content of coal increase with increases in the rank. Among the microconstituents of the same coal, the exinites and vitrinite have almost similar carbon content while fausinite has higher values.

**Total Carbon:** It means the fixed carbon plus the carbon present in the volatile matters e.g. in CO, CO$_2$, CH$_4$, hydrocarbons etc.

Total carbon is always more than fixed carbon in any coal. High total carbon containing coal will have higher calorific value.

**Hydrogen:**
It increases the calorific value of the coal. It is associated with the volatile matter of the coal. Also, the percentage of NH$_3$ in the coke oven gas is more if the coal from which it has come out contains more H$_2$. This NH$_3$ is recovered as (NH$_4$)$_2$SO$_4$ by reacting NH$_3$ with H$_2$SO$_4$ which is a valuable fertilizer.

Part of the hydrogen of coal remains as such in the coke oven gas thereby increasing its calorific value. Also, if hydrogen is to be removed from this coke oven gas for production of NH$_3$, its availability will be more if the coal with high H$_2$ content has been used for the purpose.

The content of hydrogen in coals from the peat to the bituminous stage varies between 4.5 and 6.5% and is not related to the rank. Beyond the bituminous stage,
the hydrogen content sharply decreases to a value of 1-2% in anthracites. Among the microconstituents, the exinites are characterized by high, and the fusinites by low, hydrogen contents.

**Nitrogen.** The nitrogen in coal is present up to 1-3% and comes from the proteins matter present in vegetable matter. Presence of inert nitrogen decreases the calorific value of the coal. However when coal is carbonized (i.e. heated in absence of air), its and H₂ and H₂ combine thereby producing NH₃ which is recovered as (NH₄)₂SO₄, a valuable fertilizer. The proportion of extractable nitrogen decreases with maturity of coal.

The nitrogen content does not bear any relation to the rank of coal. In most coals it is between 1 and 2%. Lower values down to 0.5 and upper values up to 2.5 are also found. The nitrogen in coal is useful in carbonization industries which recover a part of it as valuable by – products like ammonia, ammonium sulphate.

**Sulphur:** Though its presence (mainly as sulphides) increases the calorific value of the coal, but it has several undesirable effects. The oxidation product of sulphur (e.g. SO₂, SO₃, etc.) especially in presence of moisture cause corrosion (damage due to chemical and electrochemical action) of the equipment and cause atmospheric pollution. Sulphur is highly undesirable in metallurgical coal used in iron and steel making as it badly affects the properties of iron and steel. It causes hot shortness of steel, i.e. cracking of steel surface during hot rolling.

Sulphur is commonly present in coal in three forms, viz. Pyritic, organic and sulphate but occurrence of sulphides and elementary sulphur in coal have also been reported. Only organic sulfur should be included in the ultimate analysis.

**Oxygen:** The less the oxygen content, the better is the coal as it reduces its calorific value. It decreases from lignite to anthracite as the maturity of the coal increases. As the oxygen content of the coal increases, it moisture holding capacity increases and the caking power decreases.

The oxygen content of coal has a close relation to the rank. The former decreases with the increases in the latter. Among the micro – components of the same coal, vitrinite has the highest oxygen, fusinite the lowest, and exinites has the intermediate value.

**Phosphorus.** It is undesirable in metallurgical coal as it badly affects the properties of the increases in the latter.

Phosphorus occurs in small quantities coal. Indians coking coals have normally less than 0.15% phosphorous which offers no problem for common use in iron and steel production.

**Chlorine.** It is present mainly as chlorides in the coal. It reduces the fusion point of the ash of the coal. It is substantially removed during washing of the coal.
Ash. Ash is the combustion product of mineral matters presents in the coal. It comprises mainly of silica (SiO$_2$) alumina (Al$_2$O$_3$) and ferric oxide with varying amounts of other oxides such as CaO, MgO, Na$_2$O etc. high ash content in coal is undesirable in general.

A coal with high ash content:
- is harder and stronger. - Has lower calorific value.
- Produces more slag (impurities) in the blast furnace when coke made out of it is used therein.

Ash content of the coal is reduced by its washing.

4. THE STORAGE OF COAL OXIDATION AND SPONTANEOUS COMBUSTION

Freshly mined high volatile coal when stored in bulk undergoes low temperature atmospheric oxidation due to the presence of methane and other volatile matter on the surface. This exothermic oxidation causes the rise in temperature of the coal and if the heat is not removed, a stage comes when coal begins to burn. This is called spontaneous combustion which leads to outbreak of fire in the stored coal.

