

Module - III

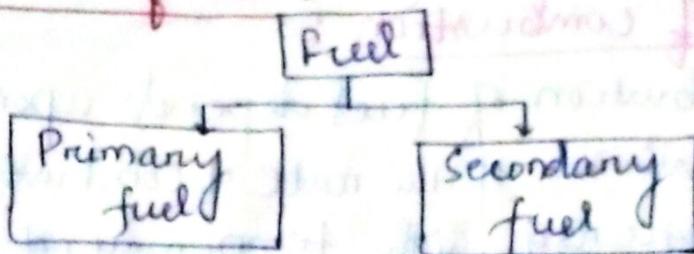
Fuels

Fuel :-

The combustible substances which on burning in air produces large amount of heat that can be used economically for domestic and industrial purposes are called "fuel".

E.g.: - Wood, coal etc.

Classification of Fuel :-



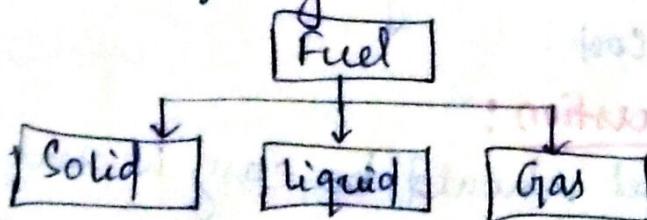
Primary fuel :-

These are fuels which occur naturally such as coal, crude petroleum and natural gas. Coal and crude petroleum, formed from organic matter many millions of years ago are referred to as fossil fuels.

Secondary fuels :-

Fuels that are derived from natural products by undergoing treatment process such as COKE, gasoline, coal gas, etc.

On the basis of Physical state, fuel can be classified



Characteristics of Good Fuel :-

1. Low moisture content :

A good fuel should have low moisture content as moisture content reduces the calorific value.

2. Low non-combustible matter content :

A good fuel should have low contents of non-combustible materials as non-combustible matter is left in the form of ash which decreases the calorific value of fuel.

3. Moderate rate of combustion :

The temp. of combustion of fuel depends upon the rate of combustion. If the rate of combustion is low, then the required high temp. may not be reached soon.

4. Minimum smoke and non-poisonous gases :

On burning, fuel should not give out objectionable and poisonous gases. Gaseous products should not pollute the atmosphere. Gases like, CO, SO₂, H₂S etc. are some of the harmful gases.

5. Cheap :

A good fuel should be cheap and readily available.

6. Easy transportation :

A good fuel should be easy to handle and transport at low cost.

7. Controllable combustion :

Combustion of fuel should be easy to start or stop when required.

8. Non-spontaneous combustion:

Combustion of fuel should be non-spontaneous otherwise it can cause fire hazards.

9. Low storage cost:

A good fuel should be easily stored at low cost.

High calorific value:

A good fuel should have high calorific value, i.e., it should produce large amount of heat on burning.

For a fuel containing carbon, oxygen, hydrogen & sulphur, the calorific value of the fuel is given by

Dulong's formula:

$$\text{Calorific value} = \frac{1}{100} [8080C + 34500 \left\{ H - \frac{O}{8} \right\} + 2240S]$$

Where C, H, O, S refers to the % age of carbon, hydrogen, oxygen & sulphur, respectively.

Gross calorific value:

The Gross calorific value refers to the heat evolved when the water produced by combustion is condensed as a liquid. The net value gives the heat liberated when water is in the form of steam or water vapour.

Thus, the gross calorific value is the quantity of heat liberated by the complete combustion of unit weight of the fuel with subsequent cooling of the products of combustion to the initial temp. of the fuel.

Net calorific value:-

The net calorific value is defined as the gross calorific value minus the latent heat of condensation of water formed by the combustion of hydrogen in the fuel.

The latent heat of steam at ordinary temp. may be taken as 587 cal/g.

$$\text{Net calorific value} = \text{Gross calorific value} - \frac{\text{Latent heat of water vapour}}{}$$

$$\text{NCV} = \text{GCV} - \frac{\text{Weight of hydrogen} \times 9 \times \text{Latent heat of water vapour}}{}$$

Latent heat of water vapour is 587 kcal/kg

①

(Q1) A sample of coal was found to have the following percentage composition : C = 75%, H = 5.2%, O = 12.1%, N = 3.2% and ash = 4.5%. Calculate the H.C.V and L.C.V.

