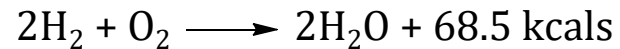
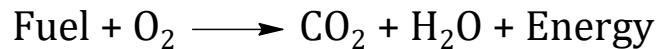


- **Fuel:** It is a combustible substance, containing carbon as a main constituent, which on proper burning gives a large amount of heat, which can be used economically for domestic and industrial purposes.
- Examples: Wood, charcoal, coal, kerosene, petrol, diesel, producer gas, oil gas, etc.
- During the process of combustion, carbon, hydrogen, etc., combine with oxygen with liberation of a large amount of heat energy.
- The combustion reaction can be explained as



- In a nutshell,



- The calorific value of fuel depends mainly on the amount of Carbon and Hydrogen
- **Fossil fuels:** Non-renewable energy resources, which are derived from the fossil remains of dead plants and animals e.g., coal, crude oil, and natural gas
- **Renewable source of energy:** one which is inexhaustible. Example: Solar energy.
- **Non-renewable source of energy:** one which is exhaustible. Example: Fossil Fuels.

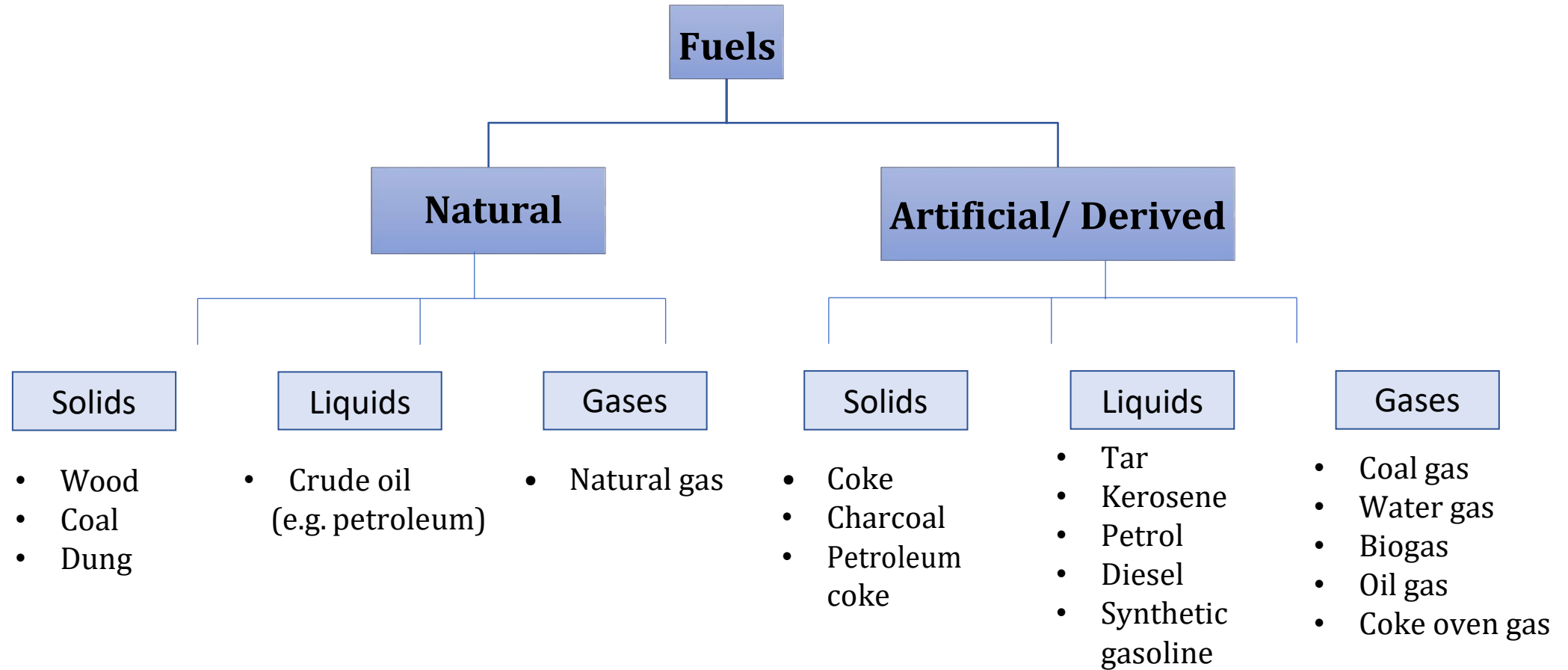
❖ **Characteristics of good/ ideal fuel:**

- i. Fuel should have a high calorific value
- ii. Must have moderate ignition temperature
- iii. Fuel should have a low moisture content
- iv. Should have low contents of non-combustible matter
- v. Available in bulk at low cost
- vi. Should not burn spontaneously
- vii. Must be free from objectionable and harmful gases like CO, SO<sub>x</sub>, H<sub>2</sub>S
- viii. Fuel should burn efficiently, without releasing hazardous pollutants
- ix. Handling, storage, and transportation should be easy

❖ **Units of heat:**

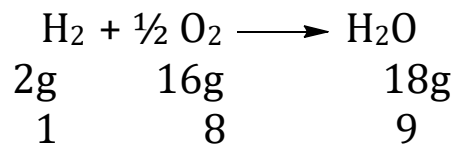
- i. **Calorie:** it is the amount of heat required to raise the temperature of 1 g of water through one-degree centigrade.
- ii. **British Thermal Unit (BTU):** it is the amount of heat required to raise the temperature of 1 pound of water to one degree Fahrenheit.  $1 \text{ B.T.U.} = 252 \text{ cal} = 0.252 \text{ kcal}$ ;  $1 \text{ kcal} = 3.968 \text{ B.T.U.}$
- iii. **Centigrade Heat Unit (CHU):** it is defined as the amount of heat required to raise the temperature of 1 pound of water to one degree centigrade.  $1 \text{ kcal} = 3.968 \text{ B.T.U.} = 2.2 \text{ C.H.U.}$

❖ **Classification of fuels:**



## Calorific Values

- **Calorific value** of fuel can be defined as the amount of heat evolved when one unit mass or volume of the fuel undergoes complete combustion in the presence of oxygen. It is the most important characteristic property of any fuel.
- Different expressions for calorific value:
  - Gross or High Calorific Value (GCV or HCV):** The total heat generated when a unit quantity of fuel is completely burnt and the products of combustion are cooled to room temperature (25 °C or 77 °F).
  - Net or Low Calorific Value (NCV or LCV):** The net heat produced when a unit quantity of fuel is completely burnt and the products of combustion are allowed to escape.
    - ❖ Therefore, the net calorific value is always lower than the gross calorific value by the amount corresponding to the heat of condensation of water vapors, i.e., 587 kcal/kg
    - ❖  $\text{LCV} = \text{HCV} - \text{latent heat of water vapor}$
    - ❖  $\text{LCV} = \text{HCV} - \text{mass of hydrogen} \times 9 \times \text{latent heat of steam (587 kcal/kg)}$
    - ❖ 1 part by weight of H<sub>2</sub> produces 9 parts by weight of H<sub>2</sub>O as follows:



Thus,

$$\text{LCV} = \text{HCV} - \frac{H}{100} \times 9 \times 587 \text{ kcal/kg}$$

$$\text{LCV} = \text{HCV} - 0.09 H \times 587 \text{ kcal/kg}$$

where, H = % of H<sub>2</sub> in the fuel.