If the temperature rise due to oxidation does not exceed a critical value (say 50°C for lignite and 80°C for bituminous coals), spontaneous combustion does not take place but the quality of coal is affected depending on the degree of oxidation.

Low temperature oxidation of coal causes:
- Decreases in its caking power and calorific value.
- Decrease in carbon and hydrogen content.
- Decreases in its size grading.
- Increases in its oxygen content.
- Fire, if the temperature rise exceeds the critical value, i.e. 70°C.
- Decrease in gas and tar yields on its carbonisation.

Oxidation of high volatile matter containing coal (i.e. low rank coal) is more compared to that of low volatile coals (high rank). That means the chances of catching fire in anthracite is less compared to bituminous coal. As the maturity of the coal increases, its tendency to catch fire during storage decreases. It is worth noting that the rate of oxidation doubles for a rise in temperature of 10°C.

Low temperature oxidation is accelerated by:
- Temperature rise.
- Access to diffused air.
- Presence of small particles.
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- Presence of small particles.
- Presence of porous or friable particles.
- Storage in large heaps with small surface to volume ratio.

On the other hand, low temperature oxidation is retarded by:
- Cooling either by ventilation or water spray.
- Reducing access to air, i.e. by storage in compressed piles or storage under water.
- Reducing the size of the storage piles so that heat losses by conduction and convection to the atmosphere is high thus preventing temperature rise of the stored coal. Size and nature of storage piles is determined by the rank and type of coal. The lower the rank of.

5. USED OF COAL

Coal is uses for:
- Directly burning and getting heat.
- Generating steam for producing electricity (nearly 1 lb of coal is burnt to generate of 1 kWH of electricity).
- Driving railway locomotives.
- Manufacturing coke and coal gas (e.g. coke oven gas, producer gas, water gas, etc.).
- Manufacturing synthetic liquid fuels.
- Gasification to produces nitrogeneous fertiliser from synthesis gas.

Non – fuel uses of bituminous and lower rank coals:
- Production of activated carbon used for decoloration of glycerine and petroleum products.
- Treatment with strong sulphuric acid forms a basic exchange agent used in water treatment process.
- Uses as pigments for paints.
- Powdered coal is used in dynamite.
- Used as filter for various purposes due to its lightness, chemical inertness and low cost.
- Carbonisation of bituminous coal produces chemical such as tar, benzol, ammonia and host of other chemicals.
- Used for making carbon brushes.
- Used for burning in domestic oven.

**Uses of peat:**
It can be carbonised to produce gas and coke. It is also briquetted and uses as a domestic fuel.

**Uses of lignite:**
- For manufacture of producer gas.
- For generation of electrical power.
- For gasification to produce nitrogenous fertilizer.

**Uses of anthracite coal:** It is use:
- For recarbonising steel.
- For making carbon electrodes, brushes, battery parts, resistors, carbon refractory, corrosion resisting structural materials.
- As filler and paint pigment.
- For blending with cooking coal to check its swelling and improving the coke quality.

**6. SELECTION OF COAL FOR DIFFERENT USES**

There are various factors which are to be taken into account before it is decided to use the coal for a particular purposes:

**Coal for metallurgical purposes (i.e. making coke).** Cooking coals must
- be strong and hard.
- Have low ash, sulphur and phosphorous content.
- Be consistent, i.e. of uniform quality.

**Coals for producing gas:**
Gas coal should have:
- high volatile matter content so that gas yield is more.
- Less ash content (around 8%).
- Less sulphur content (1-1.2%).
- Weak cooking properties so that coal bed does not fuse during gasification.
- High ash fusion temperature so that clinker formation can be avoided.

**Coal for railway locomotives:**
- Large, well screened and from smalls.
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- Low in ash content.
- Weakly coking.
- Free from clinkering trouble, i.e. its ash fusion temperature should be high.

**Coals for domestic ovens:**
The preferred coals for domestic ovens are the larger graded sizes of the higher volatile free burning ranks. It should be low in ash. Ash fusibility is not that important because the grate of the domestic oven seldom reach a temperature high enough to cause clinking difficulties.

**Coals for steam raising:**
A coal used in boilers for burning and generating steam is called steam coal. Almost all other types of coal which are not suitable for carbonization or gasification can be used for steam raising.