Given data :-

$$C = 75\%, H = 5.2\%, O = 12.1\%, N = 3.2\%, \text{ash} = 4.5\%$$

$$S = 0\%$$

According to Dind formula :-

$$\begin{aligned} \text{HCV} &= \frac{1}{100} [8080 \times 75 + 34500 \left(5.2 - \frac{12.1}{8} \right) + 2240 \times 0] \text{Kcal/kg} \\ &= \frac{1}{100} [8080 \times 75 + 34500 \left(5.2 - 1.5125 \right) + 2240 \times 0] \text{Kcal/kg} \\ &= \frac{1}{100} [606000 + 34500 \left(\frac{29.5}{8} \right) + 0] \text{Kcal/kg} \\ &= \frac{1}{100} [606000 + 34500 \times 3.6875 + 0] \text{Kcal/kg} \\ &= \frac{1}{100} [606000 + 127218.75] \text{Kcal/kg} \\ &= \frac{1}{100} [733218.75] \text{Kcal/kg} \\ &= \boxed{7332.1875 \text{ Kcal/kg}} \end{aligned}$$

$$\begin{aligned}
 L.C.V &= Q(H.C.V - 0.09 Y.H \times 587) \text{ Kcal/kg} \\
 &= (7332.1875 - 0.09 \times 5.2 \times 587) \text{ Kcal/kg} \\
 &= 7332.1875 - 274.716 \text{ Kcal/kg}
 \end{aligned}$$

$$= 7057.4715 \text{ Kcal/kg}$$

(Q2) A coal has the following composition by weight C = 90%, O = 3%, S = 0.5%, N = 0.5% and ash = 2.5%. Net calorific value of the coal was found to be 8490.5 Kcal/kg. Calculate the % of Hydrogen & H.C.V of the coal.

Ans- $HCV = LCV + 0.09 H \times 587 \text{ Kcal/kg}$

$$\begin{aligned}
 &= 8490.5 + 0.09 H \times 587 \text{ Kcal/kg} \\
 HCV &= (8490.5 + 52.83 H) \text{ Kcal/kg} \quad - (1)
 \end{aligned}$$

$$\begin{aligned}
 HCV &= \frac{1}{100} [8080 \times Y.C + 34500 \left(Y.H - \frac{Y.O}{8} \right) + 2240 \times Y.S] \text{ Kcal/kg} \\
 &= \frac{1}{100} [8080 \times 90 + 34500 \left(H - \frac{3}{8} \right) + 2240 \times 0.5] \text{ Kcal/kg} \\
 &= \frac{1}{100} [727200 + 34500H - 12937.5 + 1120] \text{ Kcal/kg} \\
 &= \frac{1}{100} \times 727200 + \frac{1}{100} \times 34500H - \frac{1}{100} \times 12937.5 + \frac{1}{100} \times 1120 \text{ Kcal/kg}
 \end{aligned}$$

$$\begin{aligned}
 &= [7272 + 345H - 129.375 + 1.12] \text{ Kcal/kg} \\
 &= [7283.2 - 129.375 + 345H]
 \end{aligned}$$

(3)

$$= (7153.825 + \frac{129.2375}{345H}) \text{ kcal/kg} - (ii)$$

from eqn (i) & (ii)

$$8490.5 + 52.83H = 7153.825 + 345H$$

$$\Rightarrow 8490.5 - 7153.825 = 345H - 52.83H$$

$$\Rightarrow 1336.675 = 292.17H$$

$$\Rightarrow 292.17H = 1336.675$$

$$\Rightarrow H = \frac{1336.675}{292.17}$$

$$= 4.57499058767$$

$$\boxed{H = 4.575 \text{ Ans}}$$

$$\begin{aligned} H.C.V. &= 7153.825 + 345H \\ &= 7153.825 + 345 \times 4.575 \\ &= 8732.2 \text{ kcal/kg} \end{aligned}$$

Calorific value :-

It is defined as the quantity of heat (expressed in calories or kilocalories) liberated by the complete combustion of unit weight (1 gm or 1 kg) of the fuel in air or oxygen, with subsequent cooling of the products of combustion to the initial temperature of the fuel.

- (i) calorific value depends upon the nature of the fuel and the relative proportions of the elements present, increasing with increasing amounts of hydrogen.
- (ii) If moisture is present, it reduces the calorific value of a fuel.

Liquid fuel: - Two types of liquid fuel are:-
The liquid fuels can be classified as follows:

- a) Natural oil
- b) Artificial oil.

Advantages :-

- a) They possess higher calorific value per unit mass than solid fuels.
- b) They burn without dust, ash, clinkers, etc.
- c) Their firing is easier and also fire can be extinguished easily by stopping liquid fuel supply.
- d) They are easy to transport through pipes.
- e) They are clean in use and economic to handle.
- f) They require less excess air for complete combustion.

Disadvantages :-

- The cost of liquid fuel is relatively much higher as compared to solid fuel.
- costly special storage tanks are required for storing liquid fuels.
- There is a greater risk of fire hazards, Particulately, in case of highly inflammable & volatile liquid fuels.
- They give bad odour.
- For efficient burning of liquid fuels, specially constructed burners and spraying apparatus are required.

Petroleum :-

Petroleum is a basic natural fuel.

It is a dark greenish brown, viscous mineral oil, found deep in earth's crust.

