Unit 4
Fuel

Prof. S. K. Hasan
Institute of Technology & Management, GIDA, Gorakhpur

FUELS

The carbonaceous combustible substance, which on combustion liberates a large amount of heat energy and light, is called as a Fuel.

$C + O_2 \rightarrow CO_2 + Heat$

$2H_2 + O_2 \rightarrow 2H_2O + Heat$

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + Heat$

The quality of a fuel depends upon the quantity and intensity of the heat obtained per unit mass of the fuel.

Heat evolved by burning of fuel can be employed for heating, cooking, drying and many industrial processes.

Classification

1. On the basis of occurrence:

i. Primary (Natural Fuel)

ii. Secondary fuels (Synthetic or Derived Fuel)

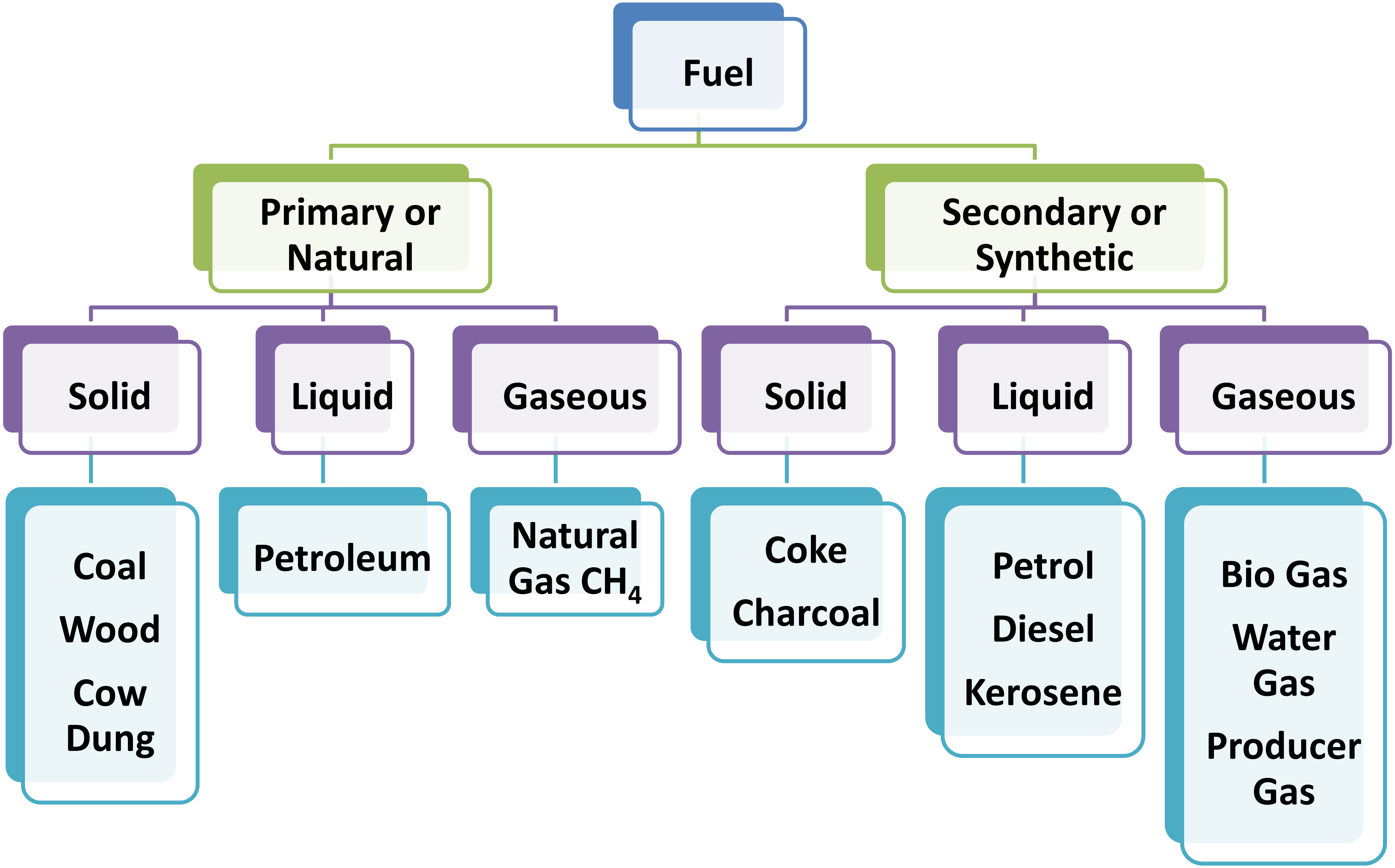
- Primary fuels occur in nature and are used without processing.
- Secondary fuels are prepared or obtained by chemical processing of primary fuel

2. On the basis of physical state, fuels are classified as

i. Solid,

ii. Liquid and

iii. Gaseous fuels



- Fuel
  - Primary or Natural
    - Solid
      - Coal
      - Wood
      - Cow Dung
    - Liquid
      - Petroleum
    - Gaseous
      - Natural Gas CH_4
  - Secondary or Synthetic
    - Solid
      - Coke
      - Charcoal
    - Liquid
      - Petrol
      - Diesel
      - Kerosene
    - Gaseous
      - Bio Gas
      - Water Gas
      - Producer Gas

Units of heat

- '**Calorie**' is the amount of heat required to raise the temperature of one gram of water through one Degree Centigrade (15-16°C).