**Coal for combustion practices:**
The describable qualities in a coal for combustion practices are:

- Calorific value should be high.
- Ash content should be low.
- Moisture should be low.
- Uniform size is desirable, fine dust and large lumps are objectionable.
- Successive deliveries of coal should be as far as possible of the same quality.

7. PROPERTIES AND TESTING OF COAL

**Proximate analysis of coal:**

Determination of moisture, volatile matter, ash and fixed carbon in coal comprises its proximate analysis.

**Determination of moisture content in coal:**

Loss in weight of coal caused by heating of weighed quantity of coal sample for one hour at 105°C is the moisture content in coal.

A known amount of finely powdered coal sample is kept in a silica crucible and heated in a muffle furnace at 105-110°C for one hour. There after the crucible is taken out, cooled in a dessicator and weighted. The process of heating, cooling and weighting is repeated a number of times till the constant weight of coal (anhydrous) is achieved. The percentage of moisture is given by:

\[
\% \text{ Moisture in coal} = \frac{\text{loss in weight of coal}}{\text{Weight of coal initially taken}} \times 100
\]
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Determination of volatile matter in coal:
It is the loss in weight of moisture free powdered coal when heated in a crucible fitted with cover in a muffle furnace at 950°C for 7 minutes.

\[
\% \text{ Volatile matter} = \frac{\text{loss in weight of moisture free coal}}{\text{Weight of moisture free coal}} \times 100
\]

Determination of ash in coal:
It is the weight of residue obtained after burning a weighed quantity of coal in an open crucible (i.e. in presence of air) at 750°C in a muffle furnace till a constant weight is achieved.

\[
\% \text{ Ash in coal} = \frac{\text{Weight of residue ash formed}}{\text{Weight of coal initially taken}} \times 100
\]

Determination of fixed carbon:
It is determined indirectly by deducting the sum total of moisture, volatile matter and ash percentage from 100.

\[
\% \text{ fixed carbon in coal} = 100 - (\% \text{ moisture} + \% \text{ volatile matter} + \% \text{ ash}).
\]

Ultimate analysis of coal:
Determination of total carbon, hydrogen, nitrogen, oxygen and sulphur percentages in coal comprises its ultimate analysis.

Determination of carbon and hydrogen in coal:
A known amount of coal is burnt in a current of dry oxygen thereby converting C and H of coal into CO\(_2\) (C + O\(_2\) = CO\(_2\)) and H\(_2\)O (H\(_2\) + 0.5 O\(_2\) = H\(_2\)O) respectively. The products of combustion (CO\(_2\) and H\(_2\)O) are passed over weighed tubes of anhydrous calcium chloride and potassium hydroxide which absorb H\(_2\)O and CO\(_2\) respectively. The increases in the weight of CaCl\(_2\) tube represents the weight of water (H\(_2\)O) formed while increases in the weight of KOH tube represents the weight of CO\(_2\) formed.

\% \text{ of H and C in coal can be calculated as below:}
\]

let, \(x = \text{weight of coal sample taken.}\)

\(y = \text{increase in the weight of CaCl}_2\) tube.

\(z = \text{increase in the weight of KOH tube.}\)

\[
\therefore \text{Amount of carbon in the coal sample} = \frac{12}{44} X z
\]

\[
\text{since, 44 gms of CO}_2 \text{ is produced from 12 gms of carbon and 32 gms of oxygen} \Rightarrow C_{12} + O_{32}^2 = CO_{44}^2
\]

\[
\therefore \% \text{ carbon in coal} = \frac{12Xz}{44Xx} \times 100
\]
Similarly, amount of hydrogen in coal sample:
\[
\frac{2}{18} \times y
\]
Since, 18 gms of water is formed by 2 gms of hydrogen and 16 gms oxygen, \( \Rightarrow \) \( H_2 + \frac{1}{2} O_{2\_g} = H_2O \)
\( \therefore \) hydrogen in coal
\[
= \left[ \frac{2 \times y}{18 \times x} \right] \times 100
\]