- **Units of calorific value:**
- The calorific value is either expressed in either calorie/gram (cal/g) or kilocalorie/kg (kcal/kg) or British thermal unit/lb (B.T.U./lb) in the case of a solid or a liquid fuel
- In the case of gaseous fuels, the units are kcal/m<sup>3</sup> or B.T.U./ft<sup>3</sup>

- **Theoretical Calculation of Calorific Value:**

- **Dulong's formula:** based on the percentage of the constituents (C, H, O, and S) present in the fuel

$$\text{GCV (or) HCV} = 1/100 (8080C + 34500 [H - O/8] + 2240S) \text{ kcal/kg}$$

where, C, H, O & S represent the % of the corresponding elements in the fuel

- It is based on the assumption that the calorific values of C, H & S are found to be 8080, 34500, and 2240 kcal, when 1 kg of the fuel is burnt completely.
- However, all the oxygen in the fuel is assumed to be present in combination with hydrogen as water (fixed hydrogen) in the ratio H : O as 1 : 8 by weight. So, the surplus hydrogen available for combustion is  $H - O/8$ .

- ❖ Fixed hydrogen = *Mass of oxygen in the fuel / 8*

- ❖ Then the amount of hydrogen available for combustion

= total mass of hydrogen in fuel – fixed hydrogen

=  $[H - O/8]$

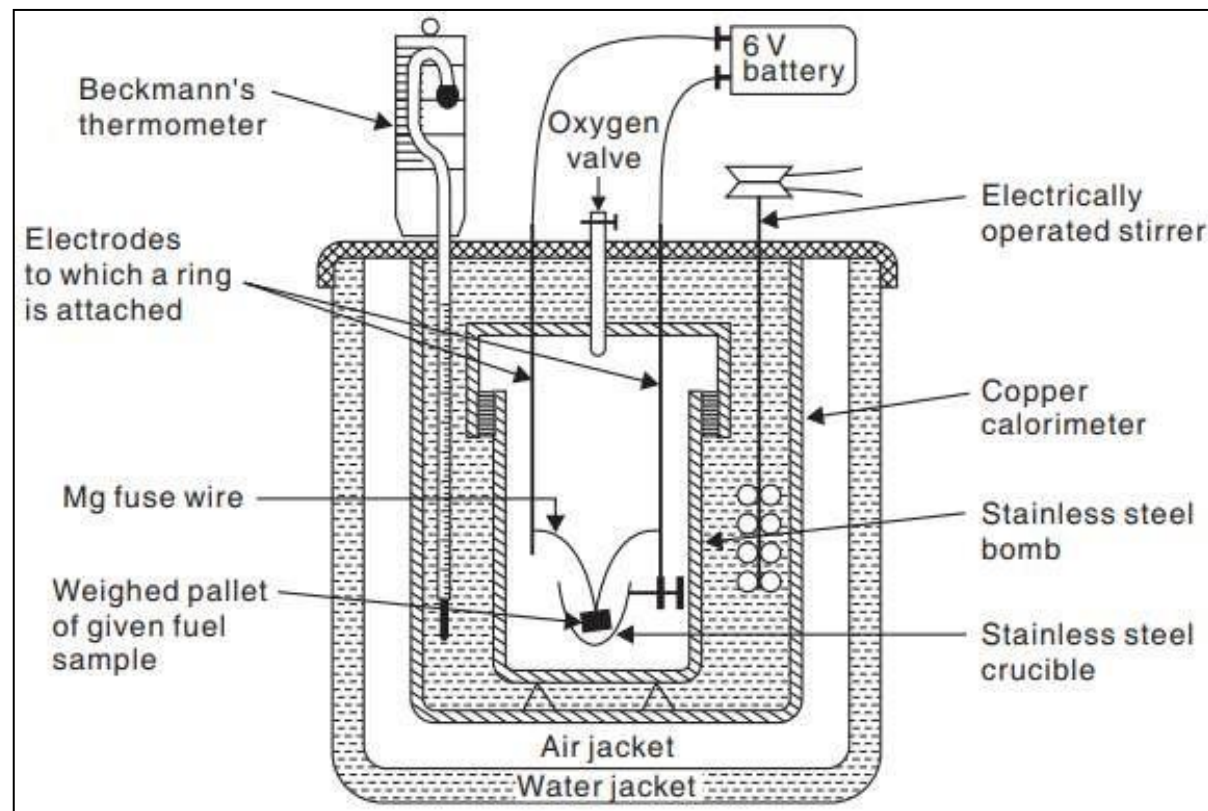
And **LCV = HCV –  $H/100 \times 9 \times 587$  kcal/kg**

## Determination of calorific value:

I. **Bomb Calorimeter:** The apparatus used to determine the calorific value of solid and liquid fuels.

- **Description of the apparatus:**

- A bomb calorimeter contains a cylindrical bomb made by stainless steel inside which combustion of the fuel takes place.
- The lid is screwed to the bomb to make it air tight. The lid contains two stainless steel electrodes and an oxygen inlet valve through which oxygen is supplied for combustion. The electrode is attached with a small ring which supports nickel or stainless steel made crucible, where the sample is placed.
- The bomb is taken in a copper calorimeter containing a known weight of water. The copper calorimeter is also surrounded by air and water jacket in order to prevent the heat loss by radiation.
- The copper calorimeter also contains electrically operated stirrer and Beckmann's thermometer (take reading with temperature difference up to  $0.01^{\circ}\text{C}$ ).



Bomb Calorimeter

- **Working of the Bomb Calorimeter:**

- In a crucible, a known amount of the fuel is placed in the nickel or stainless-steel crucible which is supported by a ring.
- A fine magnesium wire touches the fuel sample, which is already connected to the electrodes.
- The bomb lid lightly screwed and filled with oxygen at about 25 atm pressure, is placed in a copper calorimeter containing a known amount of water.
- The electrically operated stirrer is driven and the initial temperature of water ( $T_1$ ) is recorded.
- After that both the electrodes are connected to a 6V battery to complete the circuit. The fuel sample is burnt and heat is liberated, which raises the temperature of water in the calorimeter.
- To maintain the uniform temperature, water is continuously stirred and the final temperature ( $T_2$ ) of water is noted.



- The calorific value of the fuel can now be calculated as follows:

Mass of fuel (solid or liquid) =  $x$  g

Mass of water taken in the calorimeter =  $W$  g

Water equivalent of calorimeter =  $w$  g

Initial temperature of water in calorimeter =  $T_1$  K

Final temperature of water in calorimeter =  $T_2$  K

High or gross calorific value =  $L$

Heat absorbed by water =  $W(T_2 - T_1)$  cal

Heat absorbed by calorimeter =  $w(T_2 - T_1)$  cal

Heat absorbed by water and calorimeter =  $W(T_2 - T_1) + w(T_2 - T_1) = (W + w)(T_2 - T_1)$  cal

The heat liberated by fuel =  $x \times L$

Therefore, the heat liberated by fuel = heat absorbed by water, and the calorimeter

$$x \times L = (W + w)(T_2 - T_1) \text{ cal}$$

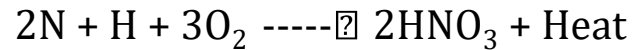
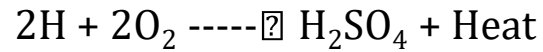
$$L \text{ (HCV)} = (W + w)(T_2 - T_1) / x \text{ cal/g}$$

The water equivalent of a calorimeter can be determined by burning a fuel of known calorific value and using the above equation, e.g. benzoic acid (HCV = 6325 kcal/kg) and naphthalene (HCV = 9688 kcal/kg)

- **Correction factors** used to get more accurate results:

i. **Fuse wire correction:** Heat liberated during sparking should be subtracted from the heat liberated

ii. **Acid correction:** During ignition S and N present in the fuel get oxidized to the corresponding acids: S +



Formation of these acids is an exothermic process and hence, should be subtracted from the heat liberated

iii. **Cooling correction:** When the bomb calorimeter is allowed to cool from maximum temperature to room temperature, some amount of heat is radiated. From the rate of cooling the and actual time of cooling, cooling correction is made and is added to the temperature difference.