- "**Kilocalorie**" is equal to 1,000 calories. It may be defined as 'the quantity of heat required to raise the temperature of one kilogram of water through one degree Centigrade.

Thus: **1 kcal = 1,000 cal**

- "**British Thermal Unit" (B.T.U.)** is defined as "the quantity of heat required to raise the temperature of one pound of water through one degree Fahrenheit (60-61°F). This is the English system unit.

1 B.T.U. = 252 cal = 0.252 kcal

1 kcal = 3.968 B.T.U.

- **Centigrade Heat Unit (C.H.U.)** is define as the quantity of heat required to raise the temperature of pound of water through one Degree Celsius.

Thus: 1 kcal = 2.2 CHU

1 kcal. = 3.968 BTU = 2.2 CHU

Characteristics of an ideal fuel

1. It should possess high calorific value.
2. It should have a moderate ignition temperature. The ignition temperature of the fuel should neither be too low nor too high (~ 80°C).
3. No toxic gases: It should not produce poisonous and toxic products during combustion.
4. Non pollutant: It should not cause pollution on combustion.
5. It should have moderate rate of combustion.
6. Combustion should be easily controllable

Contd…..

7. It should not leave behind much incombustible ash content on combustion.
8. Easy availability: It should be easily available in plenty.
9. Low moisture content: It should have low moisture content.
10. Low cost: It should be cheap.
11. It should be easy to handle and transport. Supply should be continuous
12. It should take minimum storage space.

Determination of Calorific Value
by
Bomb Calorimeter

CALORIFIC VALUE

Calorific value of a fuel is defined as "**the total quantity of heat liberated, when a unit mass of the fuel is burnt completely.**"

Unit of calorific value is cal/g or Kcal/g or joule/g or Kj/g

1 Cal = 4.2 Joule

a. Lower or Net Calorific Value (LCV or NCV)
b. Higher or Gross calorific value (HCV or GCV)

Net or lower calorific value (LCV) is "the net heat produced, when unit mass of the fuel is burnt (in open environment) completely and the volatile products are permitted to escape".

Gross or higher Calorific Value is "the total amount of heat produced, when unit mass of the fuel has been burnt completely and the volatile products of combustion have been condensed at room temperature".

Determination of Net Calorific Value (NCV)

NCV = GCV – Latent heat of condensation of water vapor produced

$2H + O \rightarrow H_2O$

2g 18g

1g 9g

This is based on the fact that 1 part of H by mass gives 9 parts of H_2O, and latent heat of steam is 587cal/g.

NCV=GCV – (9/100)H%×Latent heat of steam cal/g

NCV=GCV – 0.09H%×Latent heat of steam cal/g

NCV=GCV – 0.09H%×587 cal/g

(Latent heat of steam = 587cal/g)

Dulong's formula

for calorific value from the chemical composition of fuel is :

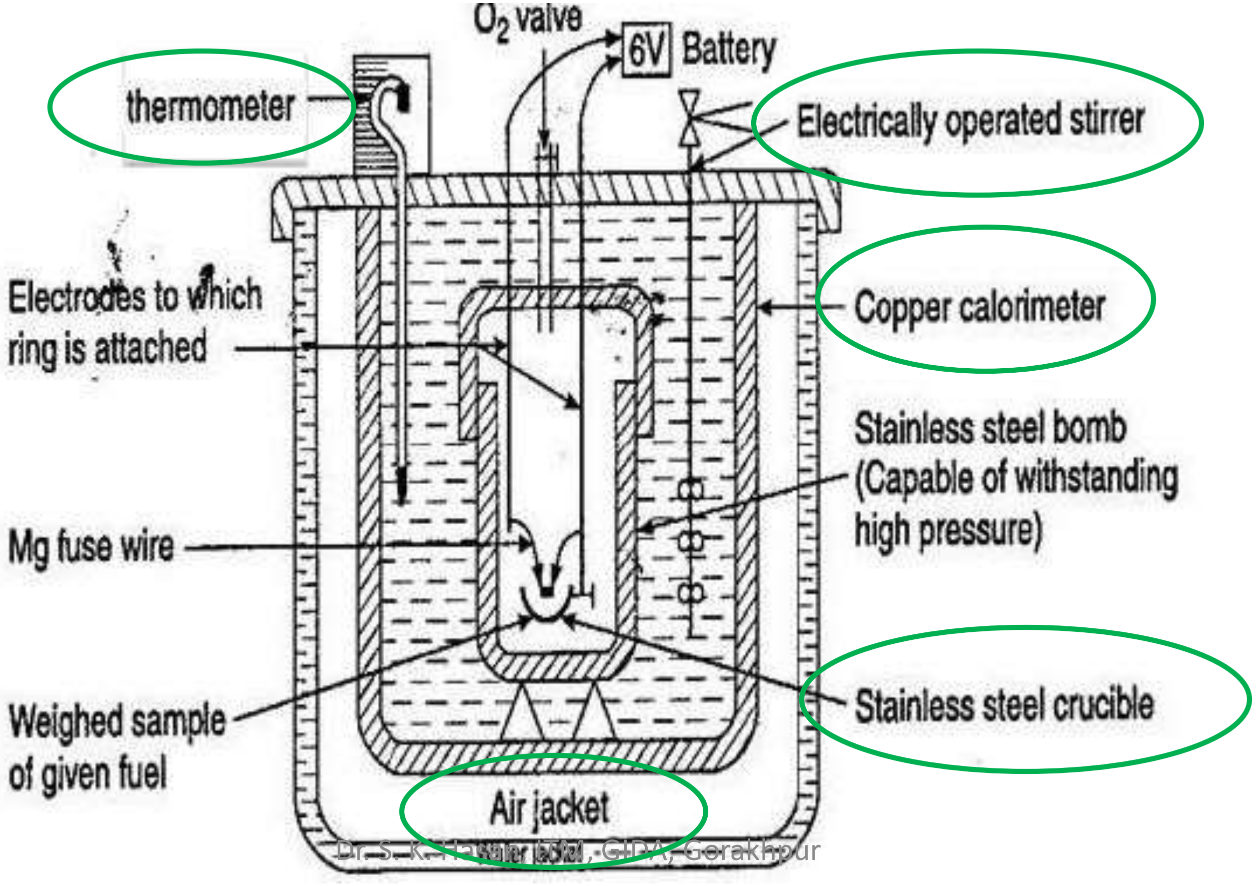
$HCV = 1/100\ [8080\ C + 34500\ (H - O/8) + 2240\ S]$ cal/g