**Determination of nitrogen in coal:**

Nitrogen estimation in coal is done by kjeldahal’s method. A known weight of powdered coal is heated with concentrated sulphuric acid in presence of potassium sulphate and copper sulphate in a long necked flask (called kjeledahal’s flask) thereby converting nitrogen of coal to ammonium sulphate. When clear solution is obtained (i.e. when whole nitrogen is converted into ammonium sulphate) it is treated with 50% NaOH solution. The ammonia thus formed is distilled over and absorbed in a known quantity of standard sulphuric acid solution. The volume of unused sulphuric acid is then determined by titration against standard NaOH solution. Thus, the amount of acid neutralized by liberated ammonia (from coal) is determined:

\[
\text{Volume of acid used} = V_1 - V_2
\]
Where
\[
V_1 = \text{volume of H}_2\text{SO}_4 \text{ neutralized in blank, c.c.}
\]
\[
V_2 = \text{volume of H}_2\text{SO}_4 \text{ neutralized in determination, c.c.}
\]

**Determination of sulphur in coal.** A known quantity of coal is burnt completely in bomb calorimeter in a current of oxygen. Ash, thus obtained contains sulphur of the coal as sulphate which is extracted with dilute hydrochloric acid and the acid extract is treated with barium chloride solution to precipitate the sulphate as barium sulphate.
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\[
\begin{align*}
& \text{S} \rightarrow \text{SO}_4 \rightarrow \text{BaSO}_4 \\
& \text{32gms} \rightarrow \text{233 gms}
\end{align*}
\]

The precipitate of BaSO₄ is filtered, washed, dried and weighed from which the sulphur in coal can be computed as follow:

32 gms sulphur in the coal will give 233 gms BaSO₄.

If,

\[ x = \text{weight of coal sample taken.} \]
\[ y = \text{weight of BaSO}_4 \text{ precipitate formed.} \]

Then, amount of sulphur in coal sample:

\[
\frac{32y}{233} = 0.1374y
\]

so, \% of sulphur in coal = \(\frac{0.1374y}{x} \times 100\)

**Determination of oxygen in coal:**

It is deduced indirectly as follows.

\% oxygen in coal = 100 – (% of C + H + N + S + ash)

**Calorific value:**

It is defined as the quantity of heat liberated by the combustion of unit quantity of fuel.

**Principle of C.V determination:**

When a weighed quantity of fuel is burnt in the calorimeter, the heat liberated is used up in heating the calorimeter and the water in the calorimeter. By equating the heat given out by the fuel with heat taken up by the calorimeter and water, the calorific value (also called heating value) is determined. It is of two types viz. Higher (gross) calorific value and lower (net) calorific value.

**Higher and lower calorific values:**

Higher or gross calorific value. Hydrogen is found to be present in almost all fuels and when the calorific value of such fuel is determined hydrogen is converted into steam. Now, when the products of combustion are condensed to room temperature (25°C), the latent heat of condensation of steam also gets included in the measured heat. The total value so calculated is known as higher or gross calorific value and thus may be defined as the total amount of heat liberated when one unit of the fuel is burnt completely and the combustion products are cooled to room temperature.

Lower or Net calorific value. In actual practice, the water vapors escape as such along with hot combustion gases and thus are not condensed with the result a
lesser amount of heat is available. The amount of heat, so available, is called as lower or net calorific value and may be defined as the amount of heat liberated when one unit of the fuel is burnt completely and the combustion products are allowed to escape. Thus,

**Units of calorific value:**

(i) for solid and liquid fuels. Since solids and liquids are measured in terms of their masses, their calorific values are expressed as below.

- Calories/ gm (in C.G.S. system).
- K. Calories/ kg (in M.K.S system).
- B.T.U./1b (in F.P.S. or British system).

\[ 1\text{kcal/kg} = 1.8 \text{ B.T.U / 1b} \]

(ii) For gaseous fuels. Since gases are measured in terms of their volumes, their calorific values are expressed as below:

- kcal/ cubic metre (kcal/m$^3$)
- B.T.U. / cubic feet (B.T.U/FT$^3$)

\[ 1\text{kcal / m}^3 = 0.1077 \text{ B.T.U. / ft}^3 \]
\[ 1\text{B.T.U/ ft}^3 = 9.3 \text{ kcal/m}^3 \]

**8. CARBONISATION OF COAL – COKE MAKING AND BY – PRODUCTS RECOVERY**

**Carbonisation:** Heating of coal in absence of air to produce coke is called its carbonization or destructive distillation. ItS main purpose is to produce coke whereas the co-product is called coke oven gas from which various liquid products like tar, benzol, naphthalene, phenol, anthracene etc. are separated.

