

**S.S. Jain Subodh P.G. College**  
**(Autonomous)**  
**Generic Elective Syllabus**  
**Department of Chemistry**

**Industrial Chemistry**

**UNIT-I Cement and Glass**

Portland Cement; Definition, Manufacturing by Rotary kiln. Chemistry of setting and hardening of cement. Role of Gypsum.

Glass: Definition, Manufacturing by tank furnace, significance of annealing, Type and properties of soft glass, hard glass, borosilicate glass, glass wool, safety glass

**UNIT II Fuel Chemistry**

Energy sources (renewable and non-renewable). Classification of fuels and their calorific value.

Coal: Introduction of coal, uses of coal (fuel and non-fuel) in various industries (atleast three examples), its types and composition, carbonization of coal. Coal gas, producer gas and water gas

Petroleum and Petrochemical Industry: Composition of crude petroleum, Refining and different types of petroleum products and their applications.

**Outcomes:**

1. Students will gain knowledge of the principles and scientific techniques of industrial Chemistry.
2. It educates and trains Chemists to acquire a meaningful picture of Chemical industries.
3. Students get prepared for professional participation in Chemical industries so as to adapt themselves to jobs which are problem solving.
4. Students will be trained in the chemical, petrochemical, biochemical and allied technological fields.

**Books Suggested:**

1. C.A. Heaton, An Introduction of Industrial Chemistry, Blackie Academic and Professional, 3rd edition 1996
2. James D. Burrington, Industrial Catalysis: Chemistry and Mechanism, Imperial College Press, May 2016
3. E. Stocchi: Industrial Chemistry, Vol-I, Ellis Horwood Ltd. UK.
4. R. M. Felder, R. W. Rousseau: Elementary Principles of Chemical Processes, Wiley Publishers, New Delhi.
5. W. D. Kingery, H. K. Bowen, D. R. Uhlmann: Introduction to Ceramics, Wiley Publishers, New Delhi.
6. O. P. Vermani, A. K. Narula: Industrial Chemistry, Galgotia Publications Pvt. Ltd., New Delhi.
7. S. C. Bhatia: Chemical Process Industries, Vol. I & II, CBS Publishers, New Delhi.
8. P. C. Jain, M. Jain: Engineering Chemistry, Dhanpat Rai & Sons, Delhi.
9. R. Gopalan, D. Venkappayya, S. Nagarajan: Engineering Chemistry, Vikas Publications, New Delhi.
10. B. K. Sharma: Engineering Chemistry, Goel Publishing House, Meerut.

# UNIT - I

## PART - A

### CHAPTER 5

## CEMENT

The megalith structures, built in prehistoric era are made by placing huge stones one over another, without any cementing material in between. The Egyptians were the first to use cementing material for uniting blocks and slabs of stone. The Greeks and Romans were acquainted with the use of mortar (a mixture of lime and water) as a cementing material. The hardness of these mortars has been attributed to the thorough mixing of the ingredients, and efficient ramming. They were also aware that by intimately mixing volcanic material (partially or completely consolidated volcanic ash) with lime and sand, mortars with superior strength could be obtained, and these were not disintegrated by water. Other similar materials are Santorin earth and Pozzolona. Such mixtures of lime paste and volcanic ash are capable of giving a hard mass with water, and is not disintegrated by water. These lime pastes, quite stable to water, are called hydraulic limes.

William Aspdin is credited for the discovery of Portland cement 1824. He produced an improved cement by heating a mixture of lime stone and clay and crushing the resulting product to a fine powder. The name "Portland cement" was given because this powder, on mixing with water, gives a hard, stone like mass which resembling stone taken out from the mines in Portland island, England. Portland cement is a type of cement, not a brand name. The usefulness of cement lies in its ability to cement or bind together pieces of gravel or bricks, to give hard mass. The mixture of cement, fine aggregate (sand) and water is called mortar. If the mortar is applied as a paste between coarse aggregate (gravel or crushed rocks) so as to fill all void spaces between the aggregates, a hard, rock like conglomerate or mass results after a few days. The mixture of cement, gravel and sand with water is given the name concrete.

In the broadest sense, the word cement means substance that acts as bonding agent for material. The pastes, glue, portland cement, lime, gum, plaster of Paris, etc., are the examples of cementing material. The term cement is strictly used to designate a fine gray powder that is used for construction work, which has desirable adhering property. On mixing with water, it forms a paste, which binds firmly the aggregates such as, gravel, stone, sand and other such similar substances.

### 1. Classification

The cement generally used in engineering construction work, can be divided in to the following types :

- (1) Natural cement
- (2) Pozzolana cement
- (3) Slag cement
- (4) Portland cement

**(1) Natural cement :** The cement produced by calcining and pulverizing natural cement rocks consisting of argillaceous or clay and limestone, is known as natural cement. The properties of the cement varies according to the composition of the cement rocks. Natural cements do not impart sufficient strength, but they are cheaper.

**(2) Pozzolana cement :** Pozzolanic cement is the most ancient of the manufactured cements. It was first made from volcanic ash from mount Vesuvius situated around a place called pozzuoli in Italy. Volcanic ash consisting of silicates of calcium, iron and aluminium, when mixed with lime and heated, produces pozzolanic cement.

**(3) Slag cement :** It is prepared from blast furnace slag and hydrated lime. The blast furnace slag, which contains mixture of calcium and aluminium silicate, is granulated by pouring it into a stream of cold water. It is then dried and finely pulverized. Slag cements are slow to harden, so an accelerator like clay, salt or caustic soda is sometimes added. They have lower strength.

**(4) Portland cement :** It is most important and valuable cementing material, used for constructional work. Portland cement was discovered in 1824 by Joseph Aspidin, It was named because paste of cement with water on setting and hardening resembled in colour and hardness to Portland stone, a limestone quarried in Dorset. There are many types : (a) Ordinary Portland cement, (b) Rapid hardening cement, (c) Extra rapid hardening cement, (d) Portland blast furnace cement, (e) Low heat Portland cement, (f) White Portland cement and (h) Coloured Portland cement.

## 2. Manufacture of Portland Cement

### 2.1 Raw Material for Cement Manufacture :

Following are required for the manufacture of Portland cement :

(i) Calcareous materials, (ii) Argillaceous materials, (iii) Fuel oil or powder coal, (iv) Gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ).

**(1) Calcareous Materials :** These materials supplies lime. The following kind of calcareous, materials used to supply lime are.

(i) Lime stone (contains 65–80%  $\text{CaCO}_3$ ), (ii) Chalk, (iii) Shale, (iv) Calcite etc.

Lime is the main constituent of cement. The proportions of lime should be properly maintained, because it makes the cement to expand and disintegrate.