It is mainly composed of various hydrocarbons (like straight chain paraffins, cycloparaffins or naphthenes, olefins and aromatics) together with small amount of organic compounds containing oxygen, nitrogen & sulphur.

The average composition of crude petroleum is

$$C = 79.5 \text{ to } 87.1\%$$

$$H = 11.5 \text{ to } 14.8\%$$

$$S = 0.1 \text{ to } 3.5\%$$

$$N = 0.1 \text{ to } 0.5\%$$

Properties of Petroleum :-

- a) specific gravity.
- b) calorific value.
- c) Ignition point.
- d) viscosity.
- e) Moisture & sediment content.
- (f) Sulphur contents.
- (g) specific heat and coefficient of expansion.

Classification of Petroleum :-

It is classified into 3 types.

1. Paraffinic Base type crude petroleum :-

This type of Petroleum is mainly composed of the Saturated hydrocarbons from CH_4 to $\text{C}_{35}\text{H}_{72}$ and a little of the naphthenes & aromatics.

The hydrocarbons from $\text{C}_{18}\text{H}_{38}$ to $\text{C}_{35}\text{H}_{72}$, are called waxes.

2. Asphalitic Base type crude petroleum :

It mainly contains cycloparaffins or naphthenes with smaller amount of paraffins and aromatic hydrocarbons.

3. Mixed Base Type crude Petroleum :

It contains both paraffinic & asphalitic hydrocarbons and is generally rich in semi-solid waxes.

Origin of Petroleum :-

- According to Modern theory, Petroleum has resulted from the partial decomposition of marine animals and vegetable organisms of Pre-historic forests.
- Changes in earth (like volcano's etc) had buried these materials underground, where they have been subjected to intense pressure and heat, during the ages of time.
- By bacterial decomposition under anaerobic and strongly reducing conditions and temp. under high pressure, these materials are converted into hydrocarbons.

Refining of Crude Oil :-

The crude oil is separated into various useful fractions by fractional distillation and finally converted into desired specific products. The process is called "refining of crude oil" and the plant set up for the purpose, are called the oil refineries. The process of refining involves the following steps:-

1. Separation of water (Cottrell's process) :-

- The crude oil generally mixed with water.
- The colloidal water droplets coalesce to form large drops, which separate out from the oil fog froth flotation method.

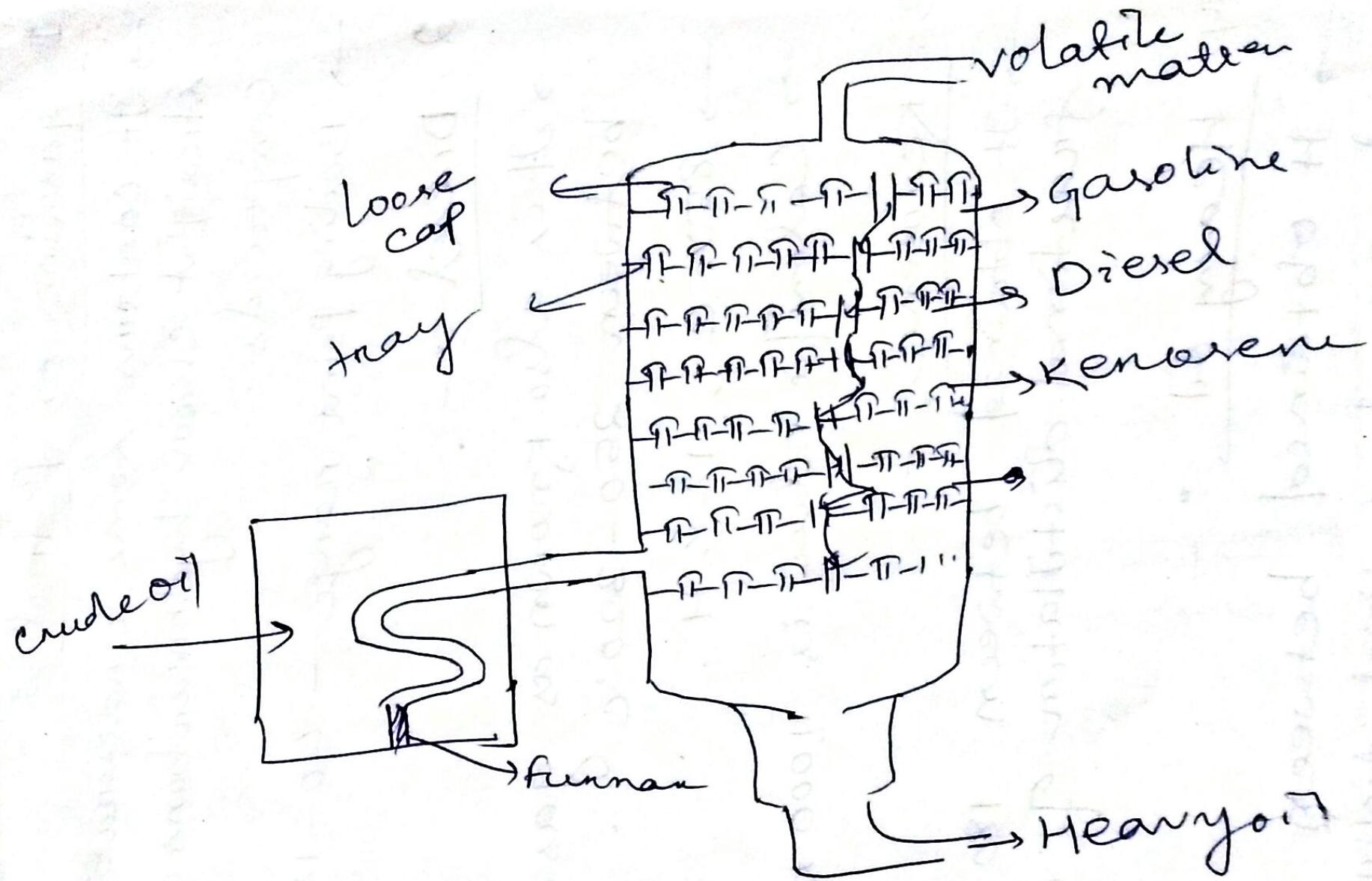
(2)

