Module

6

# FUELS AND COMBUSTION

**SYLLABUS** **Weightage : 23 Marks**

Definition, classification, characteristics of a good fuel, units of heat (no conversions).
Calorific value- Definition, Gross or Higher calorific value & Net or lower calorific value, Dulong's formula & numerical for calculations of Gross and Net calorific values.
Solid fuels- Analysis of coal- Proximate and Ultimate Analysis- numerical problems and significance.
Liquid fuels- Petrol- Knocking, Octane number, Cetane number, Anti-knocking agents, unleaded petrol, oxygenates (MTBE), catalytic converter.
Combustion- Calculations for requirement of only oxygen and air (by weight and by volume only) for given solid & gaseous fuels

**Topic :**

## 6.1 DEFINITION, CLASSIFICATION OF FUELS - SOLID, LIQUID & GASEOUS

### 6.1.1 Definition

**Q.1 Define fuels. How are they classified ?**

**Ans.:** **Definition** : A fuel is a combustible substance containing carbon as main constituent which on proper burning gives large amount of heat, which can be used economically for domestic and industrial purposes.

### 6.1.2 Classification of Fuels

Fuels may be divided into two types.

(i) Primary fuels which occur in nature
(ii) Secondary fuels which are derived from the primary fuels.

Fuels may also be classified into three groups

(i) Solid fuels
(ii) Liquid fuels &
(iii) Gaseous fuels.

**FUELS**

- Primary or NATURAL
  - Solid: wood, peat, lignite, coal
  - Liquid: crude petroleum
  - Gaseous: Natural gas
- Secondary or DERIVED
  - Solid: Coke, Charcoal, briquette coal
  - Liquid: Tar, Kerosene, Diesel, petrol, Fuel oil, Synthetic Gasoline
  - Gaseous: Coal gas, Watergas, Oil gas, Bio gas, LPG, Producer Gas

## 6.2 CALORIFIC VALUE, DULONG'S FORMULA & NUMERICALS, CHARACTERISTICS OF A GOOD FUEL

**Q.1 Define the term calorific value and ignition temperature ?**

**Ans.:** The efficiency of fuel is judged by calorific value.

**Definition :** The total quantity of heat liberated when a unit mass of the fuel is burnt completely.

Calorific value of solid and liquid fuels is usually expressed in calories per gram (cals/gm) or Kcal/kg whereas the calorific value of gases is expressed in kilocalories per cubic metre. (Kcal/$m^3$)

The calorific value of a fuel can be considered in two ways.

(i) Higher or gross calorific value
(ii) Lower or net calorific value

### 6.2.1 Higher OR Gross Calorific Value

**Q.2 Define Gross and Net calorific value of a fuel.**

**Ans.:** Usually all fuels contain some hydrogen and when the calorific value of hydrogen containing fuel is determined experimentally, the hydrogen is converted into steam. When the products of combustion are cooled to 60°F or 15°C, the steam gets condensed into water and latent heat is evolved on condensing the steam. The latent heat of condensation of steam so liberated also gets included in the total heat and as a result more amount of heat is available. The gross or higher calorific value is defined as the total amount of heat produced when a unit mass of fuel is burnt completely and the products of combustion are cooled down to room temperature usually 60°F or 15°C.

### 6.2.2 Net OR Lower Calorific Value

In actual use of any fuel, the water vapour is not condensed but escapes into the atmosphere along with hot combustible gases and as a result lesser amount of heat is available.

The net or lower calorific value is defined as the net amount of heat produced. When a unit mass of fuel is burnt completely and the products of combustion are allowed to escape into the atmosphere.

Net calorific value

= [Gross calorific value – latent heat of $H_2O$ vapour formed]

= [Gross calorific value – (wt. of H per unit wt. fuel × g × latent heat of steam]

$$\therefore \quad \text{Net C.V.} = \text{Gross C.V.} - 9 \times \frac{H}{100} \times 587$$

$$^*\text{Net C.V.} = \text{Gross C.V.} - 0.09 \times H \times 587$$ where, H = % of hydrogen in fuel.

[$^*2H_2 + O_2 \rightarrow 2H_2O$

$4 \text{ g } H_2 \rightarrow 36 \text{ g of } H_2O$

$1 \text{ g } H_2 \rightarrow 9 \text{ g } H_2O$]

Thus one part by wt. of H gives 9 parts by wt. of water as per above equation. Latent heat of steam is 587 cals/g or (kcal/kg).]

### 6.2.3 Determination of Calorific Value by Dulong's Formula

The calorific value of a fuel can be calculated approximately from the ultimate analysis, which gives the % of elements like C, H, N, S, & O.

According to Dulong, the calorific value of a fuel is the sum of calorific values of all the elements present. The calorific values of different elements are given as under.

Calorific value of C = 8080 cal/g

Calorific value of H = 34500 cal/g

Calorific value of S = 2240 cal/g

Thus the Dulong's formula for calculating gross calorific value of a fuel in MKS system is

$$\text{H.C.V} = \frac{1}{100}\left[8080C + 34500\left(H - \frac{O}{8}\right) + 2240S\right] \text{ Kcal/Kg.}$$

where C, H,O & S are the % of C, H, O, and S respectively. In this formula, oxygen is assumed to be present in combination with hydrogen as water and

$$\text{L.C.V.} = \left[HCV - \frac{9}{100} H \times 587\right]$$

### 6.2.4 Characteristics of a Good Fuel

**Q.3 What are characteristics of good fuel?**

**Ans.:** A good fuel should have the following characteristics.

1. **Calorific value** : A good fuel should have high calorific value since the amount of heat liberated and temperature attained thereby depends upon the calorific value of fuel.
2. **Moderate ignition temperature** : A good fuel should have moderate ignition temperature. Low ignition temperature is dangerous for storage and transport of fuel, since it can cause fire hazards. On the other hand high ignition temperature causes difficulty in initiating a fire.
3. **Low moisture content** : The moisture content of the fuel should be low, because moisture reduces the heating value (calorific value) of fuel.
4. **Low non-combustible matter content** : After combustion, the non combustible matter remains in the form of ash or clinker. This reduces the calorific value, adds to the cost of storage, problems in handling and disposal of the waste products produced. Hence a fuel should have low content of non-combustible matter.
5. **Low cost :** A good fuel should be readily available in bulk at a cheap rate.
6. **Moderate velocity of combustion** : Fuel should have a moderate rate of combustion. If the rate of combustion is low, then the required high temperature is not attained and high rate of combustion is not desirable.
7. **Products of combustion** : The fuel should not produce obnoxious or objectionable gases during burning. Fuel should be clean in use and economical in labour without polluting the atmosphere.
8. **Easy to transport :** Fuel must be easy to handle, store and transport at a low cost. Transportation of gaseous fuels is costly and can cause fire hazards.
9. **Spontaneous combustion** : Fuel should not undergo spontaneous combustion. It should be easily controllable.
10. **Pyrometric Effect. :** The highest temperature obtained with the fuel is known as pyrometric heating effect. A good fuel should have high pyrometric effect. Gaseous fuels have highest pyrometric effect.
11. **Storage cost** of fuel in bulk should be low.
12. The fuel should burn freely and with **high efficiency**, once it is ignited.
13. **Supply of fuel :** The supply of fuel should be reliable and regular.
14. In case of solid fuel, the **size** should be **uniform** so that **combustion is regular**.

## 6.3 SOLID FUELS- PROXIMATE & ULTIMATE ANALYSIS, NUMERICALS

Coal is a highly carbonaceous fuel which is formed in nature as the final product of a series of decomposition of vegetable matter under the influence of heat and pressure in a limited supply of air. It is chiefly composed of C, H, N, O and S besides non-combustible inorganic matter.

### 6.3.1 Analysis of Coal

The composition of coal varies widely and hence it is necessary to analyse and interpret the results from the point of view of commercial classification, price fixation and proper industrial utilization of coal. The quality of the coal is ascertained by following two types of analysis. (1) Proximate Analysis, (2) Ultimate Analysis.

### 6.3.2 Proximate Analysis

**Q.1 How is proximate analysis of coal conducted? What is its significance?**

**Ans.:** This 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.

**(i) Moisture :**

Moisture increases in transport costs and reduces the efficiency of fuel. It is determined by heating 1 gm. of finely powdered coal in an oven at 105° – 110°C for 1 hr. and the loss in weight is expressed as % of moisture. The heating and cooling procedure is continued till constant weight.

$$\therefore \quad \% \text{ of moisture} = \frac{\text{Loss in weight}}{\text{weight of coal}} \times 100$$

**(ii) Volatile matter :**

The classification of coal depends on volatile matter content. Bituminous coal contains more volatile matter than anthracite coal. Lesser the percentage of volatile matter, better is the quality of coal.

It is determined by heating 1g of moisture free coal in silica crucible with a closely fitted lid (to exclude air or oxygen) in a muffle furnace at 950 ± 20°C for exactly 7 minutes. The loss in weight represents the amount of volatile matter.

$$\% \text{ of volatile matter} = \frac{\text{loss in weight}}{\text{weight of moisture free coal}} \times 100$$

**(iii) Ash content :**

It reduces the calorific value of the fuel. It creates cleaning and disposal problems. It causes hindrance in the flow of heat. Ash results in the formation of clinkers which reduces supply of air. A good fuel should have least % of ash.

Determination of ash content is done as follows:

A known weight of dried sample is taken in an open silica crucible and heated to open air at 700°C–750°C in a muffle furnace until a constant weight is obtained. The weight of the residue is reported as ash.

$$\% \text{ of ash} = \frac{\text{weight of residue}}{\text{weight of dried coal}} \times 100$$

**(iv) Fixed Carbon :**

The quality of coal is better if the % of fixed C in coal is more and hence the calorific value is also greater. The % of fixed C helps in the design of a furnace and the shape of a firebox as fixed C burns in a solid state. It is determined by subtracting from 100, the sum of total % of moisture; volatile matter and ash.

$$\% \text{ Fixed C} = 100 - (\% \text{ of moisture} + \% \text{ V matter} + \% \text{ Ash})$$

### 6.3.3 Ultimate Analysis

**Q.2 How is ultimate analysis carried out ? What is its significance ?**

**Ans.:** The significance of this analysis is that it is useful in classification of coal and combustion calculations as it basically determines the % of the elements. It is required for detailed and accurate heat balance for the equipment in which the fuel is used.

**(i) Carbon and hydrogen** : They are determined by burning a known weight of coal sample (about 0.2g) in a stream of pure oxygen in a combustion apparatus similar to that of used for the analysis of organic compounds. C & H of the coal are converted into $CO_2$ & $H_2O$ respectively. The gaseous products of combustion are absorbed respectively in KOH and $CaCl_2$ tubes of known weights. The increase in weights of these tubes are then determined.

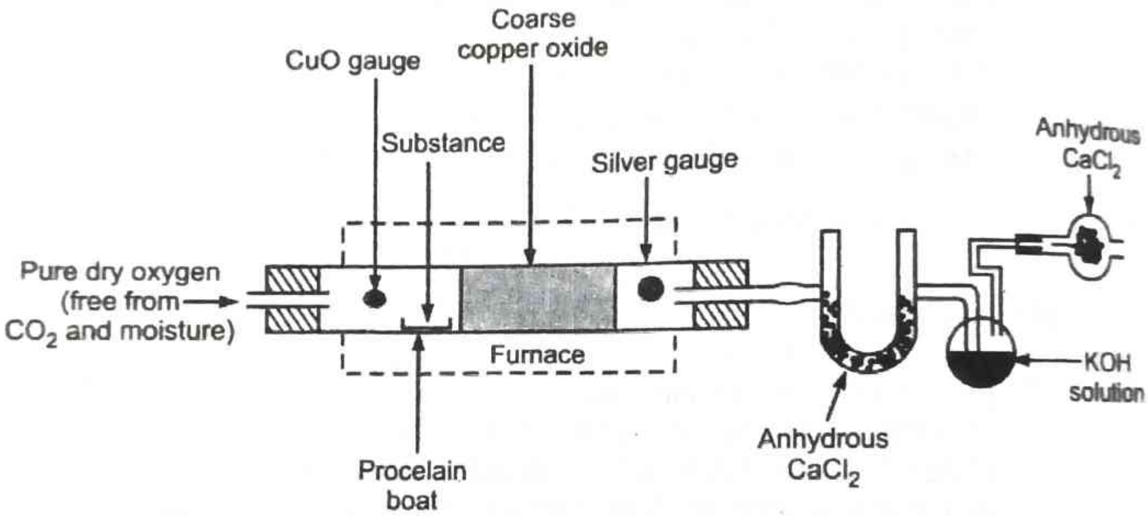
$$\underset{(12)}{C} + O_2 \rightarrow \underset{(44)}{CO_2};\ \underset{(2)}{H_2} + 1/2\ O_2 \rightarrow \underset{(18)}{H_2O}$$

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

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

$$\therefore \%\text{ of C} = \frac{\text{Increase in weight of KOH tube} \times 12 \times 100}{\text{Weight of coal sample taken} \times 44}$$

$$\therefore \%\text{ of H} = \frac{\text{Increase in weight of } CaCl_2 \text{ tube} \times 2 \times 100}{\text{weight of coal sample taken} \times 18}$$




**(ii) Nitrogen :** It is determined by digesting 1g of coal sample in Kjeldahl flask (long necked flask) with conc. $H_2SO_4$ along with $K_2SO_4$. 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. From the volume of acid used by ammonia liberated, the % of N in coal is calculated as follows :