**(2) Argillaceous materials:** These materials supplies silica, iron oxide and alumina. The argillaceous material used are :

(i) clay, (ii) marl, (iii) sand, (iv) slate, (v) blast furnace slag. etc.

Silica imparts the strength to the cement and alumina makes the cement quick setting. However excess of alumina, weakens the cement. The colour, strength and hardness are provided by iron oxide. Gypsum helps to retard the setting action of cement. In fact enhances the setting time of cement.

## 2.2 Manufacturing process :

The actual manufacturing process involve the following steps :

(i) Crushing, (ii) Mixing, (iii) Burning, (iv) Grinding, (v) Packaging.

There are two methods of manufacture of cement :

(1) Dry process,

(2) Wet process.

**(1) Dry Process :** In dry process the raw materials are separately crushed to 50 mm or smaller pieces and then dried and stored separately. Crushing is done in gyratory crushers and drying is done by means of rotary driers.

The raw materials are then mixed in proper ratio by automatic weighing machines. The mixture is finely ground and then burnt.

Dry process is quite similar to wet process with the only difference that no water is added to the material in grinding and thus no slurry is made, the process has the advantage of low fuel cost

**(2) Wet Process :** The wet process is quite common and is universally employed for the manufacture of portland cement. The process involves the following steps.

**(i) Crushing :** Raw material are crushed by crushers. Which reduces the size of raw materials to an approximately 3/4 inches.

**(ii) Grinding :** The grinding of raw materials to be carried out in two stages. First by ball mills and then by tube mills. Material from ball mill to the tube mill is conveyed by means of screw driver. The material is mixed with 30-40% water before grinding.

**(a) Ball Mill grinding :** It consists of cast iron drums containing iron or steel balls of different sizes. Dust passes through the perforated plate and falls on the fine sieve. The coarse particles are retained by the screen and return to the interior of the drum through an opening (Fig. 1).

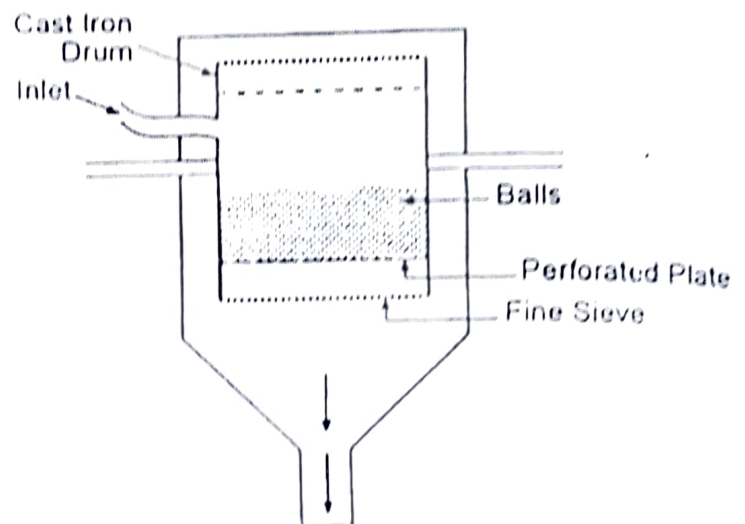


Fig. 1. Ball Mill

The principle used in the ball mill is impact and shear produced by sliding tumbling and rolling of a large number of steel or flint balls or pebbles.

**(b) Tube Mills Grinding :** After grinding in ball mills the material enters to the tube mills. The tube mill is just like ball mill but has a different slope. It is conical at the discharge end Fig. 2. In principle the tube mill in principle is the same but it continually operation. On one side the material is fed and from the other end the material comes out. The size of grinding

depends upon the speed of the feeding. The slower the speed of feeding, the layer the material receives the impact of the pebbles and finer the product coming out of the tube mill. After the grinding the material passes through a 100 mesh sieve. The finer the particles the better is the quality of cement produced as the reacting particles when finer have got large surface area of contact.

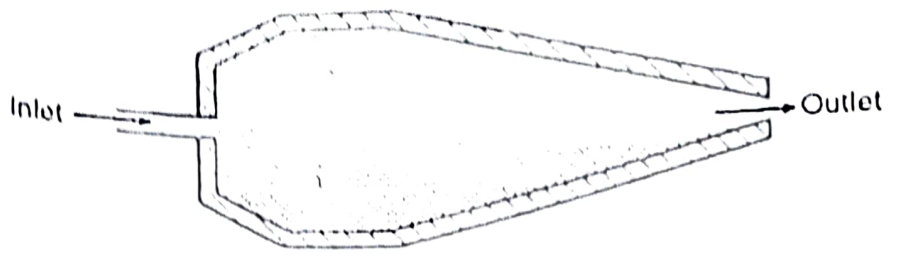


Fig. 2. Tube Mill

(iii) **Storage of Ground materials** : The ground materials containing 30-40% of water are stores in separate tanks equipped with agitators.

(iv) **Correction tank** : From raw storage tanks the materials are transferred to correction tanks. When correction tank is full, a sample of material is taken out for analysis. If the slurry is not of the required composition, it is corrected by adding more of the deficient raw materials.

(v) **Burning** : The slurry is transferred to rotary kiln where burning of raw material takes place and actual chemical changes takes place. The rotary kiln is long steel cylinder with length 30-60 meters and diameter 2-4 meters lined with refractory bricks (Fig. 3). The kiln is slightly inclined downwards towards the exit end. It can be rotated a desired speed as it rotates, the material passes slowly from the upper to lower end at a rate controlled by slope and speed of rotations of the kiln. Heating of kiln is done by burning of pulverised coal which is introduced through special burners. Temperature maintained is 1400-1500°C. As the material passes through the kiln, its temperature is raised to the point of clinkering temperature where the actual chemical reactions takes place. In fact, there are different zones in the rotary kiln viz.