Therefore, 
$$L \text{ (HCV)} = (W + w) (T_2 - T_1 + \text{cooling correction}) - (\text{Acid} + \text{fuse correction}) / x \text{ cal/g}$$

**II. Boy's Gas Calorimeter:** The apparatus used to determine the calorific value of gaseous and liquid fuels.

- A known volume of gas is burnt at a uniform rate by a burner.
- Around the burners, there is a chimney containing coils, wherein water at a constant rate is passed.
- Separate thermometers measure the incoming and outgoing temperatures of water ( $t_1$  and  $t_2$ ).

Let  $V$  = volume of gas burning.

$W$  = mass of cooling water used in time  $t$ .

$t_1$  and  $t_2$  = Incoming and outgoing water temperatures

$m$  = mass of steam condensed in time  $t$ .

$L$  = HCV.

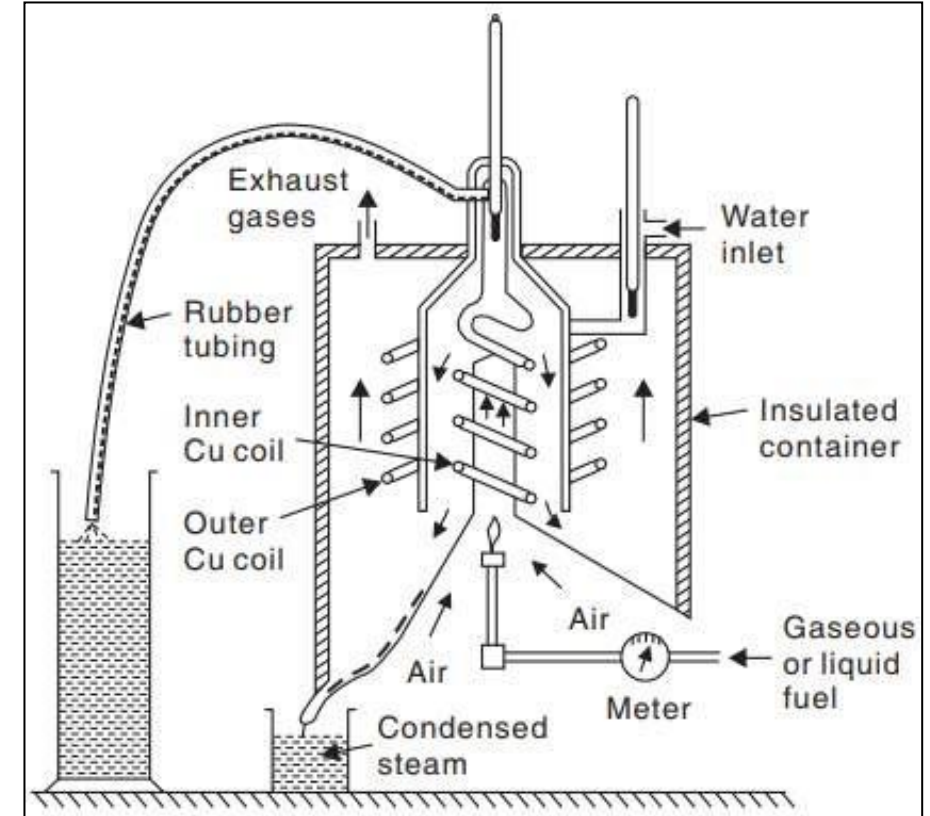
$$\text{We get } L = \frac{W(t_2 - t_1)}{V}$$

Mass of  $\text{H}_2\text{O}$  condensed per  $m^3$  of gas =  $m/V$  kg

Latent heat of steam per  $m^3$  of gas

$$= \frac{m \times 587}{V} \text{ kcal}$$

$$\therefore \text{NCV} = \left[ L - \frac{m \times 587}{V} \right] \text{ kcal/m}^3.$$



Boy's Gas Calorimeter

- **SOLID FUELS:**

- **Examples:** wood, coal, charcoal, coke

- **Advantages of Solid fuels**

1. Handling and transportation of solid fuels is easy
2. Solid fuels are cheap and easily available
3. They have a moderate ignition temperature
4. This type of fuel can be stored conveniently without any risk

- **Disadvantages of solid fuels:**

1. During burning, solid fuels produce a large amount of ash, and disposal of ash is a big problem
2. The calorific value of solid fuel is comparatively low
3. Since a lot of air is required for complete combustion, its thermal efficiency is not so high
4. Combustion is a slow process and it cannot be easily controlled
5. A large space is required for storage

## I. WOOD

- Wood is derived from trunks and branches of trees
- It contains lignocellulose- wood pulp mainly consists of  $\alpha$ -cellulose and a very small amount of  $\beta$ -cellulose, resins and proteins
- It contains about 15% moisture after air-drying
- Average composition on moisture free basis: C = 50%, H = 6%, O = 43% and ash = 1%
- Calorific value: 4000-6400 BTU/lb
- Mainly used as domestic fuel

## II. COAL

- Important primary solid fuel, derived from prehistoric plants
- Highly carbonaceous and composed of C, H, N, O and non-combustible inorganic matter
- It is formed as a result of alteration of vegetable matter under some favorable conditions through a continuous process extended over millions of years
- Vegetable matter, under the action of pressure, heat and anaerobic conditions, gets converted into different stages of coal:

Wood  $\rightarrow$  peat  $\rightarrow$  lignite  $\rightarrow$  sub-bituminous coal  $\rightarrow$  bituminous coal  $\rightarrow$  anthracite

- The process of conversion of lignite to anthracite is called **coalification (or) metamorphism of coal**.

- Coal is classified on the basis of its rank. The rank of coal denotes its degree of maturity.
- With the progress of coal forming reaction, moisture content and oxygen content reduces and % of carbon increases. Also calorific value increases from peat to bituminous. (see Table)
- Peat is the most immature coal, hence it is lowest in rank where as anthracite is the most matured coal, and hence it is highest in rank.
- Peat deposits are found in Nilgiri hills, lignites occur in Assam, Kashmir, Rajasthan and Tamil Nadu. Bituminous coal are found in Bihar, Bengal, M.P., Chhattisgarh and Orissa, while anthracites are found in Kashmir and eastern Himalayas.

Fuel	Nature	Calorific value k.cals/kg	Composition %	Uses
Peat	Highly fibrous light brown in colour	4000 - 5400	C = 57 H = 06 O = 35	Domestic fuel, power generation
Lignite	Fibrous, brown coloured coal	6500 - 7100	C = 67 H = 05 O = 26	Manufacture of producer gas & steam
Sub-bituminous coal	Black coloured, homogenous smooth mass,	7000 - 7500	C = 77 H = 05 O = 16	Manufacture of gaseous fuels
Bituminous coal	Black, brittle, burns with yellow smoky flame	8000 - 8500	C = 83 H = 05 O = 10	Power generation, coke making, domestic fuel
Anthracite	Hard & most matured coal, burns without smoke	8500 - 8700	C = 93 H = 03 O = 03	Boiler heating, metallurgical furnace

- **Classification of coal:**

- a) Peat**

1. Peat is the first stage in the formation of coal.
2. Its calorific value is about 4000-5400 kcal/kg.
3. It is an uneconomical fuel due to its high proportion of (80 - 90%) moisture and lower calorific value.
4. It is a brown fibrous mass.