Step-2 :- Removal of harmful sulphur compounds:-

- Crude oil is treated with copper oxide.
- A reaction occurs with sulphur compounds, which results in the formation of Cu_2S (copper sulphide solid) which is then removed by filtration.

Step-3 :- Fractional distillation :-

- The crude oil is then heated to about $400^{\circ}C$ in an iron-retort, whereby all volatile constituents, except the residue are evaporated.
- The hot vapours are then passed up a "fractionating column", which is a tall cylindrical tower containing a number of horizontal stainless steel trays at short distances.
- Each tray is provided with small chimney, covered with a loose cap.
- As the vapours go up, they become gradually cooler and fractional condensation takes place at different height of column.
- Higher boiling fraction condenses first; while the lower boiling fractions turn-by-turn.



Knocking :-

In IC engines, the gasoline and air drawn into the cylinder is compressed by the piston & ignited by an electric spark. As the flame front travels towards the feed end of the combustion chamber, rapidly expanding combustion gases and compress the remaining unburnt fuel ahead of flame front & raise its temperature.

- If the flame front travels rapidly at optimum speed, the combustion of unburnt fuel takes but smoothly.
- If the flame front travels too slowly, the entire last portion of the fuel-air mixture may get heated up beyond its ignition temp. and undergoes instantaneous explosive combustion.
- This produces thermal shock wave which hits the cylinder walls and piston. This result in emitting of characteristic rattling sound called Knocking or pinking.
- The tendency of Knocking increases with CR. (compression Ratio)
- n-alkanes > mono substituted alkanes > cycloalkanes > alkenes > poly substituted alkanes > aromatics.
- It depends on the engine design, shape of head, location of plug.

Anti-Knocking :-

The octane rating of gasoline samples can be increased by the addition of certain organometallic compounds called anti-knocking agents and the process is called "doping".

Example - tetraethyl lead (TEL).

Mechanism :-

- (i) About 0.5 ml of TEL per litre is added for motor-fuel and about 1 ml of TEL per litre is generally added for aviation petrol. It is believed that during combustion of gasoline, TEL forms Pb & PbO .
- (ii) These species act as free-radical chain inhibitors and thus minimize knocking.
- (iii) TEL is always used with ethylene dibromide or ethylene dichloride in order to minimize the air pollution and damage to engine parts.

Cetane Number :-

It is an indicator of the combustion speed of diesel fuel and compression needed for ignition.

→ It is an important factor in determining the quality of diesel fuel, but not the only one; other measurement of diesel's quality include energy content, density, lubricity, cold-flow properties and sulphur content.

The main operation procedure of diesel engine is -

- (i) Inside the cylinder, air is drawn.
- (ii) The pressure of the compressed air inside the chamber is driven up to 50 kg/m^2 , which leads to rise in temp. up to 500°C .

Producer Gas :-

- It is essentially a mixture of carbon-monoxide and nitrogen.
- It is prepared by passing air mixed with little steam over a red hot coal bed maintained at about 1100°C .
- The average composition of Producer gas is as follows:
- $\text{CO} : 25 - 30\%$, $\text{N}_2 : 50 - 55\%$, $\text{H}_2 : 10\%$, $\text{CO}_2 : 5\%$.
- Hydrocarbons : 2-3%.
- The calorific value of Producer gas is $(4000 - 5000 \text{ KJ/m}^3)$.