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

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

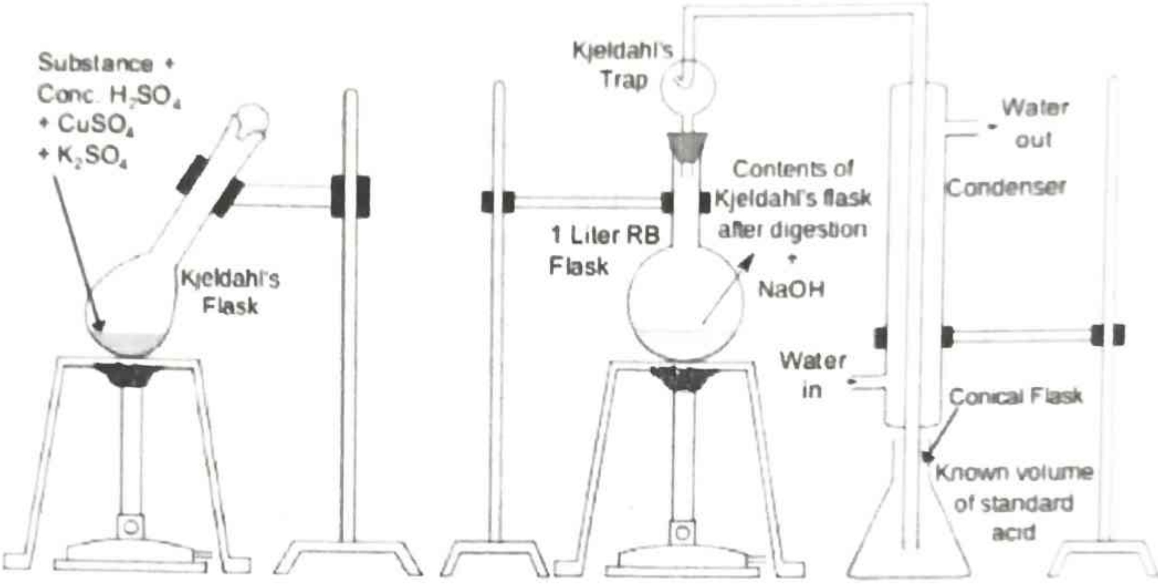
Let weight of coal taken = W gm.
Vol of N/10 NaOH required for blank Rdg = Y ml.
Vol. of N/10 NaOH required = xml (to titrate unreacted acid)
Vol. of N/10 acid reacted with ammonia = (y–x) ml.
Vol. of N/10 ammonia = (y–x) ml.
1000 ml of 1N ammonia solution = 17 gm of $NH_3$
1000 ml of 1N $NH_3$ Solution = 14 gm of N.

$\therefore$ Amount of Nitrogen in $(y - x)$ ml of $N_{acid}$ $NH_3$

$$= \frac{14 \times (y - x) \times N_{acid}}{1000} = \frac{14 \times (y - x) \times N_{acid} \times 100}{1000 \times \text{w of coal}}$$

**OR** $$\%\text{ of N} = \frac{\text{vol. of acid used} \times \text{normality} \times 1.4}{\text{weight of coal taken}}$$

**Kjeldhal**




**(iii) Sulphur :** It is determined from the washings obtained from the known mass of coal, used in 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.

$$\%\text{ of S in coal} = \frac{\text{weight of } BaSO_4 \text{ obtained} \times 32 \times 100}{233 \times \text{weight of coal sample taken in bomb}}$$

**(iv) Ash :** It is determined same as in proximate analysis.

**(v) Oxygen :** It is obtained by difference

$\%$ oxygen = $100 - \%$ of $(C + H + S + N + Ash)$.

**Significance and importance of ultimate analysis**

(i) **C & H :** Greater the percentage of C and H, better is the coal in quality and calorific value. However, H is mostly associated with volatile matter and hence it influences the use of coal. Since H is mainly present in combination with O as water it lowers the calorific value of fuel, so lesser the percentage of H better is the quality of coal.

(ii) **N :** N is an inert and incombustible gas and does not contribute any useful property. It is generally found in small amounts (around 1 %)

(iii) **S :** S present in metallurgical coal is harmful for use in metallurgy as it transfers to the metal and adversely affects the properties of metal. Oxidation products of S ($SO_2$ and $SO_3$) especially formed in presence of moisture, have corrosive effect on the equipment and also causes atmospheric pollution. Hence the presence of S is undesirable.

(iv) O : O content decreases the calorific value of coal. High O content coals are characterized by high inherent moisture, low calorific value and low coking power. Moreover oxygen is in combined form with hydrogen in coal and thus H available for combustion is lesser than actual. An increase in 1% oxygen content decreases the calorific value by about 1.7 % and hence O is undesirable. Thus a good quality coal should have lower % of O. (A good quality coal should have high % of C, less % of H, less % of N, less % of S and less % of O as well as Ash.)

## 6.4 PETROL- REFINING OF PETROL, UNLEADED PETROL (USE OF MTBE), CATALYTIC CONVERTER, POWER ALCOHOL, KNOCKING, OCTANE NUMBER, CETANE NUMBER, ANTIKNOCKING AGENTS

### 6.4.1 Refining of Petrol OR Gasoline

**Q.1 Write a short note of Refining of Petrol.**

**Ans.:** The straight-run gasoline (obtained either from fractionation of crude petroleum or by synthesis) contains some undesirable unsaturated straight-chain hydrocarbons and sulphur compounds. The former gets oxidised and polymerized, thereby causing gum and sludge formation on storing. Sulphur compounds lead to corrosion of internal combustion engine.

**Characteristics of an ideal gasoline :**

(1) It must be cheap and readily available.
(2) It must burn clean and produce no corrosion, etc., on combustion.
(3) It should mix readily with air and afford uniform manifold distribution, i.e., it should easily vaporise.
(4) It must be knock-resistant.
(5) It should not preignite easily.
(6) It should not tend to decrease the volumetric efficiency of the engine.
(7) It must have a high calorific value.

**Refining :**

(1) The sulphur compounds are, generally, removed by treating gasoline with an alkaline solution of sodium plumbite with controlled addition of S. This refining process (called 'sweetening') converts sulphur compounds into disulphides (Doctor's process).

$$2RSH + \underset{\text{Sodium plumbite}}{Na_2PbO_2} \longrightarrow Pb(SR)_2 + 2NaOH$$

$$Pb(SR)_2 + S \longrightarrow PbS(s) + \underset{\text{Disulphide}}{RSSR}$$

The PbS (s) is removed by filtration. Since the disulphides in gasoline are also objectionable, so the the disulphides so-formed are extracted with a suitable solvent.

(2) Olefines and colouring matter of gasoline are, usually, removed by percolating gasoline through 'fuller's earth', which adsorbs preferentially only the colours and olefins.

(3) After the refining of gasoline, some inhibitors are added. These retard the oxidation reactions, thereby improving storing qualities of gasoline.

Even after refining, the gasoline does not have good combustion qualities and it is, generally, blended suitably with other fractions produced by catalytic cracking processes to meet the required specifications.

### 6.4.2 Unleaded Petrol

**Q.2 Write a short note on unleaded petrol.**

**Ans.:** Octane rating of petrol is in leaded petrol is increased by adding tetra ethyl lead or tetramethyl lead. However, combustion of lead petrol leads to formation of litharge (PbO), which deposition the inner wall of cylinder and jams the piston. Also leaded petrol cannot be used in automobiles equipped cost catalytic converter, because lead present in exhaust gas poisons the catalyst, thereby destroying the active sites. Alternative method of increasing octane number of petrol is to add high octane compounds like isopentane, isooctane, ethyl benzene, isopropyl benzene, methyl tertiary butyl ether (MTBE). Out of these MTBE is preferred, because it contains oxygen in the form of ether group and supplies oxygen for the combustion of petrol in internal combustion engines, thereby reducing the extent of peroxy compound formation. "Unleaded petrol" is one where in the enhancement of octane rating is accomplished without the addition of lead compounds.

### 6.4.3 Catalytic Converter

A catalytic converter is an emissions control device that converts toxic gases and pollutants in exhaust gas to less toxic pollutants by catalyzing a redox reaction (an oxidation and a reduction reaction). Catalytic converters are used with internal combustion engines fueled by either petrol (gasoline) or diesel.

It may be pointed here that a major advantage of unleaded petrol is that it permits the use of catalytic converter attached to the exhaust in automobiles. A catalytic converter contains a catalyst {rhodium), which converts the toxic gases (CO and NO) to harmless gases ($CO_2$ and $N_2$ respectively).

Moreover, it oxidises unburnt hydrocarbon into $CO_2$ and $H_2O$.

### 6.4.4 Knocking

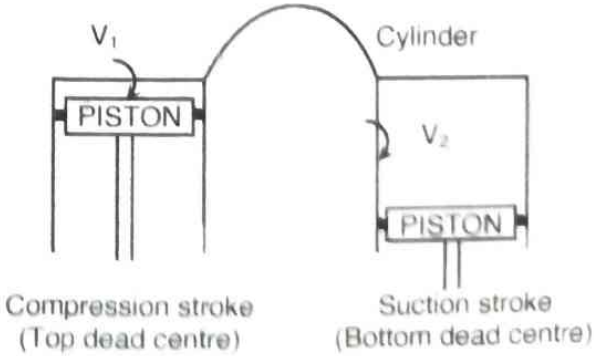
**Q.3 What is knocking? Define octane number. What is unleaded petrol? [D-15]**

**Ans.:** **Definition:** A sharp metallic sound produced in the internal combustion engine and results into a loss of energy.

**Petrol Engine**

In an internal combustion engine (spark ignition type) a mixture of air and petrol vapour is compressed and ignited by an electric spark and the essential reaction of oxidation of hydrocarbon molecules.

It is must that the combustion of the fuel in the cylinder should proceed in a regular way.



But in certain circumstances, the rate of oxidation is so great that the mixture detonates, producing the sound called 'engine knock'. The rate of oxidation of a hydrocarbon molecule depends on the number of C atoms in the molecule, structure and temperature. The temperature in turn depends upon the 'compression ratio'. (The ratio of the cylinder volume at the end of the suction stroke to that at the end of the compression stroke of the piston. Theoretically the power output and efficiency of an IC engine should increase with increase in the compression ratio. (C.R.). But in actual practice, the power increases to a maximum and then falls rapidly with further increase in C.R. knocking becomes more pronounced and heavy as the CR is increased above the optimum value and finally pre–ignition occurs. The tendency to knock depends upon the type of fuel, engine design, plug location etc.

### 6.4.5 Octane Value

The knocking quality of petrol is measured in terms of octane number. This was introduced by Graham Edgar in 1926.

**Definition :** The percentage by volume of iso–octane in a mixture of iso–octane and n–heptane which just matches the knocking characteristics of a fuel under test. [n heptane knocks very badly and has poor resistance to knocking; has zero octane value. Iso–octane has good resistance to knocking and has octane value 100].

Fuels with octane rating greater than 100 are quite common and are compared by blending Iso–octane with TEL (tetraethyl lead) which greatly diminishes the knocking. The value of octane no in such cases is determined by extrapolation.

Higher the octane no. of the fuel, higher is the compression ratio at which the fuel can be used without knocking and as a result greater power is obtained from an engine and efficiency is also greater. Octane value of petrol does not always correspond with the behavior when used in car under normal conditions. i.e. fuel having octane no. 85 may not be superior to one with octane no.80, ∴ It should be tested in a car and rated in terms of the 'performance'.

**Diesel Engine (Compression Ignition Type)**

In this type of Engine, air is first forced into the cylinder and compressed to about 30–50kg / $cm^2$. As a result of compression the air temperature is raised to 500–600°C. At this state the fuel is injected in the form of spray into the very hot air. The fuel droplets vaporize and get heated to the temperature at which spontaneous ignition takes place and the pressure is still further increased to about 70kg / $cm^2$.

All these steps are completed within only a small fraction of second.

The fuels used must have self-ignition temperatures at least 30°C below the temperature of the compressed air. Middle or high boiling petroleum fractions are generally used as diesel fuels.

### 6.4.6 Cetane Value

**Q.4 Define Cetane no. & write a note on Anti–knock agents.**

**Ans.:** The knocking characteristics of a diesel oil are expressed in terms of cetane no. The combustion of fuel in a diesel engine is not instantaneous and the interval between the injection and start of ignition is called 'ignition delay' and is an important quality of the diesel fuel. In order to grade the diesel fuels a cetane rating is employed. Cetane ($C_{16}H_{34}$) a saturated hydrocarbon, ignites very quickly and thus has very short ignition delay. It's cetane number is 100. On the contrary $\alpha$ methyl naphthalene ($C_{11}H_{10}$) has very long ignition delay as compared to any other diesel fuel. Hence its cetane no. is zero.

**Definition of cetane number :** The percentage by volume of cetane in a mixture of cetane and $\alpha$-methyl naphthalene which just matches the knocking characteristics of diesel oil under test.

Oils having high cetane no. are good diesel fuels (least ignition delay) but are poor gasoline fuels (have low octane no.) and vice versa.

The Cetane number of diesel oil can be increased by addition of certain compounds called dopes OR ignition accelerators like ethyl nitrite ($C_2H_5NO_2$), ethyl nitrate($C_2H_5NO_3$), isoamyl nitrate [$(CH_3)_2CHCH_2CH_2NO_3$]etc.

**Anti-knock Agent**

The octane no. of many poor fuels can be raised by the addition of Tetra ethyl lead (TEL) or $(C_2H_5)_4Pb$ or diethyl telluride [$(C_2H_5)_2$ Te]. About 0.5 ml of TEL is added to 1 litre of motor fuel and 1ml of TEL is added to 1 litre of aviation fuel.