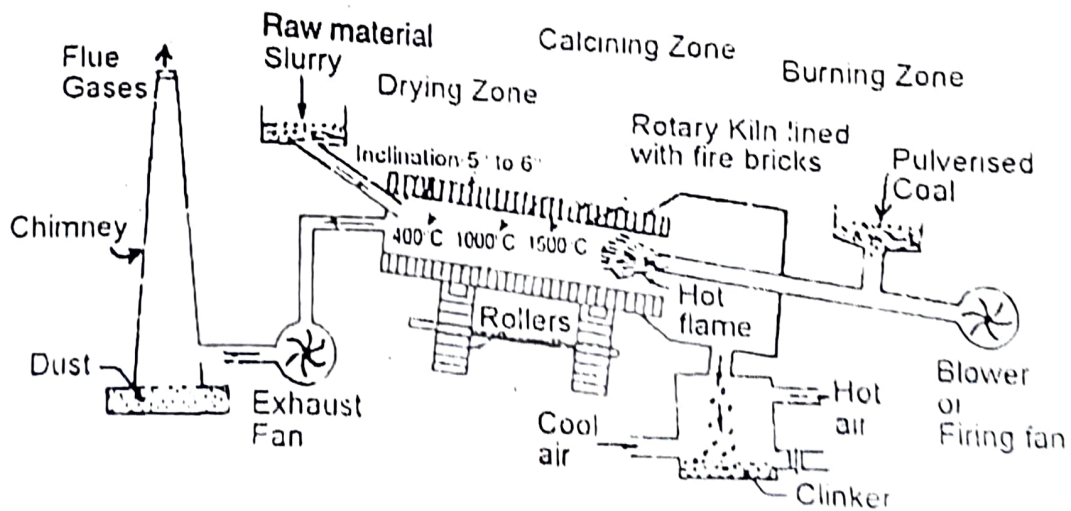
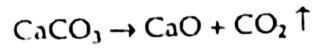


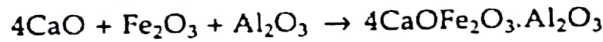
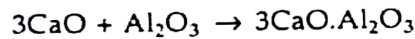
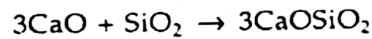
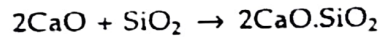
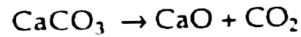
Fig. 3. Rotary Kiln for Cement manufacture.

(a) **Drying zone** : This is the upper one fourth part of rotary kiln, here the temperature is moderate (100–500°C). This zone is known as drying zone, because in this zone water is driven out of the slurry by means of hot gases.

(b) **Calcination Zones** : Its temperature is about 1000°C and it is the middle portions of the kiln here organic matter burns away. Calcium carbonate decomposes in to calcium oxide and carbon dioxide which escapes



(c) **Burning Zone** : It is the hottest and bottom portion of the rotary kiln. In this part temperature is about 1400°C–1500°C. In this zone, mixture melts and forms little rounded pasty masses about the size of the peas which are called **clinkers**. The clinkers produced is greenish or black in colour, the clinkers formed are falls out from this lower end of the kiln. The main reactions taking place are following :



Various chemical changes takes place are summarised in table 1.

**Table 1 : Reactions taking place in the cement kiln**

Temperature (°C)	Reaction and products formed	Comments
> 100	Evaporation of water	
> 500	Removal of combined water from clay	
> 800	Decomposition of $\text{CaCO}_3$ , $\text{MgCO}_3$ . Formation of $\text{C}_3\text{A}$ , $\text{C}_2\text{F}$ and $\text{C}_2\text{S}$ begins	Pure $\text{MgCO}_3$ decomposes at 600–700°C, and pure $\text{CaCO}_3$ at 900°C. But in mixtures (dolomite) decomposition occurs at lower temperature
880–900	$\text{C}_{1,2}\text{A}_7$ forms	Decomposes to $\text{C}_3\text{A}$ at higher temperatures
900–1100	Formation of $\text{C}_3\text{A}$ and $\text{C}_4\text{AF}$ commences, decomposition of $\text{CaCO}_3$ completed, maximum $\text{CaO}$ will be present	
1100–1200	Formation of $\text{C}_2\text{S}$ reaches maximum, major parts of $\text{C}_3\text{A}$ and $\text{C}_4\text{AF}$ form	
1250–1280	Formation of liquid phase	$\text{C}_3\text{A}$ , $\text{C}_4\text{AF}$ , $\text{A}$ , $\text{F}$ dissolve and recrystallise on cooling
1250–1500	Formation of $\text{C}_3\text{S}$ , free-lime content decreases	

\*  $\text{C} = \text{CaO}$ ,  $\text{A} = \text{Al}_2\text{O}_3$ ,  $\text{F} = \text{Fe}_2\text{O}_3$ ,  $\text{S} = \text{SiO}_2$

(iv) **Grinding** : After cooling the clinkers are carried to ball mills for grinding, the clinkers are mixed with 2–3% gypsum (used a retarder, for setting, otherwise cement when mixed with water will set quickly) during grinding.

A comparison between Dry process and Wet process is summarised below :

i.No.	Dry Process	Wet Process
1.	It is costly and slow process.	It is relatively cheaper and faster process.
2.	Productions of cost of cement is low, because fuel consumption low and shorten kiln is sufficient.	Productions cost is higher because relatively greater amount of fuel required longer kiln is required to expel out the excess of water.
3.	Cement produced is of inferior quality.	Cement produced is of superior quality, as more accurate control of consumption can be attained.
4.	This process is not suitable when the principal raw material has an inherent moisture content 15% or above.	This process has to be adopted in this case.

## 6. Setting and hardening of Portland cement

When water is mixed with cement, it forms a paste like mass, a hydration of compounds in cement take place. This fluid like paste eventually becomes stiff and then hard. This action of change of mixture from a fluid (paste) to solid is known as setting of cement. It is understood that during the process of chemical reaction a solid known as gel is formed which adheres firmly to the stones, sand etc binding them together to form a solid mass which on setting and hardening has a great mechanical strength and forms valuable building material. The process of solidification comprises three stages :

(i) Initial set,

(ii) Final set,

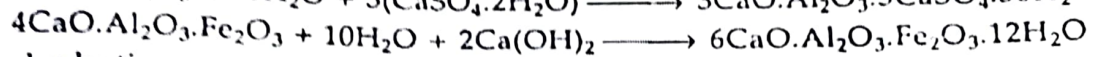
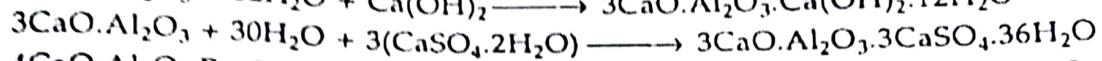
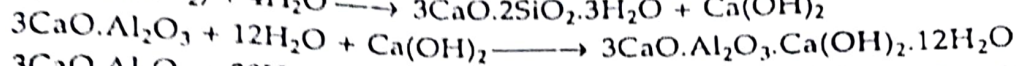
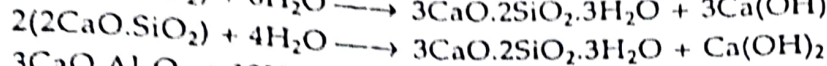
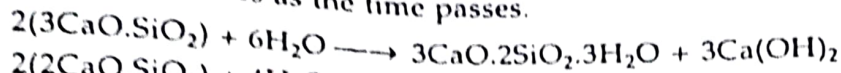
(iii) Hardening.