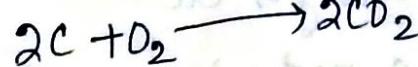
Manufacture :-

The producer is charged with coke from the top and the charge is heated to about 1100°C . A mixture of air and steam is passed over red hot coke bed through inlet at the bottom. The producer gas goes out through the outlet at the top.

Reactions that take place in Different Zones of the Fuel Bed :-

1. Oxidation Zone :

This is the lowest part of the coke bed. Here, the carbon of the coke burns in presence of excess of air to give carbon dioxide.



$$\Delta H = -393.5 \text{ KJ}$$

2. Reduction Zone : Carbon dioxide produced in the oxidation zone then rises through the hot bed and is reduced by COKE to CO.

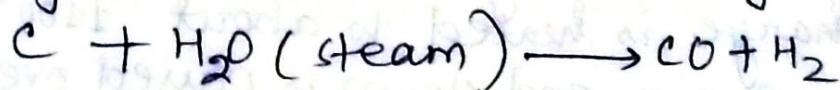


$$\Delta H = -173.5 \text{ kJ}$$

The overall reaction in the formation of CO being exothermic, the fuel bed gets heated up beyond 1100°C.

At high temp, the ash forms clinkers which are rather difficult to remove so the grate bars and refractory lining get distorted.

→ In order to avoid these problems in the Producer, a reduction in temp. is achieved by passing air saturated with steam instead of air alone. In reduction zone, steam gets reduced to water gas.



$$\Delta H = 131.4 \text{ kJ}$$

This endothermic reaction brings down the temperature to the optimum level.

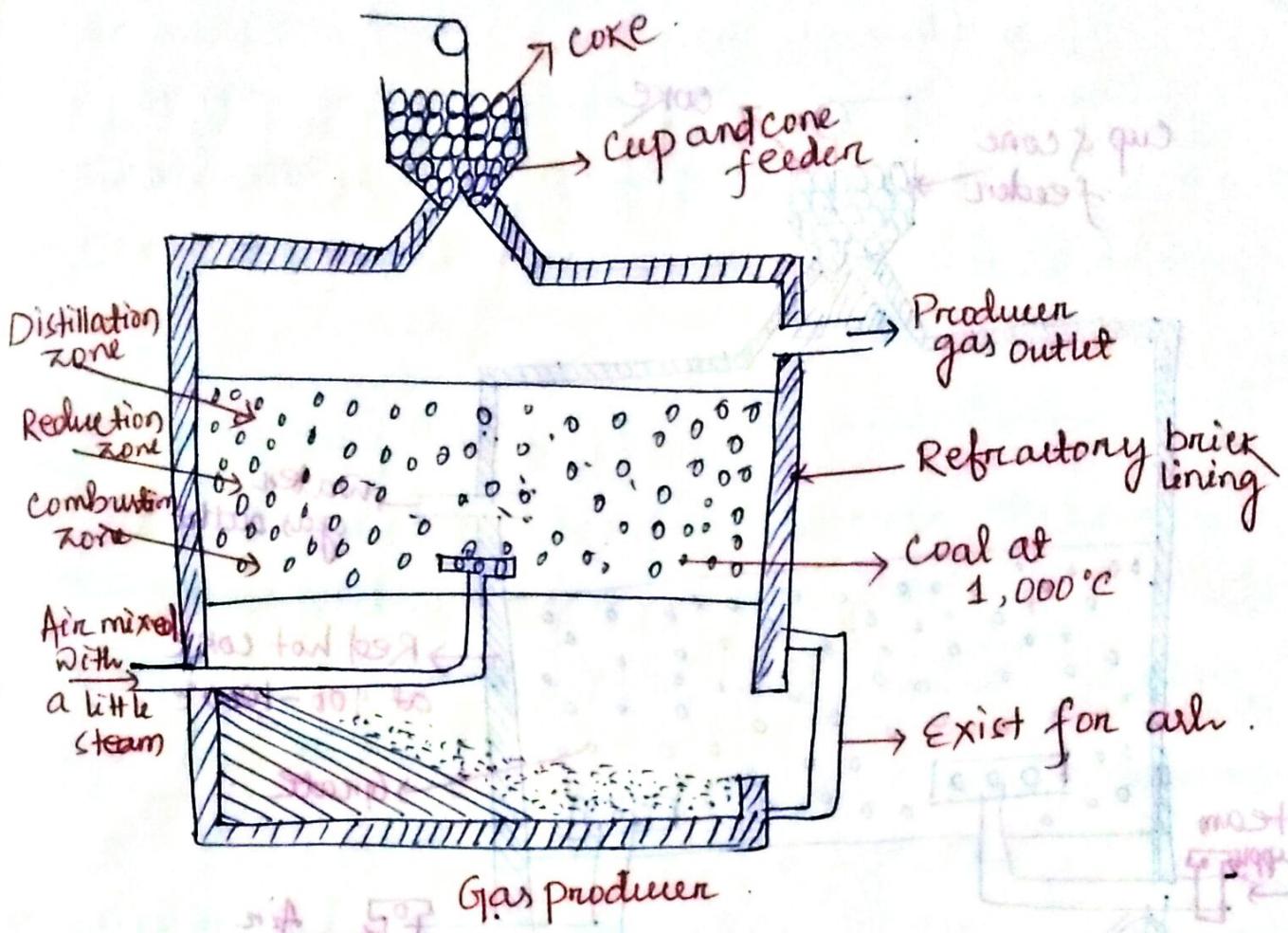
Q. Distillation zone:

This is the upper most part of the fuel bed, where the distillation of volatile matter of coke or coal occurs.