Knocking in a petrol engine is due to the spontaneous ignition of the last portion of compressed mixture of petrol and air. The process of preignition is due to the production of hydroxyl and other free radicals which leads to explosive combustion. Addition of TEL react with free radicals and lead oxide is produced which decreases the chances of early detonation. The deposit of lead oxide is harmful to engine life. Therefore, ethylene dibromide ($C_2H_4Br_2$) is added to dope to convert the lead formed by the combustion into more volatile lead bromide which is swept out with the exhaust gases. But this also leads to atmospheric pollution.

The antiknocking agents other than TEL are,

(1) Tetra methyl lead
(2) Iron carbonyl
(3) Methyl tertiary butyl ether (MTBE)
(4) Ethyl tertiary butyl ether (ETBE)
(5) Methanol
(6) Ethanol

## 6.5 SOLVED EXAMPLES

For combustion numericals

- Air contains 23% oxygen by weight and 21% oxygen by volume.
- Weight is converted into volume by following manner:
  At NTP,
  22.4liters of any gas will weigh 1gm molecule (molecular weight in gm)
- Average molecular weight of air is 28.94

**Ex.1 Calculate the weight and volume of air needed for complete combustion of 1kg coal containing : C = 66%, H = 5.5%, O = 8%, N = 2.8% and moisture = 14.5% with remaining being ash.**

**Ans.:** 1 kg of coal contains :
C = 0.66 kg,
$H_2$ = 0.055 kg,
$O_2$ = 0.08 kg and
$N_2$ = 0.028 kg

| | Combustion reactions | Weight $O_2$ required |
|---|---|---|
| (1) | $C + O_2 \rightarrow CO_2$ | $\frac{0.66 \times 32}{12} = 1.76$ kg |
| (2) | $H_2 + ½ O_2 \rightarrow H_2O$ | $\frac{0.055 \times 16}{2} = 0.44$ kg |
| | Total $O_2$ | 2.2 kg |
| | Available $O_2$ | –0.08 kg |
| | Required $O_2$ | 2.12 kg |

Air contains 23% $O_2$ by weight.

∴ Minimum quantity of air required = $\frac{2.12 \times 100}{23} = 9.217$ kg

Molecular weight of air = 28.94 kg

i.e. 28.94 kg of air at NTP weights 22.4 $m^3$

∴ 9.217 kg of air = $\frac{22.4 \times 9.217}{28.94}$

Volume of air required = 7.134 $m^3$

**Ex.2 A sample of coal was found to contain the following : C = 75%, $H_2$ = 5.2%, $O_2$ = 12.8 %, S = 1.2%, $N_2$ = 3.7% and ash = 2.1%, Calculate minimum weight of air necessary for complete combustion of 2.5 kg of coal.**

**Ans.:** 1 kg of coal contains : 0.75 kg C, 0.052 kg $H_2$, 0.128 kg, $O_2$, 0.012 kg S and 0.037 kg $N_2$.

| | Combustion reactions | Weight of $O_2$ required |
|---|---|---|
| (1) | $C + O_2 \rightarrow CO_2$ | $\frac{0.75 \times 32}{12} = 2$ kg |
| (2) | $H_2 + ½ O_2 \rightarrow H_2O$ | $\frac{0.052 \times 16}{2} = 0.416$ kg |
| (3) | $S + O_2 \rightarrow SO_2$ | $\frac{0.012 \times 32}{32} = 0.012$ kg |
| | Total $O_2$ | 2.428 kg |
| | Available $O_2$ | –0.128 kg |
| | Required $O_2$ | 2.3 kg |

Air contains 23% $O_2$ by weight

Minimum weight of air needed for combustion = $\frac{2.3 \times 100}{23}$ = 10 kg

For 2.5 kg of coal (10 × 2.5 = 25) kg air is required.

**Ex.3** **A sample of coal was found to contain the following : C = 82%, H = 6.5%, O = 3.5%, N = 1%, S = 2% and the remaining being ash. Calculate GCV and NCV of coal. Also calculate the minimum quantity of air needed for complete combustion of 2.5 kg of above coal.**

**Ans.:** 1 kg of coal contains : 0.82 kg C, 0.065 kg $H_2$, 0.035 kg $O_2$, 0.02 kg S and 0.01 kg N.

| | **Combustion reactions** | **Weight of $O_2$ required** |
|---|---|---|
| (1) | $C + O_2 \rightarrow CO_2$ | $\frac{0.82 \times 32}{12} = 2.186\,kg$ |
| (2) | $H_2 + ½\, O_2 \rightarrow H_2O$ | $\frac{0.065 \times 16}{2} = 0.52\ kg$ |
| (3) | $S + O_2 \rightarrow SO_2$ | $\frac{0.02 \times 32}{32} = 0.02\,kg$ |
| | Total $O_2$ | 2.726 kg |
| | Available $O_2$ | –0.035 kg |
| | Required $O_2$ | 2.691 kg |

Air contains 23% $O_2$ by weight

Minimum weight of air needed = $\frac{2.691 \times 100}{23}$ = 11.7 kg

For 2.5 kg of coal (11.7 × 2.5 =) 29.25 kg of air is required.

By Dulong's formula

$$GCV = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right] kcal/kg$$

$$= \frac{1}{100}\left[8080 \times 82 + 34500\left(6.5 - \frac{3.5}{8}\right) + 2240 \times 2\right]$$

= 8761.96 kcal/kg

NCV = GCV – (0.09 × H × 587) kcal/kg = 8761.96 – (0.09 × 6.5 × 587)
= 8418.56 kcal/kg

∴ For 2.5 kg of coal, GCV = 21904.9 kcal and NCV = 21046.4 kcal.

**Ex.4** **Calculate the volume of air required for the complete combustion of 1 liter of CO.**

**Ans.:**

| **Combustion reaction** | **Volume of $O_2$ required** |
|---|---|
| $CO + ½\, O_2 \rightarrow CO_2$ | ½ × 1 lit = 0.5 liter |

Air contains 21% $O_2$ by volume

Minimum volume of air needed = $0.5 \times \frac{100}{21}$ = 2.381 liters

**Ex.5** **A gaseous fuel has the following composition by volume : $CH_4$ = 35%, CO = 10%, $H_2$ = 6%, $C_3H_8$ = 10%. Calculate the weight of air required for complete combustion. (Molecular weight of air = 28.94)**

**Ans.:** 1 $m^3$ of gaseous fuel contains : 0.35 $m^3$ $CH_4$, 0.1 $m^3$ CO, 0.06 $m^3$ $H_2$ and 0.1 $m^3$ $C_3H_8$.

| | Combustion reactions | Volume of $O_2$ required |
|---|---|---|
| (1) | $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ (2 vol) | $2 \times 0.35 = 0.7\ m^3$ |
| (2) | $CO + ½\ O_2 \rightarrow CO_2$ ($\frac{1}{2}$ vol) | $0.1 \times \frac{1}{2} = 0.05\ m^3$ |
| (3) | $H_2 + ½\ O_2 \rightarrow H_2O$ ($\frac{1}{2}$ vol) | $\frac{1}{2} \times 0.06 = 0.03\ m^3$ |
| (4) | $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ | $5 \times 0.1 = 0.5\ m^3$ |
| | Total $O_2$ | $1.28\ m^3$ |

Air contains 21% $O_2$ by volume

Volume of air required for combustion $= \dfrac{1.28 \times 100}{21} = 6.095\ m^3$

Molecular weight of air = 28.94 kg
At NTP, 22.4 $m^3$ of air weighs 28.94 kg
$\therefore$ 6.095 $m^3$ of air weighs?

Weight of air needed for combustion $= \dfrac{28.94 \times 6.095}{22.4} = 7.87$ kg

**Ex.6** **A gaseous fuel has the following composition by volume : $CH_4$ = 40 %, $H_2$ = 40%, $C_2H_6$ = 6 % and $N_2$ = 1 %. Calculate the volume and weight of air required for complete combustion.**

**Ans.:** 1$m^3$ of gaseous fuel contains : 0.4 $m^3$ $CH_4$, 0.4 $m^3$ $H_2$, 0.06 $m^3$ $C_2H_6$ and 0.01 $m^3$ $N_2$.

| | Combustion reactions | Volume of $O_2$ required |
|---|---|---|
| (1) | $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ (2 vol) | $2 \times 0.4 = 0.8\ m^3$ |
| (2) | $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$ (½ vol) | $\frac{1}{2} \times 0.4 = 0.2\ m^3$ |
| (3) | $C_2H_6 + 7/2\ O_2 \rightarrow 2CO_2 + 3H_2O$ | $7/2 \times 0.06 = 0.21\ m^3$ |
| | Total $O_2$ | $1.21\ m^3$ |

Air contains 21% $O_2$ by volume

Volume of air required for combustion $= \dfrac{1.21 \times 100}{21} = 5.76\ m^3$

Molecular weight of air = 28.94 kg
At NTP, 22.4 $m^3$ of air weighs 28.94 kg
$\therefore$ 5.76 $m^3$ of air weighs?

Minimum weight of air required for combustion $= \dfrac{5.76 \times 28.94}{22.4} = 7.44$ kg

**Ex.7** **The composition of a gas was found to be : $H_2$ = 10%, $CH_4$ = 16%, $C_2H_6$ = 20%, $N_2$ = 6%, CO = 22%, $CO_2$ = 18% and remaining is oxygen by volume. Calculate the volume and weight of oxygen and air required for complete combustion of 10 $m^3$ of this gas.**

**Ans.:** 1 $m^3$ of gaseous fuel contains : 0.1 $m^3$ $H_2$, 0.16 $m^3$ $CH_4$, 0.2 $m^3$ $C_2H_6$, 0.06 $m^3$ $N_2$, 0.22 $m^3$ CO, 0.18 $m^3$ $CO_2$, remaining $O_2$ = 0.08 $m^3$

| | Combustion reactions | Volume of $O_2$ required |
|---|---|---|
| (1) | $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$ | $\frac{1}{2} \times 0.1 = 0.05\ m^3$ |
| (2) | $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ | $2 \times 0.16 = 0.32\ m^3$ |
| (3) | $C_2H_6 + \frac{7}{2} O_2 \rightarrow 2CO_2 + 3H_2O$ | $\frac{7}{2} \times 0.2 = 0.7\ m^3$ |
| (4) | $CO + \frac{1}{2} O_2 \rightarrow CO_2$ | $\frac{1}{2} \times 0.22 = 0.11\ m^3$ |
| | Total $O_2$ | 1.18 $m^3$ |
| | Available $O_2$ | –0.08 $m^3$ |
| | Required $O_2$ | 1.1 $m^3$ |

Air contains 21% $O_2$ by volume

Minimum volume of air needed = $1.1 \times \frac{100}{21} = 5.238\ m^3$

Molecular weight of air = 28.94 kg

At NTP, 22.4 $m^3$ of air weighs 28.94 kg

∴ 5.238 $m^3$ of air weighs?

Weight of air needed for combustion = $\frac{28.94 \times 5.238}{22.4} = 6.767$ kg

**Ex.8 A gas has the following composition by volume : $CH_4$ = 40%, $C_6H_6$ = 24%, $C_3H_8$ = 16%, $CO_2$ = 5%, CO = 5%, $O_2$ = 3% and $N_2$ = 7%. Calculate the weight of air supplied per $m^3$ of this gas at NTP assuming 50% excess of that theoretically required air was used.**

**Ans.:** 1 $m^3$ of gas contains : 0.4 $m^3$ $CH_4$, 0.24 $m^3$ $C_6H_6$, 0.16 $m^3$ $C_3H_8$, 0.05 $m^3$ $CO_2$, 0.05 $m^3$ CO, 0.03 $m^3$ $O_2$ and 0.07 $m^3$ $N_2$.

| | Combustion reactions | Volume of $O_2$ required |
|---|---|---|
| (1) | $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ | $2 \times 0.4 = 0.8\ m^3$ |
| (2) | $C_6H_6 + \frac{15}{2} O_2 \rightarrow 6CO_2 + 3H_2O$ | $\frac{15}{2} \times 0.24 = 1.8\ m^3$ |
| (3) | $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ | $5 \times 0.16 = 0.8\ m^3$ |
| (4) | $CO + \frac{1}{2} O_2 \rightarrow CO_2$ | $\frac{1}{2} \times 0.05 = 0.025\ m^3$ |
| | Total $O_2$ | 3.425 $m^3$ |
| | Available $O_2$ | –0.03 $m^3$ |
| | Required $O_2$ | 3.395 $m^3$ |

Air contains 21% $O_2$ by volume

Minimum volume of air needed $= \frac{3.395 \times 100}{21} = 16.16\ m^3$

50% of excess air was used $= \frac{16.16 \times 150}{100} = 24.24\ m^3$

Molecular weight of air $= 28.94$ kg

At NTP, 22.4 $m^3$ of air weighs 28.94 kg

$\therefore$ 24.24 $m^3$ of air weighs 31.317 kg

**Ex.9** **A gas has the following composition by volume : $H_2$ = 24%, $CH_4$ = 3%, CO = 18%, $CO_2$ = 5%, $O_2$ = 4 and N = 4.6%. If 30% excess air is used; find the weight of air supplied per $m^3$ of gas.**

**Ans.:** 1 $m^3$ of fuel contains 0.24 $m^3$ of $H_2$, 0.03 $m^3$ of $CH_4$ and 0.18 $m^3$ of CO.

| | **Combustion reactions** | **Volume of $O_2$ required** |
|---|---|---|
| (1) | $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$ | $0.24 \times \frac{1}{2} = 0.12\ m^3$ |
| (2) | $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ | $0.03 \times 2 = 0.06\ m^3$ |
| (3) | $CO + \frac{1}{2} O_2 \rightarrow CO_2$ | $0.18 \times \frac{1}{2} = 0.09\ m^3$ |
| | Total $O_2$ | $0.27\ m^3$ |
| | Available $O_2$ | $-0.04\ m^3$ |
| | Required $O_2$ | $0.23\ m^3$ |

Air contains 21% $O_2$ by volume

$$\therefore \quad 0.23\ m^3\ O_2,\ \frac{0.23 \times 100}{21} = 1{,}095\ m^3$$

30% excess air is used.

$$\therefore \quad \text{Volume of air} = \frac{1.0953 \times 130}{100} = 1.423\ m^3$$

At NTP 22.4 $m^3$ air weighs 28.94 kg of air

$\therefore$ 1.423 $m^3$ of air weighs 1.839 kg.