(i) **Initial Set** : When cement is mixed with water a plastic mixture is formed which can be moulded as desired as the action of setting take place gradually in 60 minutes or so. But with the time mixture begins to lose its plasticity marked by slight jellyfying of the cement paste. Further it should not be disturbed until it has hardened. The initial set stage occurs when, the cement paste attains a certain stiffness which can be marked by the use of a standard needle which may penetrate to a certain depth of the mixture prepared in a standard manner.

(ii) **Final set** : It take place after few hours of mixing. Then concrete mixture can neither be moulded into any shape nor it can be remixed. As the final setting of cement takes place the mass attains such a stiffness that the standard needle can not penetrate in the cement mass at all.



(iii) **Hardening** : After final setting of the solid cement material begins to gain strength and it is this increase in strength which is known as 'hardening.' The hardening or development of strength depends on chemical combination of cement and water and thus continue with a great speed in the beginning but afterward speed is reduced. The hardening of concrete stops as it is dried out. But if it is kept moist, the hardening process can continue for years. However, the rate of hardening decreases as the time passes.



The hydration reactions are exothermic and the volume of cement increases with hydration. In the large structures of concrete, the heat evolved is somehow removed and allowances for expansion are provided. Hydrated cements dissociate on heating by destroying the bond which held the mass together.

### 6.1 Factors affecting the rate of setting and hardening :

Unless a retarder is added, Portland cement takes an initial set too quickly for most applications. Gypsum is used as the retardant and is added at the mill before final grinding of the product. It has been found that 2% gypsum provides the most effective retarding action. The initial set of Portland cement should be between 45 minutes and 10 hours.

When the small particles of cement are mixed with water, they react to form a layer of hydrate and gel. In order to continue the reaction, water must diffuse or migrate through the everthickening coating. Thus, the hardening of concrete is dependent upon both physical (diffusion) and chemical (hydration) processes which are speeded by a rise in temperature.

Physical changes occurring in the setting, hardening and ageing of the cement can be shown in Fig. 6.

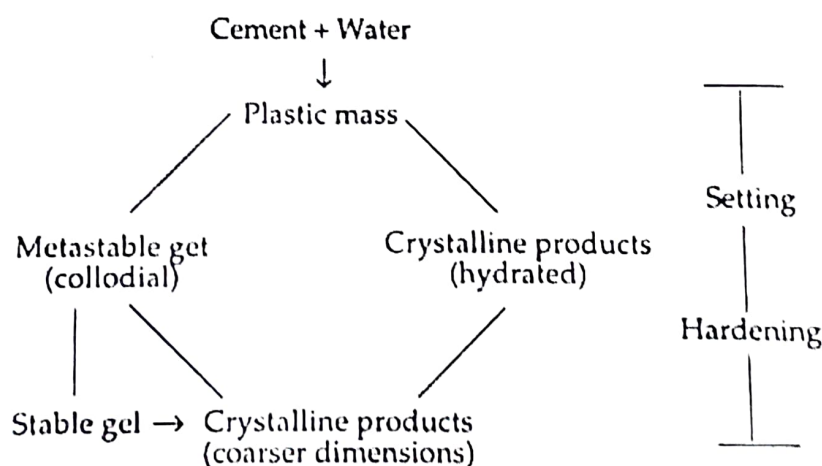


Fig. 6. Schematic diagram of setting and hardening of cement

## 7. Other Classes of Portland Cement

(1) **High alumina cement** : It contains considerable higher quantity of alumina (34-56%). This quick setting variety of cement is manufactured by calcining limestone and bauxite ( $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ ). Such cement is resistant to dilute acid solution.

(2) **Sorel cement** : It is prepared by the addition of a strong solution of magnesium chloride to finely ground calcined magnesia. The material sometimes known as magnesium oxychloride cement ( $3\text{MgO} \cdot \text{MgCl}_2 \cdot 11\text{H}_2\text{O}$ ) sets hard in three to four hours, generally used in composite flooring. Such floorings have the advantage of being non-slip, fire proof, not easily scratchable and durable.

(3) **High early strength Cement** : Such cement is prepared from materials with a high lime to silica ratio. It contains a higher proportion of tricalcium silicate than regular portland cement, and hence, hardens more quickly and with greater evolution of heat. Such cements have only five minutes and 30 minutes for initial and final setting times, respectively.

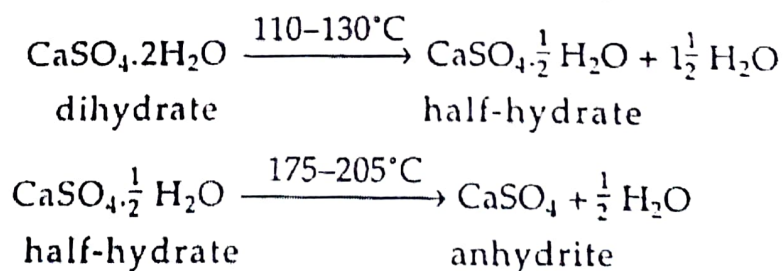
(4) **Barium and strontium cement** : Such cement is obtained by replacing calcium by strontium or barium. It contains tribarium and dibarium silicates instead of calcium silicate. Such cement has resistance to the penetration of radioactive radiations. Hence, they find extensive application in concrete shields for atomic piles.

(5) **Water proof cement** : It is obtained by adding water proofing substances like calcium stearate, aluminum stearate and gypsum with tannic acid to ordinary cement, during grinding.

(6) **White cement** : Due to absence of iron compounds, its colour is white. It is very expensive and finds useful applications, e.g., repairing and joining marble blocks, preparation of tiles and mosaic work.

## 8. Gypsum and Gypsum Products (Plaster of Paris)

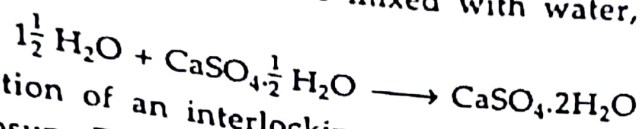
The raw material used for the manufacture of plaster of Paris ( $\text{CaSO}_4 \cdot \frac{1}{2} \text{H}_2\text{O}$ ) is a stoney mineral known as gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ). Some impurities such as  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{CaCO}_3$ , etc., are normally present (about 5%) in gypsum but these are not often considered harmful in the quantities they are normally present. Gypsum deposits are found in Rajasthan. Gypsum products tend to be white if pure and get some what darkened by the presence of sufficient impurities. In order to get various products, i.e., half hydrate and anhydrite, calcination of gypsum is carried out at different temperatures. The crushed gypsum is heated in kettles or in rotary kiln equipped with stirring mechanism to promote uniform heating of the contents and also to prevent local overheating of the kettle. The dehydration of gypsum is a two-stage process :



The half-hydrate is quite stable and is packaged in bags for use as an ingredient of plaster. The anhydrite tends to absorb water rapidly and gets converted to the half-hydrate. If the anhydrite is overheated during calcining, it tends to become inert and lose its ability to harden.