Its calorific value is 1300 kcal/m³.

Uses :-

- (i) It is used as a fuel in the manufacture of steel, glass, coalgas etc.
- (ii) It is used as a reducing agent in metallurgical operations.



Water Gas :-

- (i) It is essentially a mixture of combustible gases, CO & H_2 .
- (ii) It is also known as blue gas because it burns with a blue flame due to combustion of carbon monoxide.
- (iii) The calorific value of water gas is about $10,000 - 11,000 \text{ KJ/m}^3$.
- (iv) The average composition of water gas is as follows :

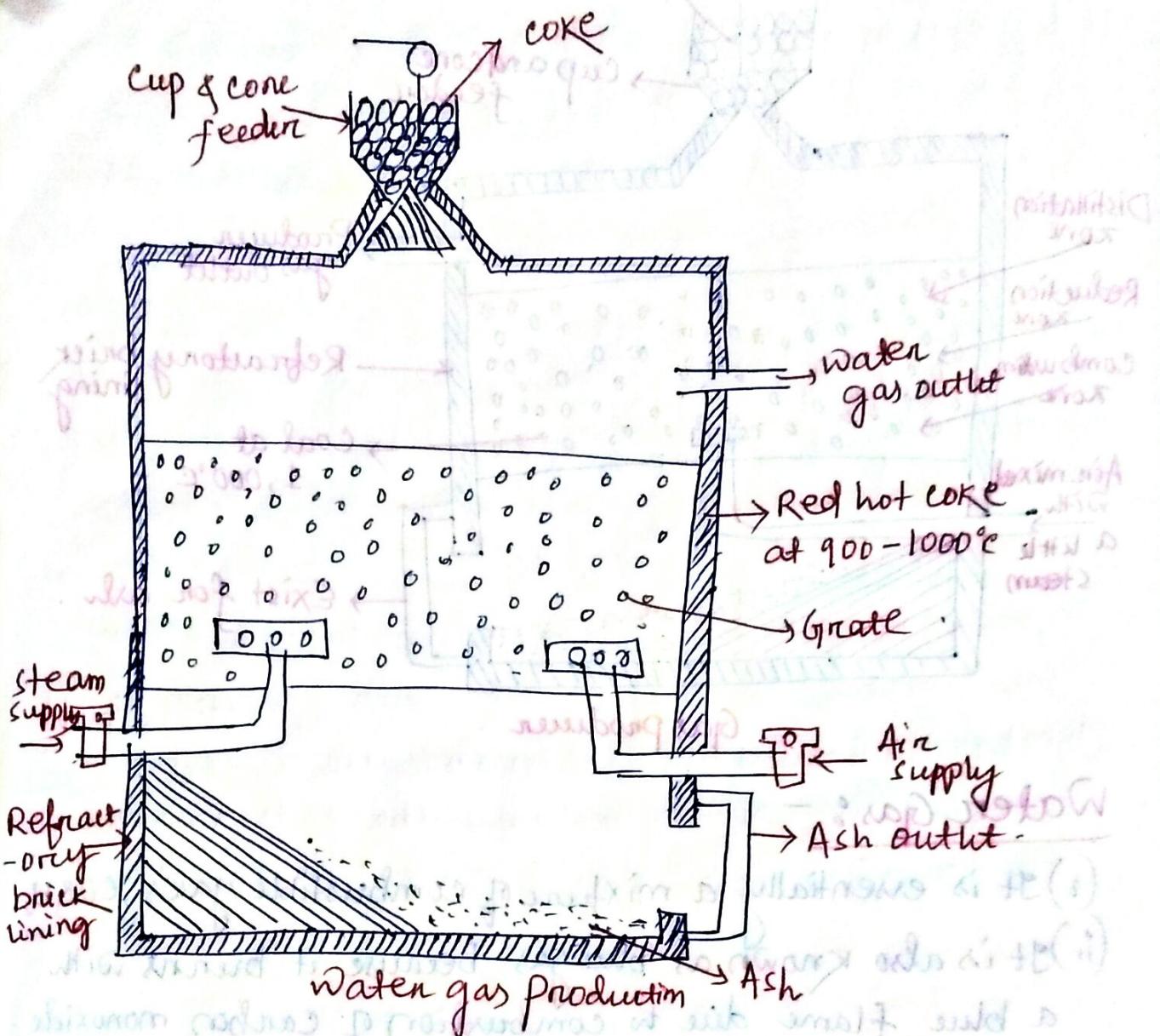
$\text{CO : 40-45\% ; H}_2 : 45-50\% ; \text{CO}_2 : 4\%$.