Where, C, H, O, and S are the percentages of carbon, hydrogen, oxygen and sulphur in the fuel respectively. In this formula, oxygen is assumed to be present in combination with hydrogen as water, and

$LCV = [HCV - 0.09\ H\% \times 587]$ cal/g

Determination of calorific value by Bomb Calorimeter

1. **Water Calorimeter**
2. **Bomb- Crucible containing fuel connected to a battery**
3. **A thermometer :** To measure the temperature change
4. **A stirrer :** To shake the water for uniform heat distribution
5. **Calorimeter enclosed with air jacket :** To prevent heat loss



The calorific value can be calculated as follows.

$$\mathbf{GCV} = \frac{(W+w)\times(t_2-t_1)\ \text{cal/g}}{m}$$

i. **(Acid Correction C_A):** Nitrogen and Sulfur present in fuel form SO_x and NO_x gases which make solution acidic when dissolved in water of calorimeter. So, some heat is produced due to exothermic reaction.

ii. **(Fusion Correction C_F):** Mg wire gets fused so, some additional heat is produced.

iii. **(Thread Correction C_T):** Heat released by burning of thread.

Thus, a modified formula may be used for calculation of GCV.

$$\mathbf{GCV} = \frac{(W+w)\times(t_2-t_1+t_c) - (C_A + C_F + C_T)\ \text{cal/g}}{m}$$

Where,

m = weight of fuel sample, g

W = weight of water, g

w = water equivalent of calorimeter (g)

t_1 = initial temperature of water in calorimeter

t_2 = final temperature of water in calorimeter

t_c = cooling correction

Q.1. Calculate the gross and net calorific value of coal having composition
carbon=85%, hydrogen =8%, sulphur =1%,
ash = 4%, nitrogen =2%.

Solution:

Given: Carbon=85%, hydrogen=8%,
sulphur =1% ash = 4% nitrogen =2%.

Dulong Formula

HCV $= 1/100[8080C+34500(H-O/8)+2240S]$

$= 1/100[8080 \times 85+34500(8-0/8)+2240 \times 1]$

$= 1/100[965040]$

$= 9650.4$ cal/g. **(Ans.)**

LCV $= HCV-0.09 \times H \times 587$

$= 9650.4-0.09 \times 8 \times 587$

$= 9227.7$ cal/g. **(Ans.)**

Q.2. A 0.5g sample of coal was estimated for its calorific value by bomb calorimeter and following data were obtained.
water equivalent= 1000g, weight of water in calorimeter = 1500g, initial temperature = 27°C, Final temperature of water =30°C, composition of coal= 90%C, 4%H, 4%O, 2% ash, Calculate GCV and NCV, Latent heat of steam=587cal/g

Solution

GCV $= (W+w)(t_2-t_1)/m$

$= (1000+1500)\ (30-27)/0.5$

$= 2500 \times 3/0.5$

$= \mathbf{15000\ cal/g}$

NCV $= GCV - 0.09H \times 587$

$= 15000 - 0.09 \times 4 \times 587$

$= 15000 - 211.32$

$= \mathbf{14788.68\ cal/g}$

Q.3 A 0.8g sample of coal was estimated for its calorific value by bomb calorimeter and following data were obtained. water equivalent= 1000g, weight of water in calorimeter = 1500g, initial temperature = 27°C, Final temperature of water =30°C, composition of coal= 90%C, 4%H, 4%O, 2% ash, Calculate GCV an NCV, Latent heat of steam=587cal/g, cooling correction = 0.2°C, Fusion correction = 10 cal/g, Acid correction = 20 cal/g

Solution

GCV = [(W+w)(t_2-t_1 +cooling correction) – (Fusion correcion +Acid Correction)]/m

$$= [(1000+1500)\ (30-27 + 0.2) - (10+20)]/0.8$$

$$= [(2500 \times 3.2) - 30]/0.8$$

$$= (8000-30)/0.8$$

$$= 7970/0.8$$

= 9962.5 cal/g

NCV= GCV- 0.09H×587

$$= 9962.5 - 211.32$$

= 9751.18 cal/g

Coal Analysis

COAL

Coal mining is the process of extracting coal from the ground.