### 8.1 Hardening of gypsum :

Gypsum is a peculiar substance in that the hydrate is less soluble in water than the half-hydrate. Thus, if the half-hydrate is mixed with water, it slowly reacts and precipitates needles of dihydrate.



The formation of an interlocking mass of dihydrate crystals is responsible for the hardening of gypsum. This is also known as hydraulic cement as it hardens slowly by reaction with water.

A number of factors affect the rate of initial stiffening or setting of gypsum. For example, use of warm water (*i.e.*, raising the temperature of plastic mass) sets its plaster, and finely ground gypsum dissolves faster in water and thereby increases the rate of reaction with water. However, in case of gypsum, the problem is not of accelerating the setting rate, but it is rather to retard the rate. This is achieved by use of animal glues which keep the mixture plastic for about one hour. Other organic substances are also used as retarding agents. Without retarders, setting occurs in about 10 minutes. The setting and hardening of gypsum are accompanied by an increase in volume and evolution of heat.

**8.2 Properties of gypsum :** The strength of gypsum depends upon several factors such as amount of water used during mixing, the amount of anhydrite present before mixing, kind and quantity of fillers, and foreign substances present. Strength increases with decreasing amounts of mixing water as long as enough water is used to give a plastic mix. Increasing amount of anhydrite results in greater strength. Since higher calcining temperatures produce a higher proportion of anhydrite, they result in improvement in strength, unless they are so high that they produce inert or dead burnt gypsum. The strength of gypsum usually varies between 70 and 150 kg/cm<sup>2</sup>, although higher strengths are possible. Gypsum is a good fire-resistant material having good insulating properties, and thus, it retards fire damage to wooden and steel framing. When exposed to fire, the insulating properties of gypsum are improved by loss of water of hydration and an accompanying increase in the porosity of the mass.

# UNIT - I

## PART - B



# Glass

## 6.1 Glass

Glass is hard, brittle, amorphous, transparent, supercooled and highly viscous liquid. It has no sharp melting point. It is a good electrical insulator. It can absorb, reflect and transmit light. It is not attacked by acids (except HF) and is a vitrified product.

**Note : Vitrification :** Glass has the characteristics of a transparent amorphous solid. When glass is formed by heating the ingredients, a highly viscous transparent liquid is formed. The liquid on slow cooling forms an amorphous solid and not crystalline. This whole process is known as vitrification.

**Manufacture of Glass :** Different ingredients of glass and their effects are :

Constituent	Effect
$\text{Na}_2\text{O}$	Facilitates melting of silica and reduces viscosity.
$\text{CaO}$	Makes glass resistant to water, weather and chemicals.
$\text{K}_2\text{O}$	Increases softening temperature of glass.
$\text{PbO}$	Increases refractive index of glass.
$\text{B}_2\text{O}_3$	Increases resistance to chemical attack, hardness and refractoriness.
$\text{Fe}_2\text{O}_3$	Do not transmit UV light.

### Raw Materials

Chief source incorporating are :

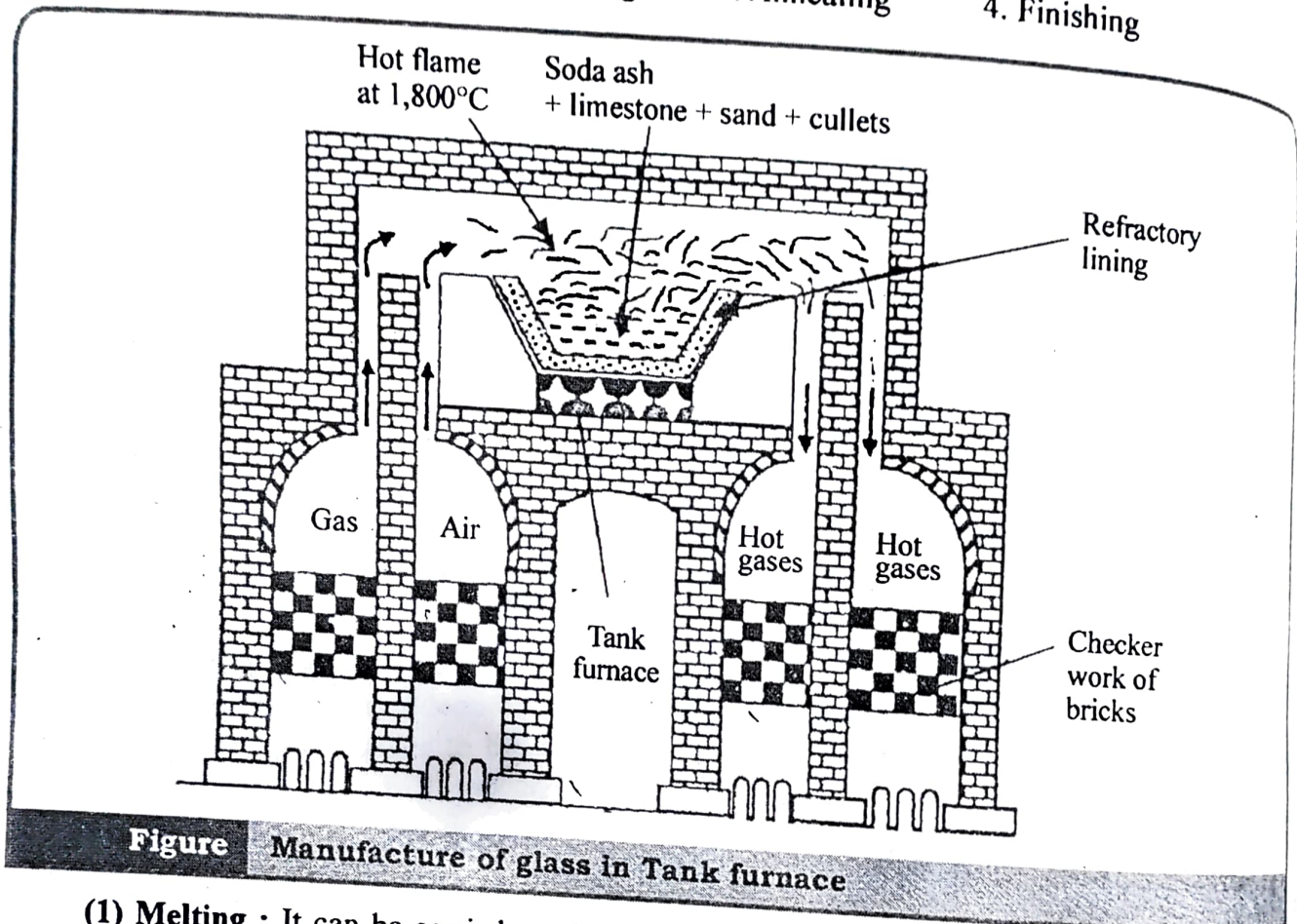
1. Sodium as  $\text{Na}_2\text{CO}_3$ .
2. Potassium as  $\text{K}_2\text{CO}_3$ .
3. Calcium as limestone, chalk etc.
4. Lead as litharge or red lead.
5. Silica as quartz.
6. Zinc as  $\text{ZnO}$ .
7. Borate as borax or boric acid.