- b) Lignite**

1. Lignite is an intermediate stage in the process of coal formation.
2. Its calorific value is about 6500-7100 kcal/kg.
3. Due to the presence of high volatile content, it burns with a long smoky flame.

- c) Bituminous coal**

- Bituminous coal is further sub-classified on the basis of its carbon content into three types:
  - i) Sub-bituminous coal
  - ii) Bituminous coal
  - iii) semi-bituminous coal

- d) Anthracite**

1. Anthracite is the superior grade of coal.
2. Its volatile, moisture and ash contents are very less.
3. Its calorific value is about 8650 kcal/kg.

- **Analysis of coal:** The quality of coal can be assessed by two analyses:

i. Proximate analysis                      ii. Ultimate analysis

**i. Proximate analysis:**

- It determines the weight percentage of volatile carbonaceous matter, fixed carbon, ash and moisture of the air-dried coal
- This analysis gives the approximate composition of the main constituents of coal
- It is useful in deciding its utilization for a particular industrial use

**a) *Determination of moisture content in coal:*** About 1 g of powdered, air-dried coal sample is heated in a silica crucible placed inside an electric hot air oven at 105 to 110 °C for one hour. The crucible is then taken out, cooled in desiccators, and weighed. The percentage of moisture can be calculated from the loss in weight of the coal sample as:

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

➤ Lesser the amount of moisture content, the better the quality of fuel.



**b) *Determination of volatile material in coal:*** The moisture free coal sample is taken in a crucible, covered with a lid and placed in a muffle furnace (electric furnace) at  $950 \pm 20$  °C for 7 minutes and then the crucible is removed from the oven and cooled first in air, then cooled in a desiccator and weighed again. The percentage of volatile matter can be calculated from the loss in weight of the coal sample as:

$$\% \text{ of volatile matter in coal} = \frac{\text{Loss in weight of moisture free coal}}{\text{The weight of coal initially taken}} \times 100$$

➤ Low quantity of volatile matter, better the quality of coal.

**c) *Determination of ash in coal:*** The residual coal sample was taken in a crucible and then heated without a lid in a muffle furnace at  $700 \pm 50$  °C for an hour or two. The crucible is then taken out, cooled first in the air, then in desiccators, and weighed again. The process of heating, cooling, and weighing are repeated until a constant weight is not obtained. The residue is reported as ash on a percentage basis. The percentage of ash content can be calculated from the loss in weight of the coal sample as:

$$\% \text{ of ash in coal} = \frac{\text{Weight of ash formed}}{\text{Weight of coal taken}} \times 100$$

➤ Ash is a non-combustible substance that reduces the calorific value of coal. Therefore, a low quantity of ash contents, better the quality of coal.

c) **Determination of fixed carbon:** It is determined by subtracting the sum of total moisture, volatile, and ash contents from 100.

$$\% \text{ of fixed carbon} = 100 - (\% \text{ of moisture} + \% \text{ of volatile matter} + \% \text{ of ash})$$

➤ Greater the calorific value, higher the % of fixed carbon.

- **Significance of proximate analysis:**

- **Moisture:** High moisture content in coal is undesirable because it,

- i) Reduces Calorific Value of coal

- ii) Increases the consumption of coal for heating purpose

- iii) Lengthens the time of heating.

➤ Hence, lesser the moisture content, better is the quality of coal.

- **Volatile Matter:** During burning of coal, certain gases like CO, CO<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub>, hydrocarbons etc. that come out are called volatile matter of the coal. The coal with higher volatile content,

- i) Ignites easily (i.e : it has lower ignition temperature)

- ii) Burns with long yellow smoky flame

- iii) Has lower Calorific Value

- iv) Will give more quantity of coal gas when it is heated in absence of air.

❖ **Ash:** Ash is the combustion product of mineral matters present in the coal. It consists mainly of  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  with varying amounts of other oxides such as  $\text{Na}_2\text{O}$ ,  $\text{CaO}$ ,  $\text{MgO}$  etc.

➤ Ash containing oxides of Na, Ca and Mg melt early (Low melting ash). During coke manufacture, the low melting ash forms a fused lumpy - expanded mass which block the interspaces of the 'grate' and thereby obstructing the supply of air leading to irregular burning of coal and loss of fuel.

➤ High ash content in coal is undesirable because it

i) increases transporting, handling, storage costs

ii) is harder and stronger

iii) has a lower calorific value.

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

## ii. Ultimate analysis:

- It means finding out the weight percentage of carbon, hydrogen, nitrogen, oxygen and sulphur of the pure coal free from moisture and inorganic constituents.
- This analysis gives the elementary constituents of coal.
- It is useful to the designer of coal-burning equipment and auxiliaries.

**a) Determination of carbon and hydrogen in coal:** A known amount (1 – 2 g) of coal is burnt in the presence of oxygen thereby by converting carbon and hydrogen of coal into  $\text{CO}_2$  ( $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$ ) and  $\text{H}_2\text{O}$  ( $\text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{O}$ ) respectively. The products of combustion ( $\text{CO}_2$  and  $\text{H}_2\text{O}$ ) are made to pass over weighed tubes of anhydrous  $\text{CaCl}_2$  and  $\text{KOH}$ , which absorb  $\text{H}_2\text{O}$  and  $\text{CO}_2$  respectively. The increase in the weight of the  $\text{CaCl}_2$  tube represents the weight of water formed while increase in the weight of  $\text{KOH}$  tube represents the weight of  $\text{CO}_2$  formed. % of carbon and hydrogen in coal can be calculated as follows.

Let X – be the weight of the coal sample taken; Y – be the increase in the weight of the  $\text{KOH}$  tube; Z – be the increase in the weight of the  $\text{CaCl}_2$  tube

**i Carbon:**  $\text{C} (12) + \text{O}_2 (32) \rightarrow \text{CO}_2 (44)$

☐ 44 g of  $\text{CO}_2$  contain 12 g of carbon

☐ 1 g of  $\text{CO}_2$  contains  $12/44$  g of carbon

☐ Y g of  $\text{CO}_2$  contains  $= (12 \times Y)/44$  g of carbon

☐ % of C in coal  $= \{(12 \times Y) / (44 \times X)\} \times 100$

**ii. Hydrogen:**  $\text{H}_2 (2) + \frac{1}{2} \text{O}_2 (16) \rightarrow \text{H}_2\text{O} (18)$

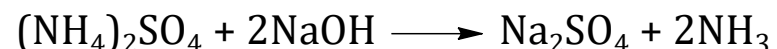
=> 18 g of water contains 2 g of hydrogen

=> 1 g of water contains  $2/18$  g of hydrogen

=> Z g of water contains  $= (2 \times Z)/18$  g of hydrogen

=> % of H in coal  $= \{(2 \times Z) / (18 \times X)\} \times 100$

**b) Determination of nitrogen in coal:** Nitrogen estimation is done by Kjeldahl's method. A known amount of powdered coal is heated with conc.  $\text{H}_2\text{SO}_4$  and  $\text{K}_2\text{SO}_4$  in a long-necked flask (called Kjeldahl's flask), thereby converting the nitrogen of coal to ammonium sulfate. When the clear solution is obtained (i.e. the whole nitrogen is converted into ammonium sulfate), it is heated with 50% NaOH solution.



The ammonia thus formed is distilled over and absorbed in a known quantity of standard 0.1N HCl solution. The volume of unused 0.1N HCl is then determined by titrating against standard NaOH solution. Thus, the amount of acid neutralized by liberated ammonia from coal is determined.