Coal is valued for its energy content, and, has been widely used to generate electricity. Thermal power is basically based on Coal energy in India

Coal is regarded as a fossil fuel produced from large accumulations of dead plants and trees due to partial decay and alteration by the action of heat and pressure over millions of years.

Coal is a highly carbonaceous matter.

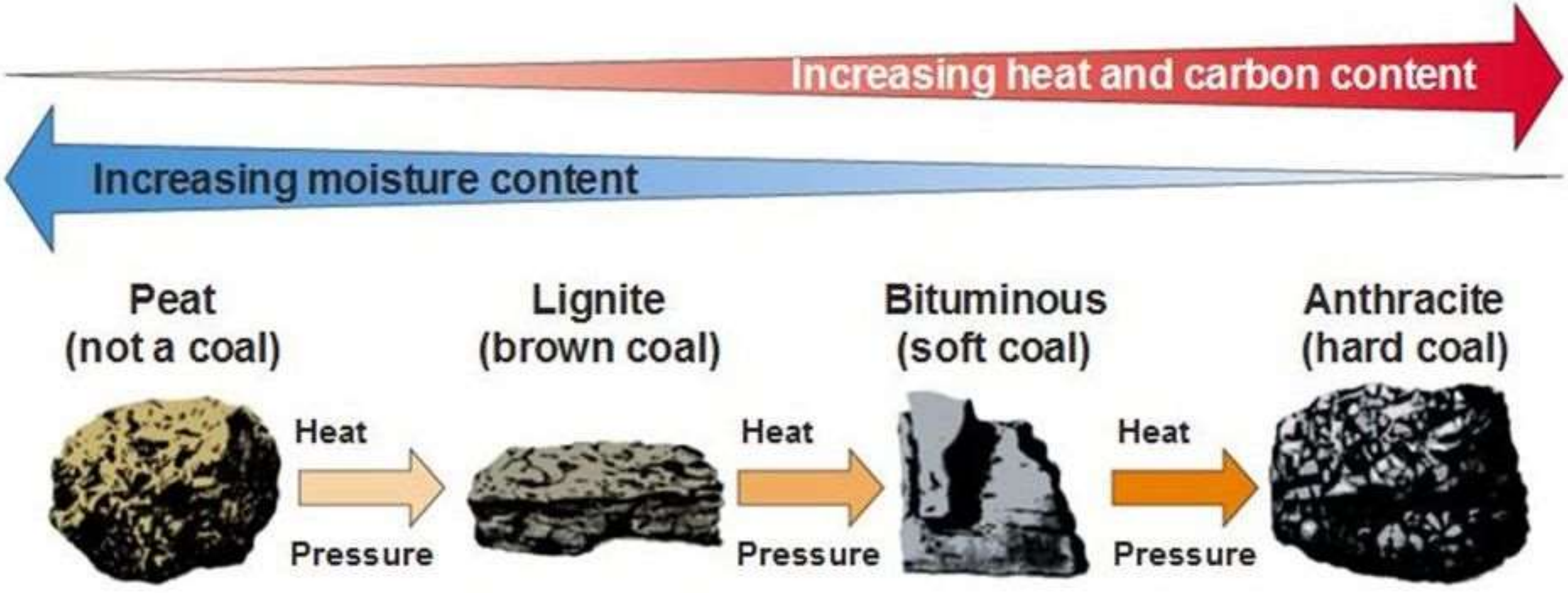
It is chiefly composed of C, H, N, and O, besides non-combustible inorganic matter.

Classification of Coal

Coals are classified on the basis of their rank. Rank is defined as the degree or extent of maturation and is therefore a qualitative measure of carbon contents. Peat & lignite coals are referred as low rank coals while bituminous coal and anthracites are classed as high rank. The lignite and sub-bituminous coals are called soft coals while bituminous coals and anthracite coals are termed as hard coals.

Coalification

Wood→ Peat →Lignite→ Bituminous →Anthracite



Peat

First stage of transformation.

- Contains **less than 40 % carbon**
- Contains sufficient volatile matter and **lot of moisture**
- It burns like **wood**, gives less heat,
- Emits more smoke and leaves a **lot of ash.**

Lignite (Brown coal)

- Lower grade coal.
- **40 to 55% carbon.**
- Intermediate stage.
- Moisture content is high (over 35%).
- It undergoes **SPONTANEOUS COMBUSTION**

Bituminous Coal

- Soft coal; most widely available and used.
- Derives its name after a liquid called bitumen.
- **60 to 80% carbon.**
- Moisture and volatile content (15 to 40%)
- Dense, compact, and is usually of black colour.
- Calorific value is **high** due to high proportion of carbon and low moisture.
- Used in production of **coke and gas**.