**Ex.10** **A gaseous fuel has the following composition by volume : $H_2$ = 35%, $CH_4$ = 47%, $C_2H_6$ = 4%, CO = 6% and $N_2$ = 8%. Calculate the theoretical volume of air required at 27°C and 740 mm pressure for complete combustion of 1 $m^3$ fuel.**

**Ans.:**

| | **Combustion reactions** | **Volume of $O_2$ required** |
|---|---|---|
| (1) | $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$ | $0.35 \times \frac{1}{2} = 0.175\ m^3$ |
| (2) | $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ | $0.47 \times 2 = 0.94\ m^3$ |
| (3) | $C_2H_6 + \frac{7}{2} O_2 \rightarrow 2CO_2 + 3H_2O$ | $0.04 \times \frac{7}{2} = 0.14\ m^3$ |
| (4) | $CO + \frac{1}{2} O_2 \rightarrow CO_2$ | $0.06 \times \frac{1}{2} = 0.03\ m^3$ |
| | Total $O_2$ | $1.285\ m^3$ |

$$\text{At NTP} \quad \frac{P_0 V_0}{T_0} = \frac{P_1 V_1}{T_1}$$

$$\frac{760 \times 1.285}{273}$$

$$= \frac{740 \times V_1}{300}$$

$$V_1 = 1.45\,m^3 \times \frac{100}{21} \qquad = 6.905\ m^3 \text{ of air}$$

6.905 $m^3$ of air needed at 27°C, 740 mm pressure.

**Ex.11 2.9 gm of coal was heated in electric oven at 110°C. The weight of sample gets reduced to 2.75 gm. Further heating at 925 °C for 7 minutes in muffle furnace with lid reduces the weight of sample to 2.45 gm. This sample of heating at 750°C for ½ hr. gives residue of 0.13 gm. Calculate % C.**

**Ans.:** % of moisture $= \dfrac{\text{Loss in weight of coal} \times 100}{\text{Weight of coal}} = \dfrac{(2.9 - 2.75) \times 100}{2.9}$

$= 5.17\%$

% of volatile matter $= \dfrac{\text{Loss in weight (in moisture) of free coal} \times 100}{\text{Weight of coal}}$

$= \dfrac{(2.75 - 2.45) \times 100}{2.9} \qquad = 10.34\ \%$

% of ash $= \dfrac{\text{Weight of residue} \times 100}{\text{Weight of coal}} = \dfrac{0.13 \times 100}{2.9}$

$= 4.48\ \%$

% C $= 100 - \%$ (Moisture + Volatile matter + Ash)

$= 100 - 19.99$

$= 80.01\ \%$

**Ex.12 A coal sample contains C = 60%. O = 33%, H = 6% , S = 0.5%, N = 0.3% and Ash = 0.2%. Calculate the gross calorific values of coal.**

**Ans.:** Using Dulong's formula .

Goss calorific value $= \dfrac{1}{100}\left[8080\,C + 34500\left(H - \dfrac{O}{8}\right) + 2240 \times S\right]$

$= \dfrac{1}{100}\left[8080 \times 60 + 34500\left(6 - \dfrac{33}{8}\right) + 2240 \times 0.5\right]$

$= \dfrac{1}{100}[484800 + 6487.5 + 1120]$

$= \dfrac{1}{100}[550607.5]$

$= 5506.075$ kcal/kg.

Net calorific value $= [\text{H.C.V.} - (0.09 \times H \times 587)]$

$= 5506.075 - (0.09 \times 6 \times 587)$

$= 5506.075 - 316.98$

$= 5189.02$ kcal/kg.

HCV $= 5506$ kcal/kg

LCV $= 5189.02$ kcal/kg

**Ex.13 A sample of coal contained C = 66%. O = 28%, H = 4% , S = 1.5%, N = 0.8% and Ash = 0.2%. Calculate the higher and lower calorific values of coal.**

**Ans.:** Using Dulong's formula

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

$$= \frac{1}{100}\left[8080 \times 66 + 34500\left(4 - \frac{28}{8}\right) + 2240 \times 1.5\right]$$

$$= \frac{1}{100}[533280 + 17250 + 3360]$$

$$= \frac{1}{100}[553890]$$

$$= 5538.90 \text{ kcal/kg.}$$

$$\text{L.C.V.} = [\text{H.C.V.}(0.09 \times H \times 587)]$$

$$= 5538.9 - (0.09 \times 4 \times 587)$$

or

$$\text{NCV} = 5538.9 - 211.32$$

$$= 5327.58 \text{ kcal/kg}$$

HCV = 5538.90 kcal/kg
LCV = 5327.58 kcal/kg

**Ex.14 Calculate the percentage of hydrogen and HCV of a coal containing C = 85%, S = 1%, O = 2%, N = 2.5% and Ash = 3.5% and that coal is having L.C.V. of 8490.5 kcal/kg.**

**Ans.:**

$$\text{LCV} = (\text{H.C.V.} - 0.09\,H \times 587) \text{ Kcal/ Kg.}$$

$$8490.5 \text{ kcal/kg} = \text{H.C.V.} - 0.09\,H \times 587$$

$$\text{H.C.V.} = 8490.5 + 0.09\,H \times 587$$

$$\text{H.C.V.} = 8490.5 + 52.8\,H \text{ kcal/kg.}$$

Using Dulong's formula

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

$$= \frac{1}{100}\left[8080 \times 85 + 34500\left(H - \frac{2}{8}\right) + 2240 \times 1\right]$$

$$= \frac{1}{100}[686800 + 34500\,H - 8625 + 2240]$$

$$= [6868 + 345H - 86.25 + 22.4] \text{ kcal/kg}$$

or

$$\text{H.C.V.} = (6804.15 + 345H) \text{ kcal/kg}$$

$$\therefore (8490.5 + 52.8\,H)\text{kcal /kg} = (6804.15 + 345H) \text{ kcal/kg}$$

$$345\,H - 52.8\,H = 8490.5 - 6804.15$$

$$292.2\,H = 1686.35$$

$$H = 5.77\%$$

Now,

$$\text{H.C.V.} = 8490.5 + 52.8 \times 5.77$$

$$= 8795 \text{ kcal /kg.}$$

$$\text{HCV} = 8795.15 \text{ kcal/kg}$$

$$\%\,H = 5.77$$

**Ex.15 A sample of coal has the following composition by mass, C = 85%, H = 7%, O = 3%, S = 3.5%, N = 2.1% and Ash = 4.4%. Calculate H.C.V. and L.C.V. using Dulong formula.**

**Ans.:** Using Dulong's formula .

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

$$= \frac{1}{100}\left[8080 \times 85 + 34500\left(7 - \frac{3}{8}\right) + 2240 \times 3.5\right]$$

$$= \frac{1}{100}[686800 + 228562.5 + 7840]$$

$$= \frac{1}{100}[923202.5]$$

$$= 9232.025 \text{ kcal/kg.}$$

$$\text{L.C.V.} = [\text{H.C.V.} - (0.09 \times H \times 587)]$$

$$= 9232.025 - (0.09 \times 7 \times 587)$$

$$= 9232.025 - 369.81$$

$$= 8862.215 \text{ kcal/kg}$$

HCV = 9232.025 kcal/kg
LCV = 8862.215 kcal/kg

**Ex.16 A sample of coal has the following composition by mass, C = 80%, H = 7%,O = 3%, S = 3.5%, N = 2.1% and Ash = 4.4%. Calculate H.C.V. and L.C.V. using Dulong formula.**

**Ans.:** Using Dulong's formula :

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

$$= \frac{1}{100}\left[8080 \times 80 + 34500\left(7 - \frac{3}{8}\right) + 2240 \times 3.5\right]$$

$$= \frac{1}{100}[646400 + 228562.5 + 7840]$$

$$= \frac{1}{100}[882802.5]$$

$$= 8828.025 \text{ kcal/kg.}$$

$$\text{L.C.V.} = [\text{H.C.V.} - (0.09 \times H \times 587)]$$

$$= 8828.025 - 0.09 \times 7 \times 587$$

$$= 8828.025 - 369.81$$

$$= 8458.215 \text{ kcal/kg}$$

HCV = 8828.025 kcal/kg
LCV = 8458.215 kcal/kg

**Ex.17 A sample of coal has the following composition by mass, C = 85%, H = 6%, O = 8%, S = 0.5%, and Ash = 0.5%. Calculate H.C.V. and L.C.V. using Dulong formula.**

**Ans.:** Using Dulong's formula :

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

$$= \frac{1}{100}\left[8080 \times 85 + 34500\left(6 - \frac{8}{8}\right) + 2240 \times 0.5\right]$$

$$= \frac{1}{100}[686800 + 172500 + 1120]$$

$$= \frac{1}{100}[860420]$$

$$= 8604.2 \text{ kcal/kg.}$$

$$\text{L.C.V.} = [\text{H.C.V.} - (0.09 \times H \times 587)]$$

$$= 8604.2 - 0.09 \times 6 \times 587$$

$$= 8604.2 - 316.98$$

$$= 8287.22 \text{ kcal/kg}$$

HCV = 8604.2 kcal/kg
LCV = 8287.22 kcal/kg

**Ex.18 A sample of coal contains C = 70%, O = 23%, H = 5%, S = 1.5%, N = 0.4% and Ash = 0.1%. Calculate gross and net calorific value of the coal.**

**Ans.:** Using Dulong's formula :

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

$$= \frac{1}{100}\left[8080 \times 70 + 34500\left(5 - \frac{23}{8}\right) + 2240 \times 1.5\right]$$

$$= \frac{1}{100}\left[8080 \times 70 + 34500\frac{[17]}{8} + 3360\right]$$

$$= \frac{1}{100}[565600 + 73312.5 + 3360]$$

$$= \frac{1}{100}[642272.5]$$

$$= 6422.725 \text{ kcal/kg.}$$

$$\text{L.C.V.} = [\text{H.C.V.} - (0.09 \times H \times 587)]$$

$$= 6422.725 - 0.09 \times 5 \times 587$$

$$= 6422.725 - 264.15$$

$$= 6158.575 \text{ kcal/kg}$$

HCV = 6422.725 kcal/kg
LCV = 6158.575 kcal/kg

**Ex.19 A solid fuel coal containing 90% carbon, 80% hydrogen, 1.5% sulphur, 2% Nitrogen, 5% oxygen and remaining ash. Calculate the high and low calorific value of the coal.**

**Ans.:** Using Dulong's formula :

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

$$= \frac{1}{100}\left[8080 \times 90 + 34500\left(8 - \frac{5}{8}\right) + 2240 \times 1.5\right]$$

$$= \frac{1}{100}[727200 + 34500\,(59/8) + 3360]$$

$$= \frac{1}{100}[727200 + 254437.5 + 3360] \text{ kcal/kg}$$

$$= \frac{1}{100}[984997.5]$$

$$= 9849.975 \text{ kcal/ kg.}$$

$$\text{L.C.V.} = [\text{H.C.V.} - (0.09 \times H \times 587)]$$

$$= 9849.975 - 0.09 \times 8 \times 587$$

$$\text{NCV} = 9849.975 - 422.64$$

$$= 9427.335 \text{ kcal/kg}$$

HCV = 9849.975 kcal/kg

LCV = 9427.335 kcal/kg

**Ex.20 A coal of sample has the following composition by weight C = 82%, H = 6%, O = 8%, S = 0.5%, N = 3% and Ash = 0.5%. Calculate the gross and net calorific value using Dulong's formula**

**Ans.:** Using Dulong's formula :

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

$$= \frac{1}{100}\left[8080 \times 82 + 34500\left(6 - \frac{8}{8}\right) + 2240 \times 0.5\right]$$

$$= \frac{1}{100}[662560 + 34500\,(5) + 1120]$$

$$= \frac{1}{100}[662560 + 172500 + 1120] \text{ kcal /kg}$$

$$= \frac{1}{100}[836180]$$

$$= 8361.8 \text{ kcal /kg}$$

$$\text{L.C.V.} = [\text{H.C.V.} - (0.09 \times H \times 587)]$$

$$= 8361.8 - 0.09 \times 6 \times 587$$

$$= 8361.8 - 316.98$$

$$= 8044.82 \text{ kcal/kg}$$

HCV = 8361.8 kcal/kg

LCV = 8044.82 kcal/kg

**Ex.21 A coal sample has the following composition by weight C = 80%, H = 4%, O = 6%, S = 3%, N = 2% and Ash = 5%. Calculate gross and net calorific value Using Dulong's formula**