Let, Volume of 0.1N HCl = A mL; Volume of unused HCl = B mL; Acid neutralized by ammonia = (A - B) mL We know

that 1000 mL of 1N HCl = 1 mole of HCl = 1 mole of  $\text{NH}_3$  = 14 g of  $\text{N}_2$

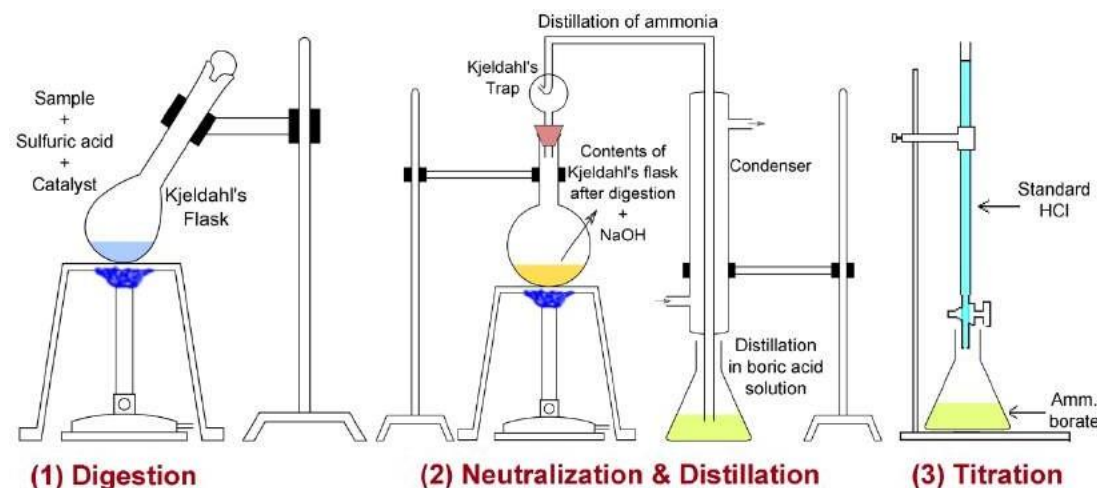
Therefore, (A - B) mL of 0.1N HCl =  $[14 \times (A-B) \times 0.1] / 1000 \times 1$  g of  $\text{N}_2$

=> X g of coal sample contains =  $[14 \times (A-B) \times 0.1] / 1000 \times 1$  g of  $\text{N}_2$

% of Nitrogen

$$= \frac{14 \times \text{Volume of Acid consumed} \times \text{Normality}}{1000 \times \text{Weight of coal sample(X)}} \times 100\%$$

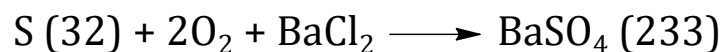
$$= \frac{1.4 \times \text{Volume of Acid consumed} \times \text{Normality}}{\text{Weight of coal sample(X)}} \%$$



**c) Determination of sulfur in coal:** A known amount of coal is burnt completely in a bomb calorimeter in the presence of oxygen. Ash thus obtained contains sulfur of coal as sulfate which is extracted with dil HCl. The acid extract is then treated with BaCl<sub>2</sub> solution to precipitate sulfate as BaSO<sub>4</sub>. The precipitate is filtered, washed, dried, and weighed, from which the sulfur in coal can be computed as follows:

Let, X = weight of coal sample taken;

M = weight of BaSO<sub>4</sub> precipitate formed.



233 g of BaSO<sub>4</sub> contains 32 g of sulfur

1 g of BaSO<sub>4</sub> contains 32 / 233 g of sulfur

∴ M g of BaSO<sub>4</sub> contains (32 / 233) x M g of sulfur

$$\% \text{ of sulphur in coal} = \frac{32}{233} \times \frac{M}{X} \times 100$$

**d) Determination of ash content in coal:** Percentage of ash calculated by method given in proximate analysis.

**e) Determination of oxygen in coal:** It is calculated by subtracting the sum of the total % of carbon, hydrogen, nitrogen, sulfur, and ash from 100.

$$\% \text{ of oxygen} = 100 - [\% \text{ carbon} + \% \text{ hydrogen} + \% \text{ nitrogen} + \% \text{ sulfur} + \% \text{ ash}]$$

- **Significance of ultimate analysis:**

- **Carbon and Hydrogen:**

- i. Higher the % of carbon and hydrogen, the better the quality of coal, and the higher is its calorific value.
- ii. The % of carbon is helpful in the classification of coal.
- iii. Higher % of carbon in coal reduces the size of the combustion chamber required.

- **Nitrogen:**

- i. Nitrogen does not have any calorific value, and its presence in coal is undesirable.
- ii. Good quality coal should have very little nitrogen content.

- **Sulphur:** Though sulfur increases the calorific value, its presence in coal is undesirable because:

- i. The combustion products of sulfur, i.e,  $\text{SO}_2$  and  $\text{SO}_3$  are harmful and have corrosion effects on equipment.
- ii. The coal containing sulfur is not suitable for the preparation of metallurgical coke as it affects the properties of the metal.

- **Oxygen:**

- i. Lower the % of oxygen higher its calorific value.
- ii. As the oxygen content increases, its moisture-holding capacity increases, and the calorific value of the fuel is reduced.

- **LIQUID FUELS:**

- **Examples:** petrol, diesel, kerosene, gasoline

- **Advantages of liquid fuels**

1. Liquid fuels do not yield any ash after burning.
2. They require comparatively less storage space
3. Calorific value of liquid fuel is higher than that of solid fuels.
4. Their combustion is uniform and easily controllable

- **Disadvantages of liquid fuels:**

1. Liquid fuels are comparatively costlier than solid fuels.
2. They give an unpleasant odor during incomplete combustion.
3. Portion of liquid fuels will escape due to evaporation during storage.
4. Special types of burners are for effective combustion.



- **GASEOUS FUELS:**

- **Examples:** natural gas, LPG, water gas, producer gas

- **Advantages of gaseous fuels**

1. Gaseous fuels can be easily transported through the pipes.
2. They do not produce any ash or smoke during burning.
3. They have high calorific value than solid fuels.
4. They have high thermal efficiency.

- **Disadvantages of gaseous fuels:**

1. They are highly inflammable and hence the chances for fire hazards are high.
2. Since gases occupy a large volume, they require large storage tanks.

- I. **NATURAL GAS:** It is always found above the oil in the oil wells. It is also called **Marsh gas**.
- Its calorific value varies from 12,000 to 14,000 kcal/m<sup>3</sup>.
  - It consists of methane and other saturated paraffinic hydrocarbons. The average composition of natural gas is as follows:
    - Methane (88.5 %)
    - Ethane (5.5 %)
    - Propane (4 %)
    - Butane (1.5 %)
    - Pentane (0.5 %)
  - If natural gas contains lower hydrocarbons like methane and ethane it is called **lean or dry gas**. Natural gas contains higher hydrocarbons like propane and butane along with methane is called **rich or wet gas**.
  - **Uses:**
    1. It is used as a domestic and industrial fuel.
    2. It is used as a raw material for the manufacture of carbon black and hydrogen.
    3. It is also used for the generation of electricity by using it in fuel cells.
    4. It is used in the synthetic preparation of methane.

**II. PRODUCER GAS:** It is a mixture of combustible gases such as CO (22-30%) and H<sub>2</sub> (8-12%) and a large amount of non-combustible gases like N<sub>2</sub> (52- 55%), CO<sub>2</sub> (3%) etc.