Anthracite

- **Best quality**; hard coal.
- **80 to 95% carbon.**
- Very little volatile matter.
- Negligibly small proportion of moisture.
- Semi-metallic lustre.
- **Ignites slowly** → less loss of heat → highly efficient.

Analysis of Coal

Following two types of analysis are made.

1. Proximate Analysis

It includes the determination of moisture, volatile matter, ash and fixed carbon. This gives quick and valuable information regarding commercial classification and determination of suitability for a particular industrial use.

2. Ultimate Analysis

It includes the determination of carbon, hydrogen, nitrogen, sulphur and oxygen in coal. Since it is used for the determination of elements present in the coal, it is also called elemental analysis. This analysis gives exact results and are useful in calculating the calorific value of coal using Dulong's formula.

Proximate Analysis
(1) %Moisture:

A small amount of finely powered air-dried coal sample is weighed in a crucible (w_1). The crucible is placed inside an electric hot air-oven, maintained at 105° - 110°C. The crucible is allowed to remain in oven for 1 hour and then taken out, cooled in a desiccator and weighed (w_2). Loss in weight is reported as moisture %.

%moisture = Loss in Wt. (w_1-w_2) x 100 /w_1

w_1=mass of coal taken

(2) %**Volatile matter**:

The dried sample of coal left in the crucible in (1) is then covered with a lid and placed in an electric furnace (muffle furnace), maintained at 925°± 20°C. The crucible is taken out of the oven after 7 *minutes* of heating in absence of oxygen. The crucible is cooled first in air, then inside a desiccator and weighed again (**w_3**). Loss in weight is reported as volatile matter on percentage-basis.

% volatile matter = Loss in weight (w_2-w_3)x 100/w_1

w_1=mass of coal taken

W1 g coal contains volatile matter = (w2-w3) g

100 g ,, ,, ,, ,, = (w2-w3) * 100/w1

% Volatile matter = (w2-w3) * 100/w1

(3) % **Ash Content**

The residual coal in the crucible, after removal of volatile matter, is then heated without lid in a muffle furnace at 700± 50°C for ½ an *hour.*

The crucible is then taken out, cooled first in air, then in desiccator and weighed.

Heating, cooling and weighing is repeated, till a *constant weight* is obtained (w_4).

The residue is reported as ash as %.

% Ash = Wt. of ash left (w_4)x 100/w_1

w_1= mass of coal taken

(4) % **Fixed carbon**

% fixed carbon = 100–(moisture%+volatile matter%+ ash %)

Q. 10 g (w1) coal sample was heated at 105°C for 1 h in an oven, the weight was reduced to 9.6 g (w2). then it was heated at about 925°C for 5 minute in a muffle furnace, the weight was found 9.4g (w3). After complete burning the weight of ash content was found 1.2g (w4). Calculate %free carbon in the sample.

% moisture = (w1-w2)*100/10= (10-9.6)*10 = 0.4*10 = 4%

%Volatile Matter = (w2-w3)*100/10 = (9.6-9.4)*10 = 0.2*10 = 2%

% Ash = w4*100/10 = 1.2*10 = 12%

% Free Carbon = 100-(4+2+12) = 82%

Coal Analysis
Ultimate Analysis

Ultimate Analysis

Ultimate analysis is also called as Elemental analysis because exact determination of percentage of C, H, O, N and S is carried out under this process.

So we will discuss about

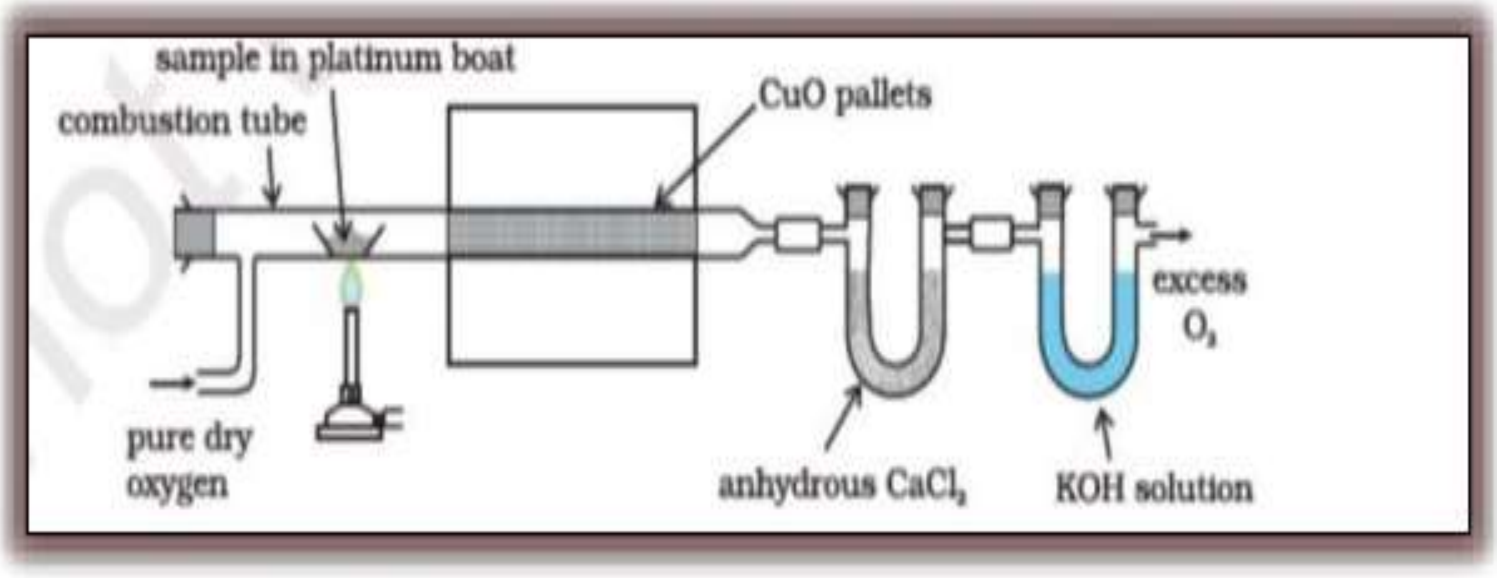
1. Determination of %C
2. Determination of %H
3. Determination of %N
4. Determination of %S
5. Determination of %O