**Ans.:** Using Dulong's formula :

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

$$= \frac{1}{100}\left[8080 \times 80 + 34500\left(4 - \frac{6}{8}\right) + 2240 \times 3\right]$$

$$= \frac{1}{100}[646400 + 34500\,(26/8) + 6720]$$

$$= \frac{1}{100}[646400 + 112125 + 6720]\ \text{kcal/kg}$$

$$= \frac{1}{100}[765245]$$

$$\text{L.C.V.} = [\text{H.C.V} - (0.09 \times H \times 587)]$$

or $$= 7652.45 - 0.09 \times 4 \times 587$$

$$\text{N.C.V.} = 7652.45 - 211.32$$

$$= 7441.13\ \text{kcal /kg.}$$

HCV = 7652.45 kcal/ kg
LCV = 7441.13 kcal/ kg

**Ex.22 A coal sample has the following composition by weight C = 75%, H = 7%, O = 8%, S = 4%, N = 2% and Ash = 4%. Calculate gross calorific value Using Dulong's formula**

**Ans.:** Using Dulong's formula :

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

$$= \frac{1}{100}\left[8080 \times 75 + 34500\left(7 - \frac{8}{8}\right) + 2240 \times 4\right]$$

$$= \frac{1}{100}[606000 + 34500\,(6) + 8960]$$

$$= \frac{1}{100}[606000 + 207000 + 8960]\ \text{kcal /kg}$$

$$= \frac{1}{100}[821960]$$

$$= 8219.60\ \text{kcal /kg}$$

HCV = 8219.60 kcal/kg

**Ex.23 A coal of sample has the following composition by weight C = 70%, H = 10%, O = 4%, S = 2%, N = 2% and Ash = 12%. Calculate gross and net calorific value Using Dulong's formula.**

**Ans.:** Using Dulong's formula :

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

$$= \frac{1}{100}\left[8080 \times 70 + 34500\left(10 - \frac{4}{8}\right) + 2240 \times 2\right]$$

$$= \frac{1}{100}\left[8080 \times 70 + 34500\,\frac{(76)}{8} + 4480\right]$$

$$= \frac{1}{100}[565600 + 327750 + 4480]$$

$$= \frac{1}{100}[897830]$$

$$= 8978.30 \text{ kcal /kg}$$

$$\text{L.C.V.} = [\text{H.C.V.} - (0.09 \times H \times 587)]$$
$$= 8978.3 - 0.09 \times 10 \times 587$$
$$= 8978.3 - 528.3$$
$$= 8450 \text{ kcal/kg}$$

HCV = 8978.30 kcal/kg
LCV = 8450 kcal/kg

**Ex.24 A coal of sample has the following composition by mass : C = 70%, H = 9%, O = 4%, S = 2%, N = 1% and Ash = 14%. Calculate gross calorific value of the fuel using Dulong's formula**

**Ans.:** Using Dulong's formula :

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

$$= \frac{1}{100}\left[8080 \times 70 + 34500\left(9 - \frac{4}{8}\right) + 2240 \times 2\right]$$

$$= \frac{1}{100}[565600 + 293250 + 4480]$$

$$= \frac{1}{100}[863330]$$

$$= 8633.3 \text{ kcal /kg}$$

HCV = 8633.3 kcal/kg

**Ex.25 A coal sample was analysed as follows :**
**Exactly 2.5g was weighed into silica crucible. After heating for 1 hour at 110°C the residue weighed 2.415g, the crucible next covered with a vented lid and strongly heated for exactly seven minutes at 950 ± 20°C. The residue weighed 1.528g. The crucible was then heated without cover at 700°C until a constant weight was obtained. The last residue was found to weigh 0.245g. Calculate the percentage results of above analysis.**

**Ans.:** (i) Weight of coal taken $= 2.5g$

Mass of moisture in coal sample $= 2.5 - 2.415$

$= 0.085g$

$\therefore$ Percentage of moisture $= \dfrac{\text{Loss in weight of coal}}{\text{Weight of cal taken}} \times 100$

$= \dfrac{0.085 \times 100}{2.5}$

$\mathbf{= 3.4\%}$

(ii) Mass of volatile matter $= 2.415 - 1.528$

$= 0.887g$

Percentage of volatile matter $= \dfrac{\text{Loss in weight due to volatile matter}}{\text{Weight of coal}} \times 100$

$= \dfrac{0.887 \times 100}{2.5}$

$\mathbf{= 35.48\%}$

Mass of ash $= 0.245$ g

Percentage of ash $= \dfrac{\text{weight of ash left}}{\text{weight of coal taken}} \times 100$

$= \dfrac{0.245 \times 100}{2.5}$

$\mathbf{= 9.8\%}$

% of fixed carbon $= 100 - (\%\ \text{Moisture} + \text{Volatile matter} + \text{Ash})$

$= 100 - (3.4 + 35.48 + 9.8)$

$= 100 - 48.68$

$\mathbf{= 52.32\%}$

**Ex.26 One gram of air dried sample of coal on heating at 110°C for 1 hour produced a residue 0.850 g and this residue on heating at 950°C for 7 minute in absence of air left 0.72 g mass which on combustion left 0.1g of non-combustible matter. Calculate the result of proximate analysis.**

**Ans.:** (i) Weight of coal taken $= 1$ g

Mass of moisture in coal sample $= 1.0 - 0.850$

$= 0.150$ g

Percentage of moisture $= \dfrac{\text{Loss in weight of coal}}{\text{Weight of coal taken}} \times 100$

$= \dfrac{0.150 \times 100}{1}$ $\mathbf{= 15\%}$

(ii) Mass of volatile matter $= 0.850 - 0.720$

$= 0.13$ g

Percentage of volatile matter $= \dfrac{\text{Loss in weight due to volatile matter}}{\text{Weight of coal}} \times 100$

$= \dfrac{0.13 \times 100}{1}$ $\mathbf{= 13\%}$

(iii) Mass of residue = 0.1

Percentage of ash $= \dfrac{\text{weight of ash left}}{\text{weight of coal taken}} \times 100$

$= \dfrac{0.1 \times 100}{1}$

**= 10%**

(iv) % of fixed carbon = 100 – (% Moisture + Volatile matter + Ash)

= 100 – (15 + 13 + 10)

= 100 – 38

**= 62%**

**Ex.27 A sample of coal was analyzed for content of moisture, volatile matter and ash From the following data, calculate the percentage of the above quantities.**

**(i) Weight of coal taken = 2.5 g**

**(ii) Weight of coal after heating at 100°C = 2.368 g**

**(iii) Weight of coal after heating covered crucible at 950 ± 20°C = 1.75 g**

**(iv) Constant weight obtained at the end of the experiment = 0.95 g**

**Ans.:** (i) Weight of coal taken = 2.5g

Mass of moisture in coal sample = 2.5 - 2.368

= 0.132 g

Percentage of ash $= \dfrac{\text{Loss in weight of coal}}{\text{weight of coal taken}} \times 100$

$= \dfrac{0.132 \times 100}{2.5}$

**= 5.28%**

(ii) Mass of volatile matter = 2.368 – 1.75 = 0.618

Percentage of volatile matter $= \dfrac{\text{Loss in weight due to volatile matter}}{\text{weight of coal}} \times 100$

$= \dfrac{0.618 \times 100}{2.5}$

**= 24.72%**

Mass of ash = 0.95g

(iii) Percentage of ash $= \dfrac{\text{weight of ash left}}{\text{weight of coal taken}} \times 100$

$= \dfrac{0.95 \times 100}{2.5}$

**= 38%**

**Ex.28 2.5g of air dried coal sample was taken in a silica crucible, after heating it is an electric oven at 105–110°C for 1 hour : the residue was weighed 2.410g. The residue was heated in a silica crucible covered with vented lid at a temperature 950 ± 20°C for exactly 7 minutes. After cooling the weight of residue was found to be 1.78 g. The residue was then ignited at 700–750°C to a constant weight of 0.246g. Calculate the percentage of fixed carbon in a coal sample.**

**Ans.:** (i) Weight of coal taken = 2.5g

Mass of moisture in coal sample = 2.5 – 2.415 = 0.085g

$$\text{Percentage of ash} = \frac{\text{Loss in weight of coal}}{\text{weight of coal taken}} \times 100$$

$$= \frac{0.085 \times 100}{2.5}$$

$$= \mathbf{3.4\%}$$

(ii) Mass of volatile matter = 2.415 – 1.78528

= 0.635g

$$\text{Percentage of volatile matter} = \frac{\text{Loss in weight due to volatile matter}}{\text{Weight of coal}} \times 100$$

$$= \frac{0.635 \times 100}{2.5}$$

$$= \mathbf{25.4\%}$$

(iii) Mass of residue after ignition at 700 – 750°C = 0.246g

$$\text{Percentage of ash} = \frac{\text{weight of ash left}}{\text{weight of coal taken}} \times 100$$

$$= \frac{0.246 \times 100}{2.5}$$

$$= \mathbf{10\%}$$

(iv) % of fixed carbon = 100 –(% Moisture + Volatile matter + Ash)

= 100 – (3.4 + 25.4 + 10)

= 100 – 38.8

= **61.2%**

**Ex.29 An air dried sample of coal weighing 2.9 g was taken for volatile matter determination. After losing volatile matter the coal sample weighed 1.96 g. If it contains 4.5% moisture, find the percentage of volatile matter in it.**

**Ans.:** (i) Weight of coal taken = 2.9g

% of moisture = 4.5 %

$$\text{Percentage of moisture} = \frac{\text{Loss in weight of coal}}{\text{weight of coal taken}} \times 100$$

$$\text{Loss in weight of coal} = \frac{4.5 \times 2.9}{100} = 0.1305 \text{ g}$$

weight or coal after removal of moisture = 2.9 – 0.1305

= 2.7675 g

(ii) Mass of volatile matter $= 2.7695 - 1.96$

$= 0.8095$ g

Percentage of volatile matter $= \dfrac{\text{Loss in weight due to volatile matter}}{\text{Weight of coal}} \times 100$

$= \dfrac{0.8095 \times 100}{2.9}$

**= 27.91 %**

**Ex.30 2.5 g of coal sample was taken in silica crucible and heated in oven maintained at 110° for one hour. The Weight after heating was 2.41g. The same sample was analyzed for volatile matter and weight obtained was 1.98g. The sample was further heated to get fixed weight of 246g. Calculate the percentage of moisture, volatile matter, ash and fixed carbon for this sample.**

**Ans.:** (i) Weight of coal taken $= 2.5$g

Mass of moisture in coal sample $= 2.5 - 2.41$

$= 0.09$ g

Percentage of moisture $= \dfrac{\text{Loss in weight of coal}}{\text{weight of coal taken}} \times 100$

$= \dfrac{0.09 \times 100}{2.5}$

**= 3.6%**

(ii) Mass of volatile matter $= 2.41 - 1.98$

$= 0.439$

Percentage of volatile matter $= \dfrac{\text{Loss in weight due to volatile matter}}{\text{weight of coal}} \times 100$

$= \dfrac{0.43 \times 100}{2.5}$

**= 17.2%**

(iii) Mass of residue after ignition at 700 – 750°C = 0.246 g

Percentage of ash $= \dfrac{\text{weight of ash left}}{\text{weight of coal taken}} \times 100$

$= \dfrac{0.246 \times 100}{2.5}$

**= 9.84 %**

(iv) % of fixed carbon $= 100 - (\%\ \text{Moisture} + \text{Volatile matter} + \text{Ash})$

$= 100 - (3.6 + 17.2 + 9.84)$

$= 100 - 30.64$

**= 69.36%**

**Ex.31 0.5 g of coal sample was burnt completely in Bomb calorimeter. The ash formed was extracted with acid and the extract obtained was treated with $BaCl_2$ solution to get $BaSO_4$ precipitate. The weight of dry precipitate was 0.04 g. Calculate the % of sulphur in the coal sample.**

**Ans.:**

Weight of coal sample $= 0.5$ g

Volume of $BaSO_4$ $= 0.04$ g

$$\% \text{ of sulphur} = \frac{\text{Weight of } BaSO_4 \text{ ppt} \times 32 \times 100}{\text{Weight of coal} \times 233}$$

$$= \frac{0.04 \times 32 \times 100}{0.5 \times 233}$$

$$= \frac{128}{116.7}$$

$$= 1.9$$

**% of sulphur = 1.09**

**Ex.32 By Kjeldah's method, 1.5 g of coal sample was analyzed. The ammonia evolved was absorbed in 50 ml of 0.1 N $H_2SO_4$. After absorption, the excess $H_2SO_4$ required 35 ml of 0.1 N NaOH for neutralization. Calculate the percentage of nitrogen.**

**Ans.:**

Volume of 0.1 N $H_2SO_4$ = Volume of 0.1 N NaOH

Volume of acid taken = 50 ml

Volume of excess acid = 35 ml

Volume of acid used = (50 – 35)

= 15 ml of 0.1 N $H_2SO_4$

= 15 ml of 0.1 N $H_2SO_4$

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

$$= \frac{15 \times 0.1 \times 1.4}{1.5} = 1.4$$

= % of nitrogen = 1.4

**Ex.33 0.2 g of coal is accurately weighed and is burnt in a combustion apparatus. The gaseous products of combustion are absorbed in potash bulb and calcium chloride tubes of known weight. The increase in weight of potash bulb and calcium chloride tubes are 0.64 g and 0.06 g respectively. Calculate the % of carbon and hydrogen in the coal sample.**

**Ans.:** (i) Increase in weight of KOH tube $= 0.64$ g

$$\% \text{ of C} = \frac{\text{Increase in weight of KOH tube} \times 12 \times 100}{\text{Weight of coal taken} \times 44}$$

$$= \frac{0.64 \times 12 \times 100}{0.2 \times 44}$$

$$= \frac{768}{8.8}$$

**= 87.27%**

(ii) Increase in weight of $CaCl_2$ tube = 0.06 g

$$\% \text{ of hydrogen} = \frac{\text{Increase in weight of } CaCl_2 \text{ tube} \times 2 \times 100}{\text{Weight of coal sample} \times 18}$$

$$= \frac{0.06 \times 2 \times 100}{0.2 \times 18} = \frac{12}{3.6}$$

$$= 3.3$$

**Ex.34 1.5g of coal sample was taken for C and H estimation by combustion method. The increase on weight of tube containing anhydrous $CaCl_2$ and bulb containing KOH was found to be 1.25 g and 4.88 g respectively. Calculate the percentage of C and H.**