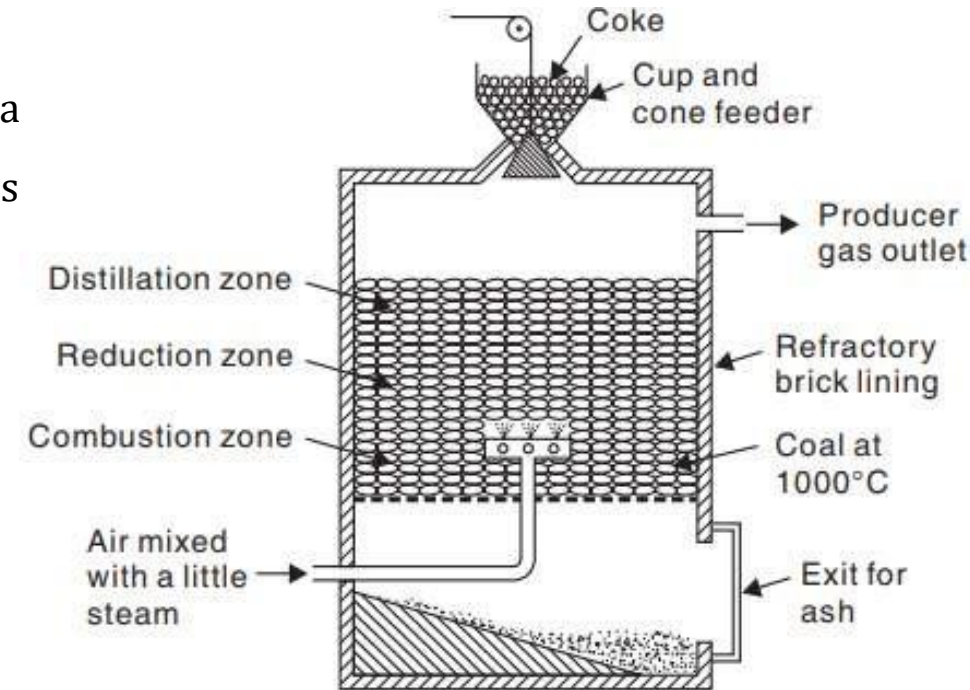
- It is prepared by passing air mixed with a little steam over a red-hot coal (or) a coke bed maintained at above 1100 °C in a special reactor called “Gas Producer”.

- Its calorific value is low and varies from 1300 to 1800 kcal/m<sup>3</sup>.

- Properties:**

- It is a poisonous gas
- It is insoluble in water
- It is heavier than air

- Synthesis:** The furnace used for the manufacture of producer gas is known as a producer. It consists of a large airtight steel cylindrical tower (4 m), lined inside with refractory bricks. At the bottom, there is an inlet for air and steam and an outlet for removing ash. Coal is added through a cone feeder at the top and producer gas comes out from the side outlet at the top.

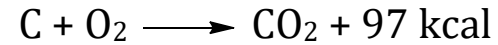


Gas Producer

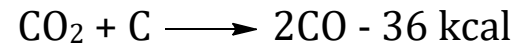
- **Reaction zones in a Gas Producer:**

**a) Ash zone:** The fuel bed in a normal producer is on a metallic grate. The air-steam blast is pre-heated by the ash zone which also protects the grate from intense heat.

**b) Combustion or oxidation zone:** The oxygen is consumed within 75 to 100 mm of the bed, which constitutes the zone. When a mixture of air and steam is passed through a bed of red-hot coal, carbon (of the coal) combines with oxygen (of the air) in the lower part of the furnace to form CO<sub>2</sub>. The temperature of this zone is 1100 °C.



**c) Reduction zone:** CO<sub>2</sub> so formed rises up through the red-hot coal and gets reduced to CO during its passage (**Boudonard reaction**). Its equilibrium constant greatly increases with the rise in temperature. N<sub>2</sub> of air remains unaffected throughout the process. Thus, a mixture of CO and N<sub>2</sub> with traces of CO<sub>2</sub> and hydrocarbons comes out through the exit at the upper end of the producer. The temperature is around 1000 °C.



**d) Drying and carbonization zone:** The water vapor and the volatile matter are added to the escaping gas which results in the production of enriched gases. The temperature of this zone is 400 - 800 °C

- **Advantage of using air with steam:**

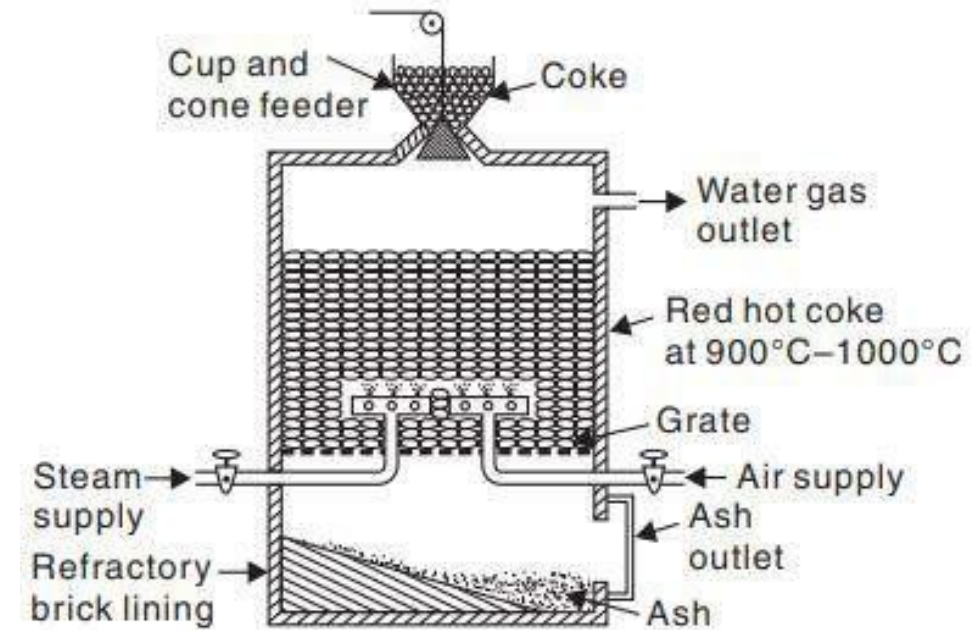
- i. It raises the content of combustible components (CO) thereby increasing the calorific value
- ii. The endothermic reaction of steam and C prevents overheating of a fuel bed and leads to diminished clinker formation

- **Uses:**

- i. It is used as fuel for heating open-hearth furnaces (used in steel and glass manufacture), and muffle furnaces (used in coal gas and coke manufacture).
- ii. It provides a reducing atmosphere in certain metallurgical operations.

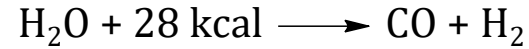
**III. WATER GAS (or BLUE GAS):** It is essentially a mixture of combustible gases like CO (41%), H<sub>2</sub> (51%) with a small amount of non-combustible gases like CH<sub>4</sub>, CO<sub>2</sub> (4%), and N<sub>2</sub> (4%)

- It is generated by gasifying solid incandescent source of carbon in superheated steam
- It is of medium calorific value: 2800 kcal/m<sup>3</sup>
- **Properties:**
  - It burns with blue flame owing to the high content of CO and hence is known as blue water gas.
  - Its flame is short but very hot.
- **Synthesis:** A Water gas generator is a steel cylindrical vessel. At the top, it is provided with a hopper for adding coke. A water gas outlet is provided near the top. At the bottom, it is provided with an arrangement of taking out ash formed.