$\text{N}_2 : 4\%$.

Manufacture :-

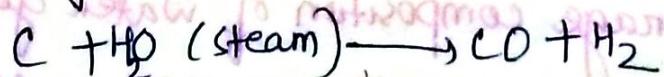
It is produced by passing steam and little air alternatively through a bed of red hot coke maintained at 1000°C .





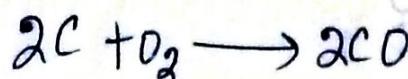
Principle :-

When steam is blown through a bed of hot coke (1000°C) water gas is produced:



$$\Delta H = 131.4 \text{ kJ}$$

This reaction being endothermic in nature, the temp. of the coke bed gradually decreases with continuous passage of steam and the drop in temp. must be prevented.



$$\Delta H = -221.9 \text{ kJ}$$

The reaction being exothermic increases the temp. of the coke bed to about 1000°C . Thus by blowing steam and air alternatively, the temp. of the coke bed can be maintained at 1000°C .

Uses :-

- (i) It is used for the production of hydrogen.
- (ii) It is extensively used for the manufacture of methyl alcohol and synthetic petrol.
- (iii) It is used as fuel in glass & ceramic industries.
- (iv) L.P.G :- (Liquified Petroleum Gas)

LPG gas can be obtained as a by-product during cracking of heavy oils or from Natural Gas. LPG is dehydrated, desulphurised and traces of odorous organic sulphides are added to give 'warning' of gas leak.

Properties :-

- (i) The gas is highly volatile.
- (ii) It burns with a blue flame in the burner of the cooking stove.
- (iii) It is supplied under the trade name like Indane, Bharat gas etc.
- (iv) Its calorific value is ($27,800 \text{ Kcal/m}^3$ or 50 kJ/g)
- (v) It is highly inflammable.

Average composition :-

n -butane = 27%, iso-butane = 25%, Butene = 43%,

Propene = 2.5%, Propane = 2.5%.

Uses :-

- (i) Used as domestic fuel & industrial fuel.
- (ii) Used as a motor fuel.

CNG :- compressed natural Gas

- (i) It is a natural gas under pressure which remains clear, odourless and non-corrosive.
- (ii) It is safer than other fuels in the event of a spill, because natural gas is lighter than air and disperses quickly when released.
- (iii) It is made by compressing natural gas which is composed of methane, CH_4 .
- (iv) It is usually in cylindrical or spherical shapes.

Properties :-

- (i) It burns with a pale blue flame liberating large amount of heat.
- (ii) Its calorific value is 12500 kcal/m^3 .

Average composition :-

$$\text{CH}_4 (\text{Methane}) = 70 - 90\%$$

$$\text{C}_2\text{H}_6 (\text{Ethane}) = 4 - 9\%$$

Uses :-

- (i) It is used as a fuel for vehicles.
- (ii) It is also used as a domestic and industrial fuel.
- (iii) It is also used as a filter in the manufacture of tyres.
- (iv) It is used for the production of hydrogen gas in the fertilizer industry.

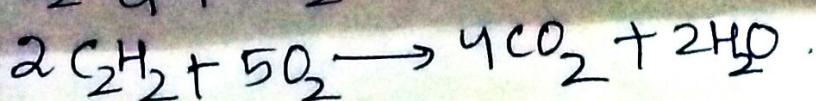
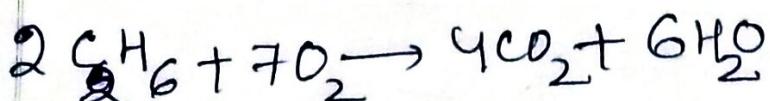
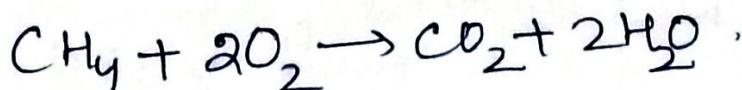
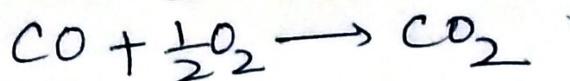
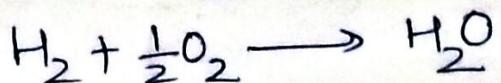
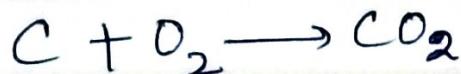
Combustion

It is a type of chemical process by which the liberation of heat and light takes place.

→ To ensure complete combustion, the substance must be brought to its ignition temperature.