8. Cullets (broken glass pieces to increase fusibility).
9. Colours (e.g. yellow-ferric salt, purple-manganese dioxide etc.)

## 6.2 Manufacturing

(Steps involved are Mainly)

1. Melting
2. Forming and shaping
3. Annealing
4. Finishing



**Figure** Manufacture of glass in Tank furnace

(1) Melting : It can be carried out in

(a) Pot furnace  $\begin{cases} \text{Regenerative} \\ \text{Recuperative} \end{cases}$

(b) Tank furnace  $\begin{cases} \text{Regenerative} \\ \text{Recuperative} \end{cases}$

**Note : Regeneration :** Utilization of heat of waste gases for heating the incoming fuel gas and air. The directions of passage of waste gases and fuel gases are changed.

**Recuperation :** In this also the heat of waste gases is utilized in heating the furnace. But the incoming gases flow continuously in one direction only.

**Pot furnace :** A number of different types of glasses, are handled at a time in different pots.

**Tank furnace :** At one time, only one type of glass is produced but in large scale.

The raw materials are mixed in proper proportions and mixed with cullets. These are finely

powdered and mixture called batch is fused in tank in the open hearth furnace. Heating is done by burning producer gas and air mixture over the charge.

### Comparison between pot furnace and Tank furnace.

Pot furnace	Tank furnace
1. Pot furnace is used for making special glasses like optical glass, art glass, plate glass etc.	Tank furnace is used for large scale production of sheet glass, bottle glass and other common glass.
2. In pot furnace the constituent mixture can be stirred. Great uniformity is achieved in this case as is required in optical glass.	Stirring is not possible. So uniformity is not achieved in tank furnace and no special glass can be made.
3. As the pots are closed, the melt is completely protected from combustion products as is required in special glass.	It is not protected and no special glass can be obtained.
4. In pot furnace process is discontinuous. Shaping is done at lower temperature than fusion temperature.	It is a continuous process charging, melting and shaping is done simultaneously and a temperature is maintained.

**Process :** Proper proportion of raw materials sand,  $\text{Na}_2\text{CO}_3$  and lime are taken and mixed with cullets (broken glass pieces which helps to lower the melting point). The mixture (called batch) is powdered and melted in tanks at about  $1400^\circ\text{C}$ . When the charge becomes free from bubbles of  $\text{CO}_2$  and  $\text{SO}_2$  and becomes transparent, it is called 'plain'. The liberated gases are passed to the regenerative chambers. The process of melting continues and when it becomes free from all types of bubbles of gas it is called 'Seeds'.

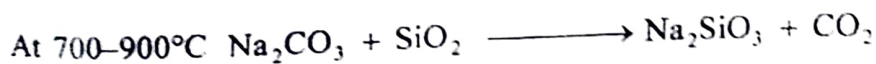
After this stage the melt is transferred into drawing chamber surrounded by working pits. About  $1000^\circ\text{C}$  temperature is maintained. The undecomposed materials like the chlorides and sulphates of Ca, Al, alkalimetals and other impurities rises to the top as a scum (called 'glass gall') and is removed. The melt is then drawn from working pits and is sent for shaping.

The reactions taking place are given below.

#### (a) For Soda Glass (Soft Glass) (Batch - $\text{Na}_2\text{CO}_3$ , $\text{CaCO}_3$ , $\text{SiO}_2$ )

At  $<600^\circ\text{C}$  moisture and oxides of As, Pb, B etc. and chlorides of Na, K, Fe etc. are evaporated.

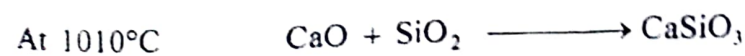
At  $700-900^\circ\text{C}$  Soda ash reacts with  $\text{SiO}_2$ .



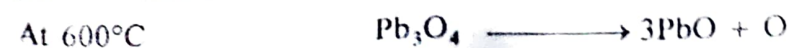
At  $900-960^\circ\text{C}$   $\text{CaCO}_3$  decomposes.

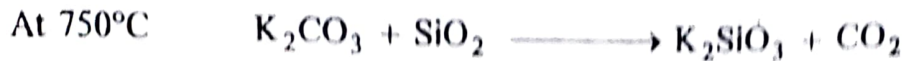
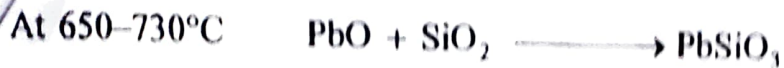


At  $1010^\circ\text{C}$  CaO reacts with  $\text{SiO}_2$ .



#### (b) Flint Glass : (Batch - $\text{Pb}_3\text{O}_4$ , $\text{K}_2\text{CO}_3$ , $\text{SiO}_2$ )





At  $850^\circ\text{C}$   $\text{PbSiO}_3$  dissolves in  $\text{K}_2\text{CO}_3$

(2) **Forming & Shaping** : Molten glass is moulded to desired shapes.

(3) **Annealing** : Glass is a bad conductor of heat. So rapid cooling, makes the outer surface to cool faster than the internal portion. This unequal cooling causes strain and glass may crack or break. So the glass obtained through melting is changed into desired shape and are cooled very slowly to reduce non-uniformity and strain. This process is known as annealing.

(4) **Finishing** : Cutting, polishing, colouring, shaping etc. include in finishing.

### Properties of glasses

1. Glasses possess no sharp melting point. On heating it gradually softens in a range of temperatures and finally changes into a viscous fluid.
2. It is a bad conductor of electricity.
3. It is a bad conductor of heat : It is highly sensitive to thermal shocks. i.e. it breaks when it is heated/cooled suddenly.
4. It undergoes devitrification due to which it loses plasticity and the ability to be shaped.  
[Note : When glass is heated and softened is kept for a long time it loses its transparency and forms a crystalline solid. This is called devitrification.]
5. Glass is amorphous and non-crystalline and hard solid insoluble in water.
6. It is chemically not reactive to most of the acids and alkalis.
7. It is brittle in presence of mechanical jerks or vibrations.
8. The hardness of glass depends upon the composition of the constituents.
9. For making durable articles, which can withstand thermal shock, annealing should be done during the manufacturing process.