**Ans.:** (i) Increase in weight of KOH = 4.88g

$$\% \text{ of C} = \frac{\text{Increase in weight of KOH tube} \times 12 \times 100}{\text{Weight of coal taken} \times 44}$$

$$= \frac{4.88 \times 12 \times 100}{1.5 \times 44}$$

$$= \frac{5856}{66}$$

$$= \mathbf{88.72\%}$$

(ii) Increase in weight of $CaCl_2$ tube = 1.25 g

$$\% \text{ of hydrogen} = \frac{\text{Increase in weight of } CaCl_2 \text{ tube} \times 2 \times 100}{\text{Weight of coal sample} \times 18}$$

$$= \frac{1.25 \times 2 \times 100}{1.5 \times 18}$$

$$= \frac{250}{27}$$

$$= \mathbf{9.25\%}$$

**Ex.35 1.95g of coal sample was taken for nitrogen estimation by Kjedahl method. The ammonia liberated required 9.5 ml of 0.4 N $H_2SO_4$ for neutralization. The same sample weighing 1.5 g in Bomb calorimeter experiment produced 0.35 g of $BaSO_4$. Calculate percentage of N and S.**

**Ans.:** (i) Volume of acid used = 9.5ml of 0.4N $H_2SO_4$

Weight of coal sample = 1.95 g

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

$$= \frac{9.5 \times 0.4 \times 1.4}{1.95}$$

$$= \mathbf{2.72\%}$$

(ii) Weight of coal sample = 1.5 g

Weight of BaSO4 ppt = 0.35 g

% of sulphur $= \dfrac{\text{Weight of } BaSO_4 \text{ ppt.} \times 32 \times 100}{\text{Weight of coal} \times 233}$

$= \dfrac{0.35 \times 32 \times 100}{1.5 \times 233} = \dfrac{1120}{349.5}$

**= 3.204%**

**Ex.36** **3g of coal was heated in Kjedalh's flask and $NH_3$ evolved was absorbed in 40 ml of 0.5N $H_2SO4$. After absorption, the excess acid required 18.5 ml of 0.5 N KOH for neutralization. 2.3 g of coal sample in quantitative analysis gave 0.35g BaSO4. Calculate the % of N and S in the sample.**

**Ans.:** (i) Volume of acid taken = 40 ml of 0.5 N $H_2SO_4$

Volume of excess acid = 18.5 ml

Volume of acid used = (40 – 18.5)

= 21.5ml of 0.5N $H_2SO_4$

% of nitrogen $= \dfrac{\text{Volume of acid used} \times \text{Normality} \times 1.4}{\text{Weight of coal taken}}$

$= \dfrac{21.5 \times 0.5 \times 1.4}{3}$

**= 5.016%**

(ii) Weight of coal sample = 2.3 g

Weight of BaSO4 ppt = 0.35 g

% of sulphur $= \dfrac{\text{Weight of } BaSO_4 \text{ ppt.} \times 32 \times 100}{\text{Weight of coal} \times 233}$

$= \dfrac{0.35 \times 32 \times 100}{2.3 \times 233}$

$= \dfrac{1120}{535.9}$

**= 2.089%**

**Ex.37** **3.2 g of coal was heated in Kjedalh's flask and $NH_3$ evolved was absorbed in 40 ml of 0.5N $H_2SO_4$. After absorption, the excess acid required 16 ml of 0.5 N KOH for neutralization. 2.5 g of coal sample in quantitative analysis gave 0.42g $BaSO_4$. Calculate the % of N and S in the sample.**

**Ans.:** (i) Volume of acid taken = 40 ml of 0.5 N $H_2SO_4$

Volume of excess acid = 16 ml

Volume of acid used = (40 – 16)

= 24 ml of 0.5N $H_2SO_4$

% of nitrogen $= \dfrac{\text{Volume of acid used} \times \text{Normality} \times 1.4}{\text{Weight of coal taken}}$

$= \dfrac{24 \times 0.5 \times 1.4}{3.2}$

**= 5.25%**

(ii) Weight of coal sample = 2.5 g
Weight of $BaSO_4$ ppt = 0.42 g

$$\% \text{ of sulphur} = \frac{\text{Weight of } BaSO_4 \text{ ppt} \times 32 \times 100}{\text{Weight of coal} \times 233}$$
$$= \frac{0.42 \times 32 \times 100}{2.5 \times 233}$$
$$= \frac{1344}{582.5}$$
$$= \mathbf{2.30\%}$$

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**Ex.38 A coal sample was subjected to ultimate analysis. 1.5g of coal on combustion produces 0.42 g. $BaSO_4$. Calculate percentage of sulphur in coal sample.**

**Ans.:** Weight of coal sample = 1.5 g
Weight of $BaSO_4$ ppt = 0.42 g

$$\% \text{ of sulphur} = \frac{\text{Weight of } BaSO_4 \text{ ppt.} \times 32 \times 100}{\text{Weight of coal} \times 233}$$
$$= \frac{0.42 \times 32 \times 100}{1.5 \times 233}$$
$$= \frac{1344}{349.5}$$
$$= \mathbf{3.845\%}$$

**Ex.39 A coal was sample was subjected to ultimate analysis. 1.5 g of coal on combustion produces 0.24 g. $BaSO_4$. Calculate percentage of sulphur in coal sample.**

**Ans.:** Weight of coal sample = 1.5 g
Weight of $BaSO_4$ ppt = 0.24 g

$$\% \text{ of sulphur} = \frac{\text{Weight of } BaSO_4 \text{ ppt.} \times 32 \times 100}{\text{Weight of coal} \times 233}$$
$$= \frac{0.24 \times 32 \times 100}{1.5 \times 233} = \frac{768}{349.5}$$
$$= \mathbf{2.197}$$

**Ex.40 2.5 g of coal sample was taken for nitrogen estimation by Kjedahl method. The ammonia liberated required 12.7 ml of 0.5 N $H_2SO_4$ for neutralization. Using Bomb calorimeter 1.5 g of coal sample produced 0.28 g of $BaSO_4$. Calculate percentage of N and S.**

**Ans.:** (i) Volume of acid used = 12.7 ml of 0.5 N $H_2SO_4$
Weight of coal sample = 2.5 g

$$\% \text{ of nitrogen} = \frac{\text{Volume of acid used} \times \text{Normality} \times 1.4}{\text{Weight of coal taken}}$$
$$= \frac{12.7 \times 0.5 \times 1.4}{2.5}$$
$$= \mathbf{3.56\ \%}$$

(ii) Weight of coal sample = 1.5 g
Weight of $BaSO_4$ ppt = 0.28 g

$$\% \text{ of sulphur} = \frac{\text{Weight of } BaSO_4 \text{ ppt.} \times 32 \times 100}{\text{Weight of coal} \times 233}$$

$$= \frac{0.28 \times 32 \times 100}{1.5 \times 233}$$

$$= \frac{896}{349.5}$$

$$= \mathbf{2.56\%}$$

**Ex.41 A coal sample was subjected to a ultimate analysis. 1.6 g of coal on combustion in a bomb calorimeter gave 0.47g $BaSO_4$. Calculate % of sulphur in the coal sample.**

**Ans.:** Weight of coal sample = 1.6 g
Weight of $BaSO_4$ ppt = 0.47 g

$$\% \text{ of sulphur} = \frac{\text{Weight of } BaSO_4 \text{ ppt.} \times 32 \times 100}{\text{Weight of coal} \times 233}$$

$$= \frac{0.47 \times 32 \times 100}{1.6 \times 233}$$

$$= \mathbf{4.03\%}$$

**Ex.42 1.5g of coal sample was burnt in a combustion apparatus. The products a combustion were collected in previously weighted KOH bulb and $CaCl_2$ tube. The increase in weights of KOH bulb and $CaCl_2$ tube were found to be 3.92 and 1.25g respectively. Calculate the percentage of Carbon and Hydrogen in the coal sample.**

**Ans.:** (i) Increase in weight of KOH = 3.92 g

$$\% \text{ of Carbon} = \frac{\text{Increase in weight of KOH tube} \times 12 \times 100}{\text{Weight of coal taken} \times 44}$$

$$= \frac{3.92 \times 12 \times 100}{1.5 \times 44}$$

$$= \frac{4704}{66}$$

$$= \mathbf{71.27\%}$$

(ii) Increase in weight of $CaCl_2$ tube = 1.25 g

$$\% \text{ of Hydrogen} = \frac{\text{Increase in weight of } CaCl_2 \text{ tube} \times 2 \times 100}{\text{Weight of coal sample} \times 18}$$

$$= \frac{1.25 \times 12 \times 100}{1.5 \times 18}$$

$$= \frac{250}{27}$$

$$= \mathbf{9.25\%}$$

**Ex.43 1.5 g of coal sample was analysed for nitrogen content by Kjedah's method. The liberated ammonia required 14 ml of 0.1 N $H_2SO_4$ solution for neutralization. In a separate experiment using Bomb Calorimeter, 1.5g of the same sample gave 0.3g of BaSO4. Calculate the percentage of Nitrogen and Sulphur in the sample.**

**Ans.:** (i) Volume of acid used $= 14$ ml of 0.1 N $H_2SO_4$

Weight of coal sample $= 1.5$ g

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

$$= \frac{14 \times 0.1 \times 1.4}{1.5}$$

$$\mathbf{= 1.31\%}$$

(ii) Weight of coal sample $= 1.5$ g

Weight of $BaSO_4$ ppt. $= 0.3$ g

$$\% \text{ of Sulphur} = \frac{\text{Weight of } BaSO_4 \text{ ppt.} \times 32 \times 100}{\text{Weight of coal} \times 233}$$

$$= \frac{0.3 \times 32 \times 100}{1.5 \times 233} = \frac{960}{349.5}$$

**% of sulphur** $\mathbf{= 2.746\%}$

**Ex.44 A coal sample was subjected to ultimate analysis. 2.45 g of coal on combustion in a Bomb Calorimeter gave 0.67 g of $BaSO_4$. Calculate the percentage of sulphur.**

**Ans.:** Weight of coal sample $= 2.45$ g

Weight of $BaSO_4$ ppt. $= 0.67$ g

$$\% \text{ of Sulphur} = \frac{\text{Weight of } BaSO_4 \text{ ppt.} \times 32 \times 100}{\text{Weight of coal} \times 233}$$

$$= \frac{0.67 \times 32 \times 100}{2.45 \times 233} = \frac{2144}{570.85}$$

$$\mathbf{= 3.755\%}$$

## 6.6 IMPORTANT FORMULAE

**Additional Formulae :**

1. **Dulong Formula**

Gross/high Calorific value (GCV/HCV)

$$= \left[\frac{1}{100}\left[8080\,C + 34500\left\{H - \frac{0}{8}\right\} + 2240\,S\right]\right]$$

Where C = % carbon

H = % hydrogen

O = % Oxygen

S = % Sulphur

$$\text{Net / Low Calorific value (NCV / LCV)} = \left[\text{H.C.V.} - \frac{9}{100} \times H \times 587\right]$$

**2. Proximate Analysis**

$$\text{Moisture \%} = \frac{\text{loss in weight}}{\text{Weight of coal sample}} \times 100$$

$$\text{Volatile Matter \%} = \frac{\text{Weight of volatile matter}}{\text{Weight of air dried Coal}} \times 100$$

$$\text{Ash \%} = \frac{\text{Weight of ash}}{\text{weight of coal}} \times 100$$

Fixed Carbon % = 100 – (moisture % + V.M. % + ash %)

**3. Ultimate Analysis**

% of Carbon and Hydrogen

$$\text{C \%} = \frac{\text{Weight of } CO_2 \text{ formed}}{\text{Weight of coal sample}} \times \frac{12}{44} \times 100$$

$$\text{H\%} = \frac{\text{weight of } H_2O \text{ formed}}{\text{Weight of coal sample}} \times \frac{2}{18} \times 100$$

% of Nitrogen

$$\text{N \%} = \frac{\text{valume of acid consumed} \times \text{Normality of acid} \times 1.4}{\text{Weight of coal sample}}$$

% of sulphur

$$\text{S\%} = \frac{\text{Weight of } BaSO_4 \text{ precipitate}}{\text{Weight of coal sample}} \times \frac{32}{233} \times 100$$

% of Oxygen

O% = 100 – (C% + H% + N% + S% + Ash%)

**Calculate of Quantity of Air required for Combustion of Fuel**

$$O_2 \text{ quantity} = \left[\frac{32}{12}C + \left(H - \frac{0}{8}\right) + S\right] \text{Kg}$$

Where C, H, S, O are masses of the elements.

$$\text{Quantity of air} = \frac{\text{Oxygen quantity} \times 100}{23} \times \text{Kg}$$

$$\text{Volume of air} = \frac{\text{volume of oxygen} \times 100}{21} m^3$$

## GRADED QUESTIONS

1. Define fuels. How are they classified ? **[Ans.:** Refer 3.1.1, 3.1.2]
2. Define fuels? Classify fuels with suitable example. **[Ans.:** Refer 3.1.1, 3.1.2]
3. Define fuel. Give the characteristics of good fuel. **[Ans.:** Refer 3.2.4]**[M-17]**
4. Define Fuel. Why a good fuel must have low ash content? **[D-18]**
5. Define the term calorific value and ignition temperature ? **[Ans.:** Refer 3.2.1]
6. Define Gross and Net calorific value of a fuel. **[Ans.:** Refer 3.2.2, 3.2.3]
7. Define H.C.V. and L.C.V. **[Ans.:** Refer 3.2.2, 3.2.3]
8. Explain the determination percentage of Moisture content in the coal sample. Give its significance. **[D-18]**