Water gas production

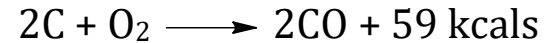
- **Working:** It is obtained by the action of steam on a bed of coke heated to 1000 - 1400 °C.  $C +$



Since the above reaction is endothermic, the coal cools down after a few minutes and the reaction proceeds in a different way to form  $CO_2$  and  $H_2$  instead of water gas ( $CO + H_2$ ).



In order to avoid the above undesirable reaction, the blow of air replaces the blow of steam. The following reaction now occurs.

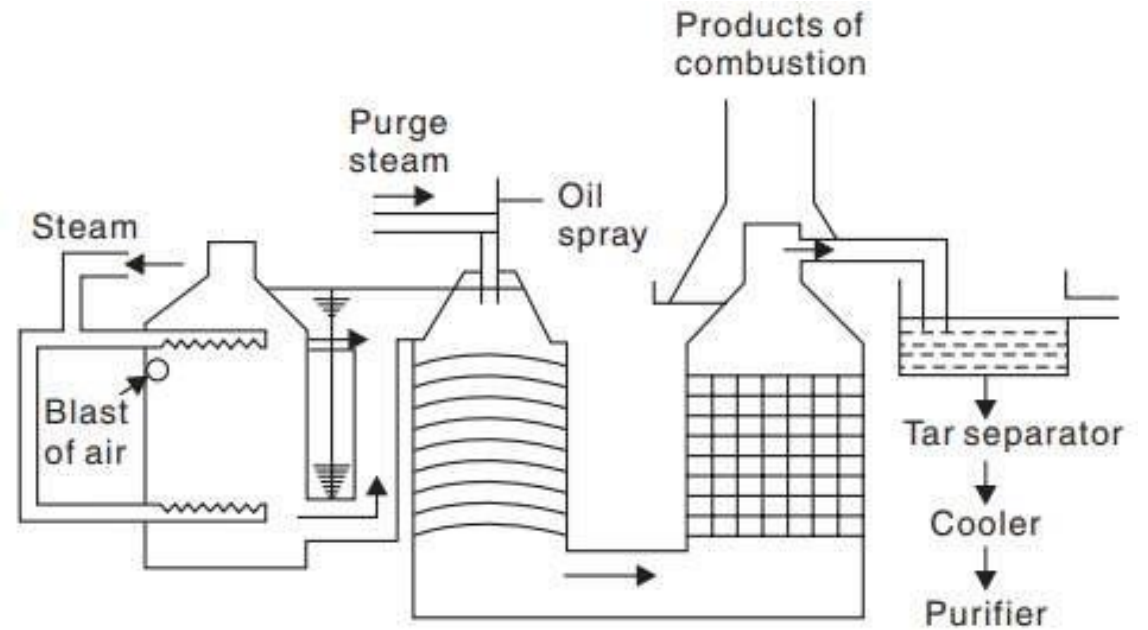


Due to exothermic reactions, the temperature of the bed rises and when the temperature increases to 1000 °C, air entry is stopped and steam is again passed. Thus, steam and air are blown alternatively. Therefore, the manufacture of water gas is intermittent.

- **Uses:**

- i. It is used for the manufacture of ammonia by Haber's process.
- ii. Used as a source of hydrogen, and as a fuel gas.
- iii. Carbureted water gas is used for lighting and heating.
- iv. Water gas is also used for welding purposes.
- v. Used for the manufacture of methyl alcohol and synthetic petrol.

- The calorific value of water gas can be enhanced by adding gaseous hydrocarbons to get carbureted water gas (calorific value: 4500 kcal/m<sup>3</sup>)
- Composition of carbureted water gas:
  - H<sub>2</sub>: 35%
  - CO: 25%
  - Saturated and unsaturated hydrocarbons: 35%
  - N<sub>2</sub> + CO<sub>2</sub>: 5%

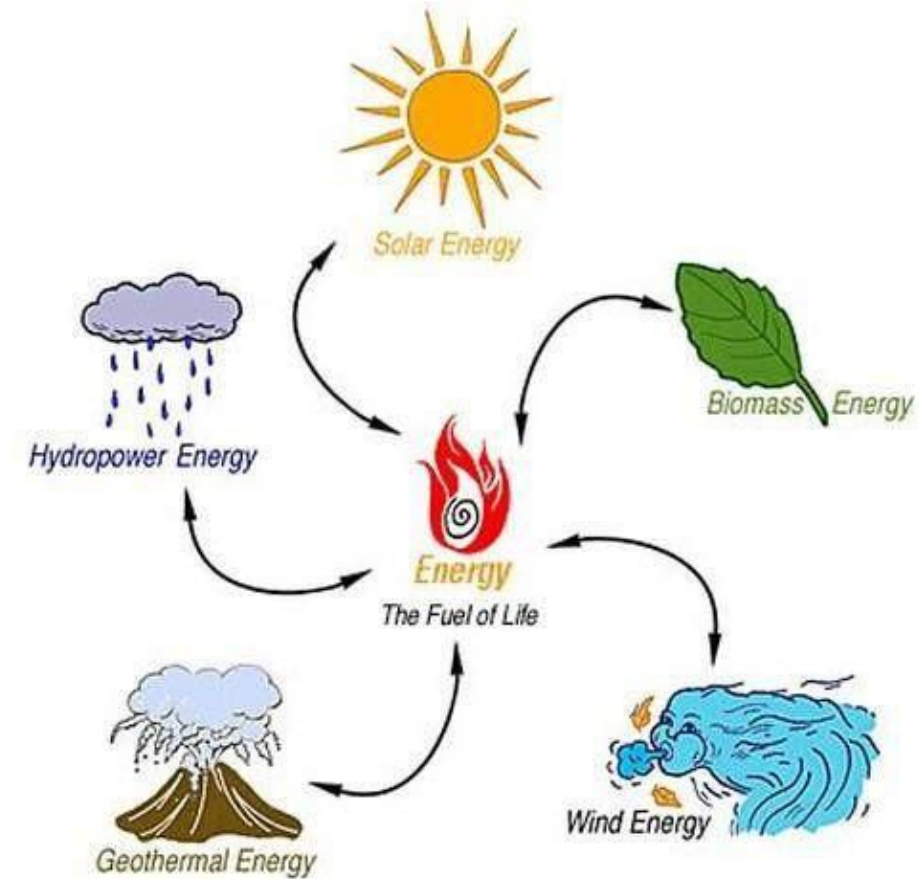


Carbureted water gas production



## ❖ NON-CONVENTIONAL SOURCES OF ENERGY

- The sources of energy which are being produced continuously in nature and are inexhaustible are called renewable or non-conventional sources of energy
- Some of these sources are:
  - Solar energy
  - Wind energy
  - Tidal energy
  - Bio-mass
- A renewable energy system transforms energy from the sun, wind, falling water, sea waves, geothermal heat, or biomass into heat or electricity that humans can utilize
- With rising energy use, the population is becoming increasingly reliant on fossil fuels such as coal, oil, and gas. These fuels are costly and therefore in order to guarantee future energy supplies, we must employ more and more renewable energy sources



- **Advantages:**

- i. They are renewable in nature.
- ii. They produce little or no pollution as compared to traditional energy sources.
- iii. They require little maintenance.
- iv. They are a long-term cost-effective choice.

- **Disadvantages:**

- i. The initial setup cost is greater.
- ii. Energy cannot be taken 24/7 year-round, because certain days will be windier than others, and the sun will shine stronger on other days.
- iii. Energy must be stored. Geographical locations might be difficult to navigate.