(B) Ultimate analysis

(1) Carbon and Hydrogen:

About 1-2 g of accurately weighed coal sample is burnt in a current of oxygen in a combustion apparatus. C and H of the coal are converted into CO_2 and H_2O respectively. The gaseous products of combustion are absorbed respectively in KOH and $CaCl_2$ tubes of known weights. The increase in weights of these are then determined.

Determination of carbon & hydrogen



$2H + \frac{1}{2} O_2 \rightarrow H_2O$

2 gm 18 gm

$CaCl_2 + 7H_2O \rightarrow CaCl_2.7H_2O$

18 gm H_2O is formed by 2 gm H

So, x gm H_2O by x ×2/18 gm H

W g coal contains H = x×2/18 gm H

100 gm coal contains H = x×2×100/18×W

$$\%H = \frac{\text{Increase in weight of } CaCl_2 \text{ tube (x)} \times 2 \times 100}{\text{Weight of coal sample taken (W)} \times 18}$$

$$\mathrm{C} + \mathrm{O_2} \rightarrow \mathrm{CO_2}$$
$$12 \qquad\qquad 44$$
$$2\,\mathrm{KOH} + \mathrm{CO_2} \rightarrow \mathrm{K_2CO_3} + \mathrm{H_2O}$$

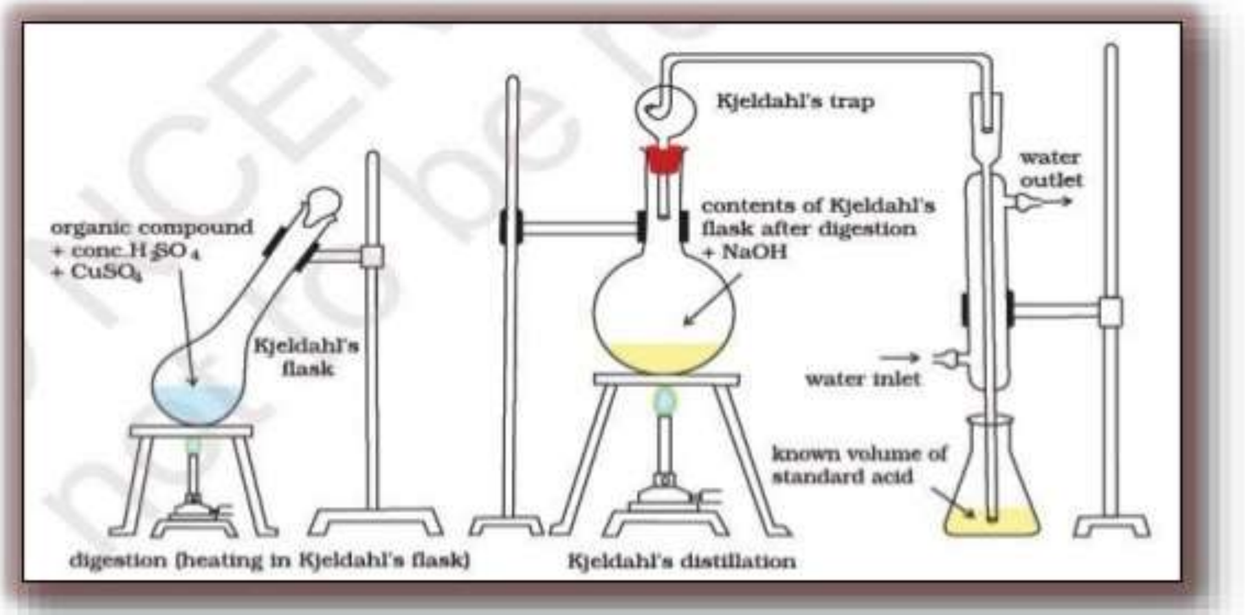
44 g CO_2 is formed by 12 g C
So,
y gm CO_2 by $y \times 12/44$ g C
W g coal contains C = $y \times 12/44$ gm C
100 gm coal contains C = $y \times 12 \times 100/44 \times W$

$$\% \mathrm{C} = \frac{\text{Increase in weight of KOH tube (y)} \times 12 \times 100}{\text{Weight of coal sample taken (W)} \times 44}$$