Ignition Temp. :-

The minimum temp. at which the substance ignites and burns without further addition of heat from outside.



N_2 and air present in fuel are non-combustible matters and hence do not consume any oxygen.

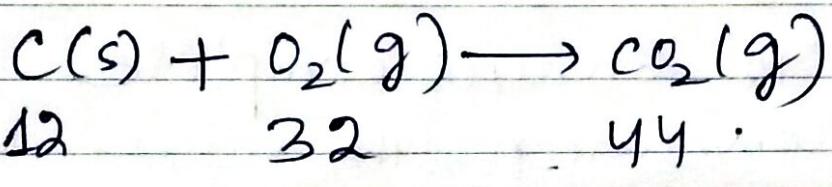
Calculation of air qualities:

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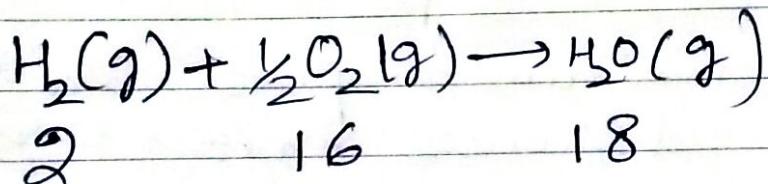
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Example :-

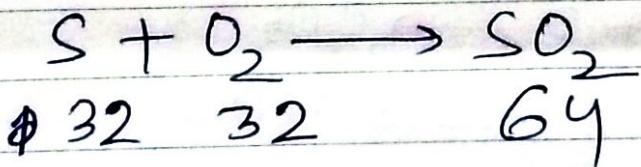
When 'C' combines with O_2 to form CO_2 . The eqn is.



→ When 'H' combines with O_2 to form steam, the eqn.



→ When Sulphur combines with O_2 to form SO_2 .



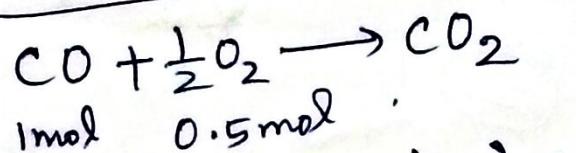
Now, % of air required

$$\frac{\text{Net amount of air used}}{\text{Weight of } O_2} \times 100$$

Q.2 Calculate the volume of air required for complete combustion of 1m^3 of gaseous fuel having the composition : $\text{CO} = 48\%$, $\text{CH}_4 = 8\%$, $\text{H}_2 = 40\%$, $\text{C}_2\text{H}_2 = 2\%$, $\text{N}_2 = 1\%$.

Here, volume [$1\text{litre} = 1000\text{ml}$]

$$\begin{array}{l|l} 48\% & 0.48 \text{ mol} \\ 8\% & 0.08 \text{ mol} \\ 40\% & 0.40 \text{ mol} \end{array} \quad \begin{array}{l} \text{C}_2\text{H}_2 = 2\% \\ = 0.02 \end{array}$$



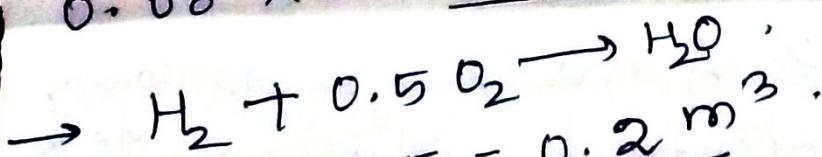
$$1\text{mol of CO required} = 0.5 \text{ mol of O}_2$$

$$0.48 \text{ mol of "} \quad " = 0.5 \times 0.48$$

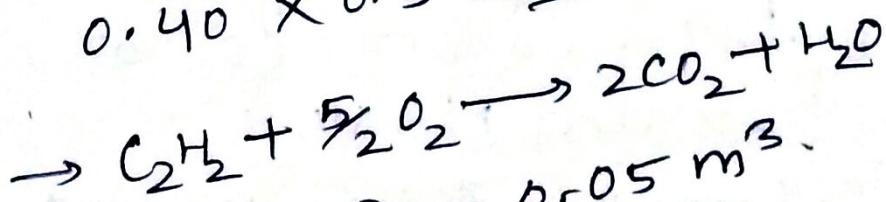
$$= \underline{\underline{0.24 \text{ m}^3}}$$



$$0.08 \times 2 = \underline{\underline{0.16 \text{ m}^3}}$$



$$0.40 \times 0.5 = \underline{\underline{0.2 \text{ m}^3}}$$



$$0.02 \times \frac{5}{2} = \underline{\underline{0.05 \text{ m}^3}}$$

Total volume of O_2 required

$$= 0.24 + 0.16 + 0.2 + 0.05$$

$$= 0.65 \text{ m}^3$$

$$\therefore \text{Vol. of air required} = \frac{0.65 \times 100}{21}$$

$$= \boxed{3.09524 \text{ m}^3}$$