## 6.3 Types of Glasses & their uses

Commercial glasses can be classified as follows :

### 1. Sodalime or Soft Glass

The raw materials are silica (sand), calcium carbonate and soda ash. Their approximate composition is  $\text{Na}_2\text{O} \cdot \text{CaO} \cdot 6\text{SiO}_2$ . They are low in cost, resistant to devitrification and relatively resistant to water. They melt easily and can be hot worked easily. Such glasses are attacked by common reagents like acids.

**Uses** : They are widely used as window glasses, electric bulbs, bottles, building blocks and cheaper table wares etc. where high temperature-resistance and chemical stability are not required.

### Potash-lime or Hard Glass

This glass is obtained from silica (sand), calcium carbonate and potassium carbonate. Their composition is  $K_2O \cdot CaO \cdot 6SiO_2$ . They possess high melting point, fuse with difficulty and are less attacked by acids, alkalis and other solvents than ordinary glasses.

Uses : These glasses (costlier than soda-lime glasses) are used for chemical apparatus, combustion tubes, etc; which are used for heating operations.

### Lead Glass or Flint Glass

It is made by using lead oxide, instead of calcium oxide, for fusing together with silica. For dense optical glasses, as much as 80% of  $PbO$  is added. In addition,  $K_2O$  is used, instead of sodium oxide. So its approximate composition is  $K_2O \cdot PbO \cdot 6SiO_2$ .

Lead glass is more expensive than ordinary lime-soda glass, but easier to shape and work with. Lead glass has a lower softening temperature than soda-glass. It has higher refractive-index and excellent electrical properties. It is bright, lustrous and possesses high specific gravity.

Uses : Lead glasses are used for high-quality table wares, Optical purposes, cathode ray tubes, electrical insulators and in art objects, because of their high lustre. High lead-content glasses are used for extra-dense optical glasses for windows and shields to protect from X-rays and gamma-rays in medical and atomic energy fields respectively.

### Borosilicate Glass

Borosilicate glass or pyrex glass is the most common of the hard glasses. Such glasses contain virtually only silica and boron, with a small amount of alumina and some alkali oxides. An approximate composition is as follows :

Percentage	80	13.5	3	3	0.5
Component	$SiO_2$	$B_2O_3$	$Al_2O_3$	$K_2O$	$Na_2O$

The substitution for alkali (eg.  $Na_2O$ ) and basic alkaline earth oxides (eg.  $CaO$ ) of the soda lime glasses by boron and aluminium oxides, makes a glass of low thermal coefficient of expansion and high chemical resistance. Borosilicate glasses have high softening points and excellent resistivity (i.e. shock proof).

Uses : They are used extensively in industry for pipelines for corrosive liquids, superior laboratory apparatus, kitchenwares, television tubes, electrical insulators, gauge glasses and in chemical plants.

### Aluminosilicate Glass

An approximate composition is

Percentage	55.5	22.5	7	9	5	1
Component	$SiO_2$	$Al_2O_3$	$B_2O_3$	$MgO$	$CaO$	$Na_2O + K_2O$

This type of glasses possess high softening temperatures.

Uses : Used for high pressure mercury tubes, chemical combustion tubes, domestic equipments, etc.



### Vitreosil (99.5% Silica Glass)

It is produced by heating pure sand ( $\text{SiO}_2$ ) to its melting point (or about  $1750^\circ\text{C}$ ). Because of the absence of fluxing agents, it is difficult to get rid of all air-bubbles. Also, due to high viscosity of the glass at its working temperature, shaping is rather difficult. The final product is translucent. Its softening temperature is about  $1650^\circ\text{C}$ . Its thermal expansion is lowest.

If vitreosil glass is heated for long periods, above its melting point, it finally becomes transparent and is then known as "clear silica glass". i.e. glass of considerable light transmission properties. (A thick of this material allows not less than 93% of light to pass.)

**Uses :** It is used mainly for chemical plants furnaces, chemical laboratory wares, electrical insulating materials in electrical heaters etc.

### 7. Safety Glass

It is made by taking two or three flat sheets of glass and in between them alternate thin layers of vinyl plastic is introduced and the whole is subjected to slight pressure. It is then heated, till the glass layers and plastic layers merge into one another to give a sandwich. On cooling, the glass become quite tough. When such a glass breaks, it does not fly into pieces, since the inner plastic layer tends to hold back the broken pieces of the glass.

**Uses :** It is mostly used in automobile and aeroplane industries as wind shields, etc.

### 8. Optical Glasses (Crooke's Glasses)

Optical or Crookes glasses contain phosphorous and lead silicate, together with a little cerium oxide. The latter is capable of absorbing u.v. light (which is injurious to eyes). They are given through homogeneity. By very careful manufacturing process and heating the molten mass for a prolonged time, optical glasses have low melting points and are relatively soft. Their chemical resistance and durability are appreciably lower than those of ordinary glass.

**Uses :** They are used for making lenses.

### 9. Polycrystalline Glass

Polycrystalline glass or pyroceram is produced by adding one or more nucleating agents to conventional glass batch, which is then shaped into a desired forms. The material is then subjected to a controlled heat-treatment. The nucleating agents induce the formation of a large number of sub-microscopic crystallites, which act as centres for further crystal growth. Crystalline glass is not ductile, it has much greater impact strength than ordinary glass. It exhibits high strength and considerable hardness and can be formed and shaped into articles by moulding.

### Toughened Glass

It is made by dipping articles still hot in an oil-bath, so that some chilling may take place. By doing so, the outer layers of the articles shrink and acquire a state of compression, while the inner layers are in a state of tension. Such a glass is more elastic and capable of withstanding mechanical and thermal shocks. When such a glass breaks, it does not fly, but a fine powder is formed.

**Uses :** It is used for window shields of fast moving vehicles (like cars, trucks, aeroplanes), window shields of furnaces, automatic opening doors etc.

## Insulating Glass

Insulating glass is a transparent unit prepared by using two or more plates of glass separated by 6 to 13 mm thick gap, filled up with dehydrated air and then, sealing around the edges. This provides a high insulation against heat. Thus, if such a glass is used for separating apartments, it does not transmit heat and the apartments will remain cool, during summer and warm, during winter.

## Wired Glass

Wired glass is formed by inserting a wire mesh at the centre of the glass sheet, during casting. The main advantage of this glass is that when it breaks, it does not fall apart into splinters. It is more fire-resistant than ordinary glass.

Uses : For making fire resisting doors, windows, roofs etc.

## Laminated Glass

Laminated glass is made by pressing (or bonding) together two or more sheets/plates of glass with one or more alternating layer of bonding materials like plastic resin, asphalt, or synthetic rubber. The laminated glass may be :

- (i) Shatter proof (i.e., its pieces do not fly off, when suddenly broken).
- (ii) Shock proof (i.e. It can withstand sudden changes of temperature pressure, without breaking).