## I. SOLAR ENERGY

- It is the energy received from the sun
- It is the most readily available source of energy
- Earth's surface receives 182 petawatts (PW) of energy from sun
- The energy supplied by the sun in one hour is almost equal to the amount of energy required by the human population in one year
- Solar thermal devices are utilized in residential and industrial solar water heaters, air warmers, solar cookers, and solar dryers
- **Advantages:**
  - i. It is renewable
  - ii. Non-polluting and eco-friendly
  - iii. Free except for capital expenses
  - iv. Low maintenance- solar panels require very little upkeep
  - v. Longevity- solar panels can last upto 30 years
- **Disadvantages:**
  - i. The major disadvantage is the cost of photovoltaic panels
  - ii. Only areas of the world with lots of sunlight are suitable for solar power generation
- **Applications of solar energy:**
  - i. Solar electric generation
  - ii. Solar cars
  - iii. Solar heaters
  - iv. Solar cookers
  - v. Solar lighting



## II. WIND ENERGY

- Wind energy is the process of harnessing wind power to generate electricity. The wind's kinetic energy is transformed into electrical energy.
- Windmills convert wind power to electrical power.
- **Applications of wind energy:**
  - i. Utility interconnected wind turbines generate power which is synchronous with the grid and are used to reduce utility bills
  - ii. Wind turbines generate DC current for battery charging
  - iii. Wind turbines for remote water pumping generate 3-phase AC current suitable for driving an electrical submersible pump directly



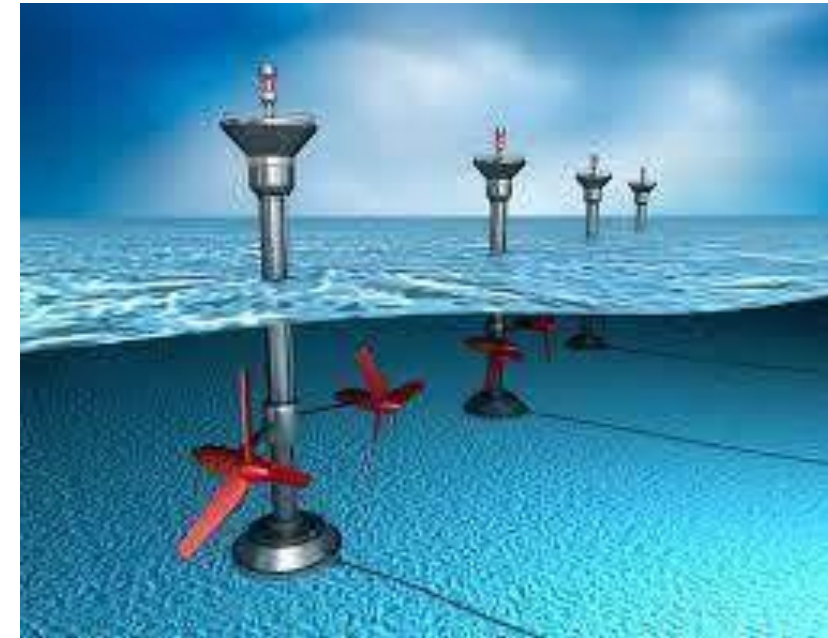
### III. OCAEN AND TIDAL ENERGY

#### a) Tidal energy:

- The building of a barrage across an estuary to prevent incoming and outgoing tides is required for tidal power generation. As with hydroelectric dams, the head of water is utilized to drive turbines that create energy from the raised water in the basin.
- Barrages can be built to generate power on the ebb, flood, or both sides of the river.
- The tidal range can range from 4.5 to 12.4 meters depending on the location. For cost-effective operation and adequate head of water for the turbines, a tidal range of at least 7 m is necessary.

#### b) Ocean energy:

- Oceans encompass more than 70% of the earth's surface, making them the biggest solarcollectors on the planet.
- Ocean energy is derived from water waves, tides, and thermal energy (heat) stored in the ocean. The sun warms the top-water far more than the deep ocean water, storing thermal energy in the process.
- **Applications of tidal energy:**
  - i. Tidal electricity
  - ii. Grain mills
  - iii. Energy storage
  - iv. Provide protection to coast in high storms





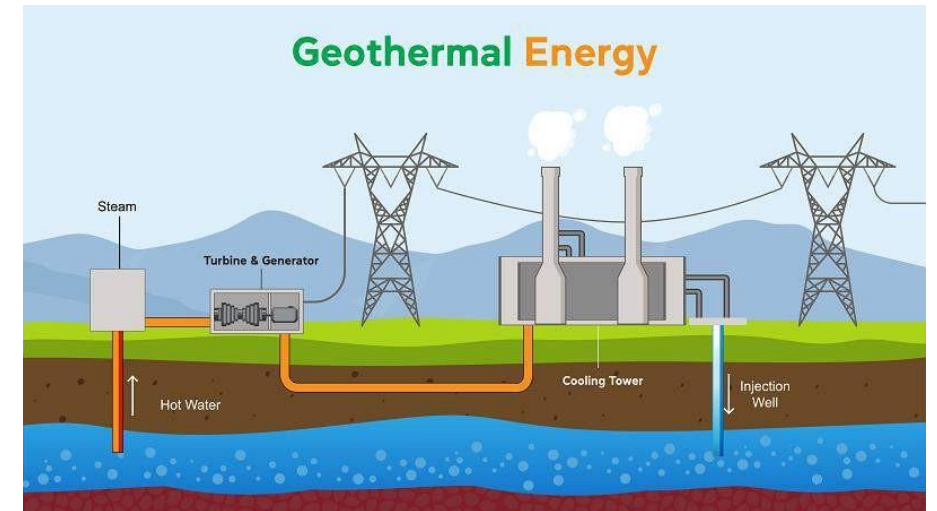
#### IV. HYDROPOWER

- The commencement of the industrial revolution was driven by the potential energy of falling water, which was collected and transformed to mechanical energy by waterwheels.
- Rivers and streams were dammed and mills were erected wherever there was enough head or change in elevation. A turbine spins because water under pressure flows through it. The Turbine is linked to a generator, which generates power.



#### V. GEOTHERMAL ENERGY

- It is a type of energy that comes from the earth. It is trapped in the earth's crust at a depth of 10 km in the form of hot springs, geysers, and other natural phenomena.
- About 250 hot springs with temperatures ranging from 90 to 130 °C have been discovered in areas like Puga Valley in Ladakh, Manikaran in Himachal Pradesh, and Tattapani in Chhattisgarh, indicating that India's geothermal potential is largely found along the Himalayas.
- The National Aerospace Laboratory in Bangalore has established a pilot project near Manikaran for research and development as well as data collection in order to construct larger geothermal power plants.



## VI. BIOMASS

- Biomass is a renewable energy source made up of carbon-based waste from human and natural activity.
- It comes from a variety of places, including wood industry by-products, agricultural crops, forest raw material, domestic trash, and so on.
- Biomass does not emit carbon dioxide into the atmosphere since it absorbs the same amount of carbon throughout its growth as it emits when burned.
- It has the benefit of being able to generate energy using the same equipment that is now used to burn fossil fuels.
- Biomass is a significant source of energy and, after coal, oil, and natural gas, the most important fuel on the planet. Bio-energy, in the form of biogas, has a better energy efficiency than direct burning and is anticipated to become one of the most important energy sources for worldwide sustainable development.
- Biogas is a clean and efficient fuel made from cow dung, human waste or any other biological substance that has been fermented anaerobically.
- The biogas contains 55-60% methane and the remainder is mostly carbon dioxide.
- Biogas is a non-toxic fuel that may be used for cooking and lighting. The by-product can be used as high-quality manure.