9. Distinguish clearly between Proximate analysis and ultimate analysis [Ans.: Refer 3.3.2, 3.33]
10. How is proximate analysis of coal conducted ? What is its significance ? [Ans.: Refer 3.3.2]
11. Explain in brief the various tests done under proximate analysis of coal giving the significance of each. [Ans.: Refer 3.3.2]
12. How is ultimate analysis carried out? What is its significance ? [Ans.: Refer 3.3.3]
13. Define Octane number and Cetane number. [Ans.: Refer 3.5.6, 3.5.7][M-17]
14. Define Octane number and Cetane number. Give their significance. [Ans.: Refer 3.5.6, 3.5.7]
15. Distinguish clearly between Octane number and cetane number. [Ans.: Refer 3.5.6, 3.5.7]
16. What is knocking ? Explain the role of antiknocking agents. [Ans.: Refer 3.5.5]
17. What is knocking? Define octane number. What is unleaded petrol? [Ans.: Refer 3.5.5, 3.5.2][D-15]
18. Define octane number of gasoline, Name any two anti-knock agents. [D-13] [Ans.: Refer 3.5.6, 3.5.5]
19. Define Octane number of gasoline. How is knocking tendency of gasoline related to chemical structure of hydrocarbons present? [M-14] [Ans.: Refer 3.5.6, 3.5.5]
20. Select the compound which possesses highest octane number and highest cetane number out of n-heptane, n – octane and isooctane. [D-17]
21. Define octane number. Name any two antiknock agents. [D-16] [Ans.: Refer : 3.5.6 & 3.5.7]
22. Write a short note on following Catalytic converter [Ans.: refer 3.5.3, 3.8]
23. Differentiate between Gross and Net calorific value of a fuel. The % composition of mass of a sample of coal is as follows.
    C = 80%. H = 6%, O = 8%, S = 1.5%, N = 1%, ash = rest.
    Calculate the gross and net calorific value of Fuel.
    [Ans.: GCV = 8222.6 kcal/kg, LCV = 7905.62 kcal/kg]
24. Calculate Gross and Net calorific value for a coal sample which contains,
    C = 70 %, H = 6 %, O = 20 %, S = 2.5 %, N = 1.5 % [Ans.: GCV = 6919.5 kcal/kg]
25. A sample of coal has the following composition by mass.
    C = 85 %, H = 6 % , O = 8 % ; S = 0.5 % and Ash = 0.5 %
    Calculate the H.C.V. and L.C.V. using Dulong's formula.
    [Ans.: GCV = 8604.2, LCV = 8287.22]
26. A sample of coal contains : C = 70%, O = 23%, H = 5%, S = 1.5%, N = 0.4%, as h = 0.1%. Calculate G.C.V. and N.C.V. of this fuel.
    [Ans.: GCV = 6422.75 kcal/kg, LCV = 6158 kcal/kg]
27. A sample of coal has the following composition: [M-18]
    C = 70%, O = 23%, H = 5%, S =1.5%, N = 0.4%, Ash = 0.1%,
    calculate the G.C.V. of this fuel. [Ans.: GCV = 6422.725 kcal/ kg]
28. A sample of coal has the following composition- C = 90%, H = 8%, N = 2%, S = 1.5%, O = 5% and remaining ash. Calculate the GCV and LCV (Latent heat of condensation of steam = 587 cal/g)
    [Ans.: GCV = 9849 kcal/kg, LCV = 9427.33 kcal/kg]
29. Calculate the Gross and Net calorific value of coal sample having the following composition : C – 85%, H – 7%, O – 3%, S – 3.5%, N – 2.1% and Ash – 4.4%
    [Ans.: GCV = 9232.02 kcal/kg ; LCV = 8862.2 kcal/kg]

**30.** Calculate the gross and net calorific value of coal having following composition:
C = 80%, H = 7%, O = 3%, S = 3.5%, N = 2.1 % and ash = 4.4%.
[**Ans.:** GCV = 8828.02 kcal/kg; LCV = 8458.21 kcal/kg]

**31.** 1.5 g of a sample of coal was taken for C and H estimation by combustion method. The increase in weights of tube containing anhydrous $CaCl_2$ and bulb containing KOH was found to be 1.25 g and 4.88 g respectively. Calculate the percentage of C and H. [**Ans.:** %C = 88.72; %N = 9.2%]

**32.** By Kjeldahle's method, 2.3 gms of coal sample was analysed for nitrogen content. The liberated ammonia was neutralised by 12.5 ml. of 0.5 N $H_2SO_4$ solution. The same weight of sample gave 0.64 gms of $BaSO_4$ precipitate. Calculate percentage of nitrogen and sulphur in the sample. [**Ans.:** %N = 3.80; %S = 3.82]

**33.** A coal sample was subjected to ultimate analysis, 0.6 gm of coal on combustion in a Bomb colorimeter, produces 0.05 gm $BaSO_4$. Calculate the percentage of 'S' in coal sample. [**Ans. :** % S = 14%]**[M-13]**

**34.** A coal sample was subjected to ultimate analysis. 1.5g of coal on combustion in a Bomb calorimeter gave 0.42g of $BaSO_4$. Calculate percentage sulphur in the coal sample. [**Ans.:** %S = 3.84%]**[D-13]**

**35.** 1.95 g of a coal sample was taken for nitrogen estimation by Kjeldahl method. The ammonia liberated required 9.5 ml of 0.4 N $H_2SO_4$ for neutralization. The same sample of coal weighing 1.5 g in a Bomb calorimeter experiment produced 0.35 g of $BaSO_4$. Calculated percentage of N and S. [**Ans.:** %N = 2.72, %S = 3.20]

**36.** 1.95 gm of a coal sample was taken for nitrogen estimation by Kjeldahis's method. The ammonia liberated required 9.5 ml of 0.4 N $H_2SO_4$ for neutralisation. Calculate the percentage of Nitrogen in coal sample. [**Ans.:** % N = 2.73] **[M-18]**

**37.** 3 g of coal was heated in Kjeldahl's flask and $NH_3$ gas evolved was absorbed in 40 ml of 0.5 N $H_2SO_4$. After absorption, the excess acid required 18.5 ml of 0.5 N kOH for exact neutralisation. 2.3 g of coal sample in quantitative analysis gave 0.35 g $BaSO_4$. Calculate the % of N and S in the sample. [**Ans.:** %N = 5.01, %S = 2.08]

**38.** 2.5 gms of coal sample was taken in Silica Crucible and heated in oven maintained at 110° C for one hour. The weight after heating was 2.368 gms. The same sample was analysed for volatile matter, and weight obtained was 1.75 gms. The sample was further treated to get a fixed weight of 0.95 gms. Calculate percentage of moisture, V.M. ash and F.C. for this sample.
[**Ans.:** %moisture = 5.28%, %VM = 30%, Ash = 38%, %C = 26.72]

**39.** A coal sample was subjected to the ultimate analysis, 0.5 gms of coal on combustion in bomb calorimeter and the content on treatment with $BaCl_2$ solution produce 0.06 gms of $BaSO_4$. Calculate % of sulphur in coal sample. [**Ans.:** % S = 1.64 %]

**40.** 3.2 gms of coal in Kjeldahl's experiment evolved $NH_3$ which was absorbed in 40ml of 0.5 N $H_2SO_4$. After absorption, the excess acid required 16 ml of 0.5 N KOH for complete neutralization. 2.5 gms of coal sample in quantitative analysis gave 0.42 gm $BaSO_4$. Calculate the % of N and S in the sample. [**Ans.:** %N = 5.25, %S = 2.30]

**41.** 1g of Coal sample was used for determination of Nitrogen by Kjeldhal's method. The ammonia evolved was passed into 50 ml of 0.1N sulphuric acid. The excess acid required 42 ml of 0.1N NaOH for neutralization. [**Ans.:** %N = 1.12]

**42.** An air dried sample of coal weighing 2.9g was taken for volatile matter determination. After losing volatile matter the coal sample weighed 1.96g. If it contains 4.5% moisture. Find the percentage volatile matter in it. [**Ans.:** VM = 27.913%]

**43.** 2.499 gms of coal sample was taken in Silica crucible and heated in oven maintained at 110°C for one hour. The weight after heating was 2.368 gms. The sample was analyzed for volatile matter and weight obtained was 1.75g. The sample was further treated to get fixed weight of 0.95 gms. Calculate the percentage of moisture, volatile matter, ash and fixed carbon for this sample.

[**Ans.:** Moisture = 5.24 %, Volatile matter = 29.97%; Ash = 38.01%, %C = 10.71]

**44.** In a Kjeldahl's apparatus, 3.5g of the coal sample was analysed. The $NH_3$ gas evolved was absorbed in 50 ml of 0.1N $H_2SO_4$. The residual $H_2SO_4$ required 15 ml of 0.1N NaOH for neutralization. Calculate percentage of nitrogen in the sample.

[**Ans.:** % N = 1.4%]

**45.** 2.5 of air dried coal sample was taken in a silica crucible, after heating it in an electric oven at 105° – 110°C for 1 hour, the residue was weighed 2.410g. The residue was heated in a silica crucible covered with vented lid at a temperature 950 ± 20°C for exactly 7 minutes. After cooling the weight of residue was found to be 1.78g. The residue was then ignited at 750°C to a constant weight of 0.246g. Calculate the percentage of fixed carbon in a coal sample.

[**Ans.:** % moisture = 3.6, % VM = 28.8%, % Ash = 9.84, %C = 57.76]

**46.** A coal sample has the following composition by weight. C = 84%, H = 6%, S = 1%, O = 8% and remaining ash. Calculate the minimum quantity of air required both by weight and volume for the complete combustion of 2 kg of this fuel. (Mol. Wt. of air = 28.94). [**Ans.:** Wt of Air = 23.04 kg, Vol. of air = 17.83 litres]

**47.** A coal sample has the following composition by weight. C = 84%, H = 6%, S = 1%, O = 8 % and remaining ash. Calculate the minimum quantity of air required both by weight and volume for the complete combustion of 2 kg of this fuel. (Mol. Wt. of air = 28.94)

[**Ans. :** Wt. of Air = 23.04 kg, Vol. of air = 17.83 litres]

**48.** A coal sample was found to contain the following constituents :
C – 81%, O – 8%, S – 1%, H – 5%, N – 1%, Ash – 4%. Calculate the minimum amount of air required for complete combustion of 2 kg of coal.

[**Ans.:** Vol. of air = 16.75 litres]

**49.** A gas has following composition by volume :
$H_2$ = 20%, $CH_4$ = 6%, CO = 22%, $CO_2$ = 4%, $O_2$ = 4% and $N_2$ = 44%, find the volume of air actually required per $m^3$ for complete combustion of this gas.

[**Ans.:** Vol. of air = 1.380 $m^3$]

**50.** A coal sample has the following composition by weight C = 85%, H = 5%, S = 2%, O = 5%, and Ash = 3%. Calculate the minimum quantity of air required both by weight and volume for the complete combustion of 2 kgs of coal.

[**Ans.:** 22.92, volume of air = 17.741 $m^3$]

**51.** The composition of a gas was found to be $H_2$ = 10%, $CH_4$ = 16%, $C_2H_6$ = 20%, $N_2$ = 6%, CO = 22%, $CO_2$ = 18%, $O_2$ = rest. Calculate the volume of air required for complete combustion of 1$m^3$ of this gas. [**Ans.:** 5.23 $m^3$]

**52.** Calculate the volume of air required for complete combustion of 1$m^3$ of gaseous fuel which possesses by volume, $CH_4$ = 40 %, $C_2H_4$ = 10 %, CO = 5 %, $O_2$ = 2.5 %, $H_2$ = 35 %, $CO_2$ = 2 %, $N_2$ = 2.5 %, Water Vapours = 3 %. [**Ans. :** 6.071 $m^3$]

**53.** Calculate weight of air needed for complete combustion of 1 kg of coal containing C = 72%, H = 10%, O = 9%, N = 3% and remaining being ash. [**Ans.:** 11.43 kg]

**54.** Calculate the Weight and Volume of air needed for complete combustion of 1kg of coal containing. C = 65 %, H = 4 % , O = 7 % , N = 3.0 %
Moisture = 15 % and remaining is Ash. (Molecular weight of air = 28.949g)

[**Ans.:** Wt. of Air = 8.60 kg, Vol. of air = 6.66 litres]

55. The composition of gas was found to be $H_2 = 10\%$, $CH_4 = 20\%$, $C_2H_6 = 16\%$, $N = 6\%$, $CO = 18\%$, $CO_2 = 22\%$, $O_2$ = rest. Calculate volume of air required for 1 $m^3$ of this gas.
[**Ans.:** Vol. of air = 4.85 litres]

56. A gaseous fuel has the following composition by volume : $H_2 = 35\%$, $CH_4 = 45\%$, $C_2H_6 = 6\%$, $CO = 12\%$ and remaining $N_2$. Calculate the minimum amount of air required at 27°C and 760mm Hg pressure for the complete combustion of 1 cum of the fuel.
[**Ans.:** Vol. of air = 7.038 litres, Wt. of air = 9.092 kg]

57. A coal sample has the following composition by weights : C = 82%, H = 3%, O = 8%, S = 2%, N = 2% and Ash = 3%. Calculate the minimum amount of air required both by weight and volume for complete combustion of 2 kg of coal. (mol-wt. of air = 28.949 gm).
[**Ans.:** wt. of air = 20.52 kg, Vol. of air = 15.88 litres] **[M-13]**