(2) Nitrogen: Kjeldal Method

About 1 g of accurately weighed powdered 'coal is heated with concentrated H_2SO_4 along-with K_2S0_4 (catalyst) in a long-necked flask(called *Kjeldahl's flask).* After the solution becomes clear, it is treated with excess of KOH and the liberated ammonia is distilled over and absorbed in a *known volume of standard acid solution.* The unused acid is then determined by back titration with standard NaOH solution. From the volume of acid used by ammonia liberated, the Percentage of N in coal is calculated as follows:

$$\textbf{\% N} = \frac{\textbf{Volume of acid used x Normality x 1.4}}{\textbf{Weight of coal taken}}$$



(3) Sulphur is determined from the washings obtained from the known mass of coal, used in a bomb calorimeter for determination of a calorific value. During this determination, S is converted into sulphate. The washings are treated with barium chloride solution, when barium sulphate is precipitated. This precipitate is filtered, washed and heated to constant weight.

$BaSO_4 \longrightarrow S$

233 32

Z gm BaSO4 contains S = Z×32/233

W gm, coal contins S = Z×32/233

100 ,, ,, ,, = Z×32×100/W×233

$$\%S = \frac{\text{Weight of BaS0}_4\text{ obtained (Z)} \times 32 \times 100}{\text{Weight of coal sample taken in bomb} \times 233}$$

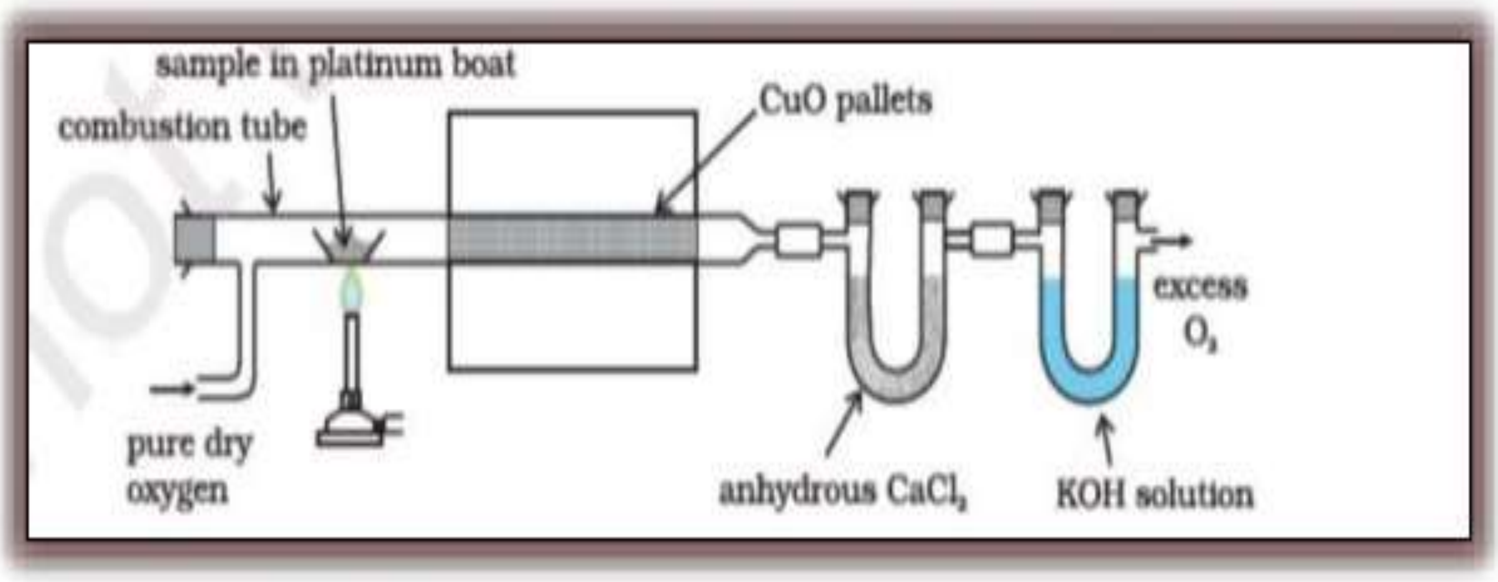
(4) **%Ash determination is carried out as in proximate analysis.**

(5) **Oxygen: It is obtained by difference.**
% O = 100 - % of (C + H + S + N + Ash)

Problems on
Ultimate Analysis of Coal & Combustion

Q.1. 1.2g of a coal sample was analysed for C and H. The increase in weight of anhydrous $CaCl_2$ was observed 1.0 g and that of KOH solution by 3.0g. Calculate %H and %C in the coal sample.