**Types of carbonization:**

There are mainly two types of carbonization depending upon the temperature up to which the coal is heated in absence of air namely. Low temperature carbonisation (LTC) and high temperature carbonisation (HTC). Their salient features are tabulated below in Table. 4.

<table>
<thead>
<tr>
<th>low temperature carbonisation (LTC)</th>
<th>High temperature carbonisation (HTC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) It is carried out at 700°C.</td>
<td>(a) It is carried out at 1100°C.</td>
</tr>
<tr>
<td>(b) It produces semi –coke which is used as a smokeless domestic fuel. It can sometimes be used in boiler also to avoid smoke.</td>
<td>(b) It produces – metallurgical coke for use in blast furnace and cupolas in foundry etc.</td>
</tr>
<tr>
<td>(c) Yiled of coke oven gas is less in LTC. It is about 150-160 Nm$^3$ gas/ ton dry coal. Less gas yiled is due to less devolatalisation of coal and less cracking of hydocarbons at</td>
<td>(c) Yiled of coke oven gas is more in HTC due to more cracking of hydocarbons (mainly methane in coke oven gas) at higher temperatue. Yield is about 292-300 Nm$^3$/ton of dry coal.</td>
</tr>
</tbody>
</table>
### INTRODUCTION AND CLASSIFICATION OF FUELS

<table>
<thead>
<tr>
<th>Description</th>
<th>LTC</th>
<th>HTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower temperature of carbonisation.</td>
<td></td>
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<tr>
<td>(d) Yield of tar is high in low temp. carbonisation. It is about 10% of dry coal.</td>
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<tr>
<td>(e) Ammonia yield is low.</td>
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<tr>
<td>(f) Calorific value of coke oven gas produced in LTC is more due to higher percentage of methane and unsaturated hydrocarbons in it. C.V. is about 6000 – 6500 kcal/Nm³.</td>
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<tr>
<td>(g) The tar produced is aliphatic in nature. It contains less quantity of aromatic ring compounds like benzen, toluence, naphthalene, phenol, anthracene etc. however, tar acid content is higher.</td>
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<tr>
<td>(h) After carbonisation, discharging of coke is difficult as it swells a lot but does not shrink much finally at the end of coking due to lower temperature of carbonisation.</td>
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<tr>
<td>(i) Free carbon in tar (which results from the cracking of hydrocarbons) is less. It is about 5-10% of tar. Since cracking (HC → H + C) is less severe at lower temperature.</td>
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<tr>
<td>(k) Volatile matter content in coke is more (5-7%) hence it is easier to ignite it because of lower ignition temperature of high volatile matte containing coke. Ignition temperature of LTC coke is about 425°C.</td>
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<tr>
<td>(l) Hydrogen content in coke oven gas is less (35-40%). Hence, difference in gross and net calorific value is less.</td>
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<tr>
<td>(m) Coke yield is more. It is about 80% of dry coal.</td>
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<tr>
<td>(d) Tar yield is less here. It is about 3% of dry coal charged.</td>
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<td></td>
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<tr>
<td>(e) Ammonia yield is more (10-15 gm/Nm³ of coke oven gas)</td>
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<td></td>
</tr>
<tr>
<td>(f) C.V. of coke oven gas produced in H.T.C is less. It is about 4200 – 4400 kcal/Nm³ only due to lesser percentage of hydrocarbons resulting from its cracking at higher temperature of carbonisation.</td>
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<tr>
<td>(g) Tar produced has more of aromatic ring compounds. (due to crystallisation reaction of straight chain compounds being favoured at higher temperature).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(h) Discharging of coke is easier as it shrinks finally to a more extent comparatively due to higher temperature of carbonisation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) Coke produced is stronger, smaller in size and less reactive (due to low porosity) due to higher amount of shrinkage of coke at higher temperature.</td>
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<td></td>
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<tr>
<td>(k) V.M. in coke is less (1-1.2%), hence its ignition temperature is more. Ignition temperature of high temp. coke is about 605°C.</td>
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</tr>
<tr>
<td>(l) H₂ content in coke oven gas is more (55-60%). It is beneficial for an adjoining nitrogenous fertiliser plant attached to steel plant which gets hydrogen (for ammonia making) from coke oven gas by its cryogenic cooling.</td>
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<tr>
<td>(m) Coke yield is less (about 77% of dry coal)</td>
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