58. A gaseous fuel has the following composition by volume: **[M-13]**
$H_2 = 10\%$, $CH_4 = 30\%$, $C_3H_8 = 20\%$, $CO = 20\%$, $CO_2, = 15\%$, $N_2 = 5\%$.
Calculate the volume of air required for complete combustion of 1$m^3$ of this gas.
[**Ans.:** Vol. of air = 8.33 $m^3$]

59. A gaseous fuel has the following composition by volume : **[D-13]**
$H_2 = 50\%$, $CO = 10\%$, $CH_4 = 30\%$, $C_2H_4 = 5\%$, $N_2 = 1\%$, $O_2 = 2\%$ and $CO_2 = 2\%$, Calculate volume and weight of air required for complete combustion of 1 $m^3$ of fuel. (Molecular weight of air = 28.949)
[**Ans.:** Volume of air=4.90 litres, Weight of air = 6.33 kg]

60. A coal sample was subjected to ultimate analysis 1.5g of coal on combustion in a Bomb calorimeter gave 0.24g of $BaSO_4$. Calculate percentage sulphur in the coal sample.
[**Ans.:** %S = 2.19] **[M-14, 15]**

61. A gaseous fuel has the following composition by volume. **[M-14]**
$H_2 = 55\%$, $CH_4 = 30\%$, $C_2H_4 = 5\%$, $CO = 5\%$, $N_2 = 3\%$, $CO_2 = 2\%$ and $O_2 = 2\%$. Calculate volume and weight of air required for complete combustion of 1$m^3$ of fuel. (Mol. wt. of air = 28.949) [**Ans.:** Vol. of air = 4904 lit. Wt. of air = 6337.76 kg]

62. A sample of coal has the following composition by mass : C = 80%, H = 4%, O = 6%, S = 3%, N = 2% and Ash = 5%. Calculate Gross and Net Calorific value using Dulong's formula. [**Ans.:** GCV = 7652.45 kal/kg; NCV = 7441.13 kcal/kg]**[M-14]**

63. A sample of coal has the following composition by mass : C = 75%, H = 7%, O = 8%, S = 4%, N = 2% and Ash = 4%. Calculate Gross Calorific value of the fuel using Dulong's formula.
[**Ans.:** GCV = 6494.6 kcal/kg] **[D-14]**

64. A gaseous fuel has the following composition by volume : **[D-14]**
$H_2 = 40\%$, $CH_4 = 30\%$, $CO = 10\%$, $C_3H_8 = 12\%$, $N_2 = 3\%$, $O_2 = 2\%$ and $CO_2 = 3\%$.
Calculate volume and weight of air required for complete combustion of 1$m^3$ of fuel. (Mol. wt. of air = 28.949)
[**Ans.:** Vol. of air = 6809 lit; Wt. of air = 8.8 kg]

65. 2.5 g of a coal sample was analysed for nitrogen content by Kjeldahl's method. The liberated ammonia required 12.7 ml of 0.5 N $H_2SO_4$ solution for neutralization. In a separate experiment, using Bomb calorimeter, 1.5 g of coal sample gave 0.28g of $BaSO_4$. Calculate percentage Nitrogen and Sulphur in the sample.
[**Ans.:** %N = 3.556; %S = 2.342]**[D-14]**

66. A sample of coal has the following composition by weight : **[D-13]**
C = 82%, H = 6%, O = 8%, S = 0.5%, N = 3% and Ash = 0.5%.
Calculate the Gross and Net Calorific value using Dulong's formula.
[**Ans.:** GCV = 8361.8 kcal/kg; LCV = 8044.82 kcal/kg]

67. A coal sample was subjected to ultimate analysis: **[M-15]**
1.6 gm of coal on combustin in a Bomb calorimeter gave 0.47 gm of $BaSO_4$ Calculate % of sulphur in the coal sample.
[**Ans.:** % S = 4.03]

Electrochemistry



68. A gaseous fuel has the following composition by volume. **[M-15]**
$CH_4$ =35%, $C_2H_4$ = 5%, CO=15%, $H_2$=40% $N_2$=1 water vapour = 4%
Calculate volume and weight of air required for complete combustin of $1m^3$ of fuel [mol.wt of air = 28.94] [**Ans.:** Vol. of air = 5360 lit; Wt. of air = 6.92 kg]

69. 2.5 gm air dried coal sample was taken in a silica crucible, after heating it in an electric oven at 110°C for 1 hr the residue was weighed 2.41 gm. The residue was heated in Silica crucible covered with vented lid at a temperature 925 ± 25°C for exactly 7 minutes. After cooling the weight of residue was found to contain 1.98 gm. The residue was then ignited to a constant weight of 0.246 gm. Report the results of above analysis. **[M-15]**

70. 1.5g of a coal sample was burnt in a combustion apparatus and the products of combustion were collected in previously weighed KOH bulb and $CaCl_2$ tube. The increase in weights of KOH bulb and $CaCl_2$tube were found to be 3.92g and 1.25g respectively. Calculate percentage carbon and hydrogen in the sample.
[**Ans.:** %C = 71.27%, %H = 9.23%] **[D-15]**

71. A gaseous fuel has the following composition by volume. **[D-15]**
CO = 46% $H_2$ = 30% $CH_4$ = 10%
$C_2H_4$ = 4% $N_2$ = 1 % $CO_2$ = 2% and $O_2$ = 7%
Calculate volume and weight of air required for complete combustion of $1m^3$ of fuel (Mol. wt. of air = 28.949) [**Ans.:** Vol. of air = 3000; Wt. of air = 3.877 kg]

72. A sample of coal has the following composition by mass : **[D-15]**
C = 70%, H = 10%, O = 4%
S = 2% N = 2% and Ash = 12%
Calculate Gross and Net calorific value using Dulong's formula.
[**Ans.:** GCV = 8978.3 kcal/kg; LCV = 8360 kcal/kg]

73. A gaseous fuel contains $H_2$ = 50%, $CH_4$ = 30%, $N_2$ = 2%, CO = 7%, $C_2H_4$ = 3%, $C_2H_6$ = 5%, and water vapour = 3%, Calculate weight and volume of air required for $2m^3$ of the gas. [Given: Mol. Wt. of an air = 28.949kg] **[M-18]**
[**Ans.:** 14.15 kg of air]

74. Explain the determination of % moisture and % volatile matter in a coal sample. **[M-18]**

75. A sample of coal contains C = 66%, O = 28%, H = 4%, S = 1.5%, N = 0.8% and ash = 0.2%. Calculate the G.C.V and N.C.V of the coal. **[D-18]**
[**Ans.:** GCV = 5538.9 kcal/kg., NCV = 5327.78 kcal/kg]

76. 0.5 gm of coal sample was burnt in Bomb Calorimeter experiment produced 0.06 gm of $BaSO_4$ .Calculate percentage of Sulphur. [**Ans.:** % S = 1.64] **[D-18]**

77. Calculate weight and volume of air required for complete combustion of $1m^3$ of gaseous fuel which possess by volume; $CH_4$ = 35%, $C_2H_4$ = 5%, CO = 15%, $H_2$ = 40%, $N_2$ = 1%, water vapour = 4%. (Molecular weight of air = 28.949) **[D-18]**
[**Ans.:** Volume of air = 5.357 $m^3$, air weights = 6.923 kg]

## EXAMINATION QUESTIONS

**Dec. '19**

1. A coal sample was found to contain the following constituents: C = 81%, H = 6%, S = 1%, N = 2%, ash = 4% and rest is oxygen. Calculate the minimum weight of air required at STP for complete combustion of 1 kg of the coal sample. [3]
2. 1.5 gm of a coal sample was kjeldahlised and the ammonia evolved was absorbed in 49 ml N/10 $H_2SO_4$. After absorption the excess $H_2SO_4$ required 32.5 [3]

ml of 0.1 N NaOH for neutralization. 0.5 gm of the same coal sample was burnt in a bomb calorimeter and on treatment with $BaCl_2$ produced 0.08 gm of $BaSO_4$. Calculate the percentage of nitrogen and Sulphur in the given coal samples.

3. A gas has following composition by volume : $H_2$ = 10%, $C_2H_6$ = 25%, CO = 16%, $H_2O$ = 20%, $C_2H_2$ = 15%, $CH_4$ = 4% and the rest $CO_2$. Calculate the volume of air supplied per $2m_3$ of the gas at STP. Also calculate the weight of air to be supplied at STP per 2m3 of the gas. (Average molar mass of air at STP = 28.94 gm) [6]
4. What is knocking? Explain the role of antiknocking agents. [4]

**May '19**

1. Define octane number and write its significance. [3]
2. Calculate higher calorific value of a coal sample containing C = 85%, H = 1%, N =1.5%, O = 5%, S = 0.4% and remaining being ash. [3]
3. 1.4 gm of coal sample on combustion gave 0.3 gm of barium sulphate precipitate. Calculate the percentage of sulphur in the sample. [3]
4. A sample of coal was found to contain C=90%,O=5%,H=1%,S=0.5% and remaining being nitrogen. Calculate weight and volume of air required for complete combustion of 1 kg of coal sample.(M.W. of air=28.949) [6]

**Dec. '18**

1. Define Fuel. Why a good fuel must have low ash content? [3]
2. A sample of coal contains C = 66%, O = 28%, H = 4%, S = 1.5%, N = 0.8% and ash = 0.2%. Calculate the G.C.V and N.C.V of the coal. [3]

   [**Ans.:** GCV = 5538.9 kcal/kg., NCV = 5327.78 kcal/kg]
3. 0.5 gm of coal sample was burnt in Bomb Calorimeter experiment produced 0.06 gm of $BaSO_4$ .Calculate percentage of Sulphur. [3]

   [**Ans.:** % S = 1.64]
4. What is Cracking. With the help of diagram explain Fixed Bed Catalytic cracking. [6]
5. Calculate weight and volume of air required for complete combustion of $1m^3$ of gaseous fuel which possess by volume; $CH_4$ = 35%, $C_2H_4$ = 5%, CO = 15%, $H_2$ = 40%, $N_2$ = 1%, water vapour = 4%. (Molecular weight of air = 28.949) [6]

   [**Ans.:** Volume of air = 5.357 $m^3$, air weights = 6.923 kg]
6. What is meant by cracking of petroleum. [2]
7. Explain the determination percentage of Moisture content in the coal sample. Give its significance. [4]

**May '18**

1. Define power alcohol. Give any two advantages of power alcohol. [3]
2. A sample of coal has the following composition: [3]
   C = 70%, O = 23%, H = 5%, S =1.5%, N = 0.4%, Ash = 0.1%,
   calculate the G.C.V. of this fuel.

   [**Ans.:** GCV = 6422.725 kcal/ kg]
3. 1.95 gm of a coal sample was taken for nitrogen estimation by Kjeldahis's method. [3]
   The ammonia liberated required 9.5 ml of 0.4 N $H_2SO_4$ for neutralisation.
   Calculate the percentage of Nitrogen in coal sample.

   [**Ans.:** % N = 2.73]

4. Define fuel cell. Explain Hydrogen Oxygen fuel cell with a neat labelled diagram. [6]
5. Define Bio-Diesel and give its advantages. [2]
6. A gaseous fuel contains $H_2$ = 50%, $CH_4$ = 30%, $N_2$ = 2%, CO = 7%, $C_2H_4$ = 3%, $C_2H_6$ = 5%, and water vapour = 3%, Calculate weight and volume of air required for $2m^3$ of the gas. [6]
[Given: Mol. Wt. of an air = 28.949kg]

[**Ans.**: 14.15 kg of air]
7. Explain the determination of % moisture and % volatile matter in a coal sample. [4]

**Dec. '17**

1. Select the compound which possesses highest octane number and highest cetane number out of n-heptane, n – octane and isooctane. [3]
2. Calculate the higher and lower calorific values of coal sample containing 84% carbon, 1.5% sulphur, 0.6 Nitrogen, 5.5% hydrogen and 8.4% oxygen. [3]

[**Ans.**: 8065.48 Kcal/kg]
3. 1.56 g of a coal sample was kjeldahlised 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 0.1 N NaOH for exact neutralization. Calculate the percentage of N in the coal sample. [3]

[**Ans.**: % N = 3.93%]
4. What is cracking? Explain in detail-fixed bed catalytic cracking. [6]
5. A sample of coal was found to contain the following constituents. C = 81%; O = 8%; S = 1%; H = 5%; N = 1% and Ash = 4% [6]
Calculate the minimum weight and volume of an required for the complete combustion of 1 kg of coal.

[**Ans.**: Weight of air = 10.82 kg; Volume of air = 8.37 $m^3$]
6. What is biodiesel? Discuss the method to obtain biodiesel. What are the advantages of biodiesel. [4]

**May '17**

1. Define octane number and cetane number. [3]
2. A coal sample contains C = 70%, O = 23%, H = 5%, N = 0.4%, Ash = 0.1%. Calculate GCV and NC V of the fuel. [3]

[**Ans.**: 6158 .575 kcal/kg]
3. 0.5 gm of coal sample was burnt in Bomb Calorimeter experiment produced 0.06 gm $BaSO_4$. Calculate percentage of Sulphur. [3]

[**Ans.**: S = 1.648 %]
4. With neat and labelled diagram explain fixed bed catalytic cracking. [6]
5. Calculate weight of air needed for complete combustion of 2 kg of coal containing C = 70 %, H = 10%, O = 10%, N = 5% and remaining ash [6]

[**Ans.**: 22 26 kg]
6. Define fuel. Give the characteristics of good fuel. [4]

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