Determination of carbon & hydrogen



Solution

Weight of coal taken = 1.2g

Increase in weight of KOH solution =3.0 g

We know that,

$$\begin{array}{lcl} \mathbf{C + O_2 \rightarrow} & & \mathbf{CO_2} \\ \mathbf{12} & & \mathbf{44} \end{array}$$

$$\% \mathrm{C} = \frac{\text{Increase in weight of KOH tube (x) x 12 x 100}}{\text{Weight of coal sample taken (W) x 44}}$$

$$= 3.0 \times 12 \times 100 / 1.2 \times 44$$

$$= 3000/44$$

$$= 68.18$$

$2H + \frac{1}{2} O_2 \rightarrow \quad H_2O$
2 gm $\qquad$ 18 gm

Weight of coal sample (W) = 1.2 g
Increase in weight of $CaCl_2$ (y) = 1.0 g

$$\%H = \frac{\textbf{Increase in weight of CaCl}_{\mathbf{2}}\textbf{ tube (y) x 2 x 100}}{\textbf{Weight of coal sample taken (W) x 18}}$$

$= 1.0 \times 2 \times 100 / 1.2 \times 18$
$= 9.26$

Q. 2 1.56 g of the coal was kjeldahlized and NH_3 gas thus evolved was absorbed in 50 ml of 0.1 N H_2SO_4. After absorption the excess (residual) acid required 6.25 ml of 0.1N NaOH for exact neutralization. Calculate %N in the coal sample.

Solution

Let x ml of excess H_2SO_4 was neutralized by NaOH

$N_1V_1 = N_2V_2$

$0.1 \times x = 0.1 \times 6.25$

So, x = 6.25 ml

Hence, Volume of H_2SO_4 used in neutralization of NH_3 = 50-6.25

=43.75 ml

$$\% \text{ N} = \frac{\text{Volume of acid used x Normality x 1.4}}{\text{Weight of coal taken}}$$

$= 43.75 \times 0.1 \times 1.4 / 1.56$

= 3.926 Ans.

Q.3. **2.6 g of the coal sample in a quantitative analysis gave 0.1755g of $BaSO_4$. Calculate the percentage of Sulphur.**

W=2.6 g x=0.1755 g

$BaSO_4 \longrightarrow S$

233 32

x gm $BaSO_4$ contains S $x \times 32/233$

W gm, coal contins S = $x \times 32/233$

100 ,, ,, ,, = $x \times 32 \times 100/W \times 233$

$$\%S = \frac{\text{Weight of } BaSO_4 \text{ obtained (x) x 32 x 100}}{\text{Weight of coal sample taken (W) x 233}}$$

$= 0.1755 \times 32 \times 100/2.6 \times 233$

= 0.927 Ans.

Air contains O_2 by volume = 21% and

O_2 by weight = 23%

Thus,

- For (x) volume of O_2 air required = (x)×100/21
- For (y) weight of O_2, air required = (y)× 100/23
- Molecular mass of air = 28.94 g/mol
- Density of air at NTP = 1.29 kg/cm^3
- 22.4 litres (or 22,400 ml) of any gas at NTP has a mass =its1mol (gram molecular weight)
- Thus 22.4 litres of CO_2 at NTP will have a mass of 44 g (44 is the molecular weight of CO_2)

Q.4. **Calculate the volume of air (Volume % of O_2 in air = 21) required for complete combustion of 1 liter of CO**

Solution

The combustion equation of CO is written as follows

$CO + \frac{1}{2} O_2 \rightarrow CO_2$

1 vol 0.5 vol

One volume (1 liter) of CO requires half volume (0.5 liter) of O_2 for complete combustion.

We know that,

Since, For 21 L of O_2 air required = 100 L of air.

∴ 0.5 L of O_2, air required $= 5.0 \times 100 / 21$ L

$= 2.38$ L

Answer

The volume of air required for the complete combustion of 1 L of CO = 2.38 L

Q.3. Calculate the weight and volume of air required for the complete combustion of 1 kg of coke (or) carbon.

Solution

The combustion equation of the carbon is as follows.

$$\begin{array}{ccccc} C & + & O_2 & \rightarrow & CO_2 \\ 12\text{ g} & & 32\text{ g} & & \end{array}$$

12 g of carbon requires 32 g of O_2 for complete combustion.

$\therefore$1 kg of coke requires $1\times32/12 = 2.67$ kg of O_2

We know that,

23 kg of O_2 is supplied by 100 kg of air.

$\therefore$ For 2.67 kg of O_2 air required $= 2.67\times100/23 =$ **11.61 kg of air.**

We know that,

1 mole of any substance occupies 22.4 litres (at NTP)

32 g of O_2 occupies 22.4 L at NTP [1 m^3= 1000 litres]

2.67 kg of O_2 = 2670 g of O_2 $= 22.4\times 2670/32 =$ **1869 L = 1.869 m^3**

We know that,

For 1.869 m^3 O_2, air required $= 1.869\times 100/21$

$\therefore$ = 8.9 **m^3 of air.**

= 8900 L

Thank you

Prof. S. K. Hasan
Institute of Technology & Management, GIDA, Gorakhpur