A bullet-resistant laminated glass is obtained by pressing together several layers of glass with vinyl resins in alternate layers. Ordinarily, thickness of such glass varies from 12.7 mm to 76.5 mm. Even thicker types are made for specific uses.

Uses : As an ideal material for use as safety glass in aircrafts, automobiles, helicopters, submarines etc. Bullet resistant laminated glass finds application in making auto mobile wind screens etc.

## Neutral Glasses

This includes the glasses which are highly resistant to chemical attack and are used in the manufacture of syringes. Neutral glasses can be regarded as specialised area of soda-lime glass, in which some of the alkali has been replaced by alumina, boron oxide, zinc oxide and other constituents.

## Glass Wool

Glass wool is a fibrous wool-like material, composed of intermingled fine threads or filaments of glass. Glass used for this purpose should be completely alkali-free. Glass filaments are obtained by forcing molten mass of glass through small holes of average diameter of 0.0005 to 0.007 mm continuously. The filaments of glass so obtained are thrown over a rapidly revolving drum to get the material in wool-like form.

It is non-combustible and fire-proof, its electrical and thermal conductivity is low and is completely heat-proof. It does not absorb moisture or water; and resists action of most chemicals. It has low density and its tensile strength is about eight times that of steel.

Uses : It is used for sound insulation and heat-insulation purposes, e.g. insulation of a metal

**(GENERAL ASPECTS)****WHAT WILL YOU LEARN ?**

After studying this chapter, the reader should be able to :

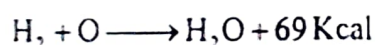
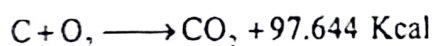
- Understand the origin and classification of organic fuels.
- Understand the carbonization of coal and manufacturing of coke by different methods.
- Explain the advantages of solid, liquid and gaseous fuels.
- Know the methods to increase the yield of petrol.

**1.1 INTRODUCTION**

Fuels are naturally occurring or manufactured combustible organic substances which act as a source of heat. Any source of heat energy is called as fuel. The fuel includes all combustible substances that combine with oxygen from the atmosphere with the evolution of large amount of heat which can be used economically for domestic and industrial purposes.

Therefore, the term 'fuel' may be defined as "any fissionable chemical material or any reactant which gives energy in the form of heat that can be used for producing power". In other words "Fuel is a combustible substance containing carbon as main constituent which is capable of releasing large amount of heat (or energy)". For example : coal, wood charcoal, petrol, diesel, oil gas, producer gas, kerosene, liquefied petroleum gas, CNG etc.

Combustion is an oxidation process which involves the atoms of carbon, hydrogen, etc react with oxygen with simultaneous liberation of heat. The energy is released during the process of combustion by "the rearrangement of valency-electron", in these atoms ~~and~~ resulting the formation of  $\text{CO}_2$ ,  $\text{H}_2\text{O}$  etc. These products have comparatively heat (energy content) and less so, the heat (or energy) released during the combustion process is the difference in the energy of the reactants (C, H and O) and that of the products  $\text{H}_2\text{O}$ ,  $\text{CO}_2$  etc.



Fossil fuels are main (primary) source of fuels which available in earth crust. Fossil fuels are formed by natural resources such as anaerobic decomposition of buried dead organisms. These fuels contain a high percentage of carbon and hydrogen. It involves coal and crude petroleum oils, the amount of which are decreasing day-by-day.

## 2 CLASSIFICATION OF FUELS

The fuels are classified according to

1. Occurrence
2. State of Aggregation

### 1.2.1 CLASSIFICATION OF FUELS ACCORDING TO OCCURRENCE

According to occurrence, fuels are classified as :

- (i) **Primary or Natural Fuel** : These are found in nature as such e.g. wood, petroleum, natural gas etc.
- (ii) **Secondary or Artificial Fuel** : Those which are derived from the primary fuels. coke, charcoal, petrol, kerosene, diesel, coal gas, oil gas, producer gas, blast furnace gas etc.

### 1.2.2 CLASSIFICATION OF FUELS ACCORDING TO STATE OF AGGREGATION

According to state of aggregation, fuels are classified as (i) Solid (ii) Liquid (iii) Gaseous which may be primary or secondary fuel.

**Table 1.1 : Classification of Fuels**

S.No.	Occurrence	State of Aggregation		
		Solid Fuel	Liquid Fuel	Gaseous Fuel
1.	Primary or natural fuel	Wood, Peat, Lignite Bituminous, Anthracite, Dung Coal	Crude petroleum oil	Natural gas
2.	Secondary fuel	Coke, Charcoal, Petroleum etc.	Kerosene, Diesel, Petrol, Synthetic gasoline, Coaltar, L.P.G.	Coal gas, Producer gas, Water gas, Oil gas, Biogas, Blast furnace gas, Coke oven gas etc.

**Table 1.2 : Comparison of Solid, Liquid and Gaseous Fuels**

S.No.	Solid Fuel	Liquid Fuel	Gaseous Fuel
1.	Cheap and easily available.	Costly than solid fuels.	Costly, except natural gas.
2.	Least risk of fire accidents.	Greater risk.	Very high risk of fire hazards, due to their highly inflammable nature.
3.	They have easy storage	They should be stored in closed containers.	They must be stored in leak proof containers and under pressure in iron cylinders (LPG).
4.	Their handling cost is high because labor is required in their storage and transport	They can be easily transported through pipelines.	They can be easily transported through pipelines.
5.	Combustion rate is slow but its control and stop is not easy.	Quickly combustible and can be controlled and stopped when required.	Combustion rate is fast, controlled and stopped easily.
6.	They cannot be used in internal combustion engines.	They can be used in ICE.	They can also be used in ICE.

7.	They produce ash and its disposal is a big problem.	No ash problem.	No ash contents are produced.
8.	They produce smoke.	Only high carbon or aromatic liquid fuels may produce smoke.	No smoke is produced.
9.	They have lower calorific value.	They have higher calorific value.	They have highest calorific value.
10.	They have low thermal efficiency.	They have higher thermal efficiency.	They have highest thermal efficiency.

### 1.3 CHARACTERISTICS OF A GOOD FUEL

- High Calorific Value :** A good fuel should have a high calorific value, *i.e.* high heat content. Since the amount of heat liberated and temperature attained depends upon the calorific value of fuel.
- Low Moisture Content :** The fuel should have low moisture content, because moisture content of the fuel reduces the heating value.
- Moderate Ignition Temperature :** An ideal fuel should possess moderate ignition temperature so that it can burn smoothly.
- Low Cost :** A good fuel should be readily available in bulk at low cost.
- Easy to Transport :** The fuel supply should be reliable and transport at a low cost.
- Low Percentage of Non-combustible Matter :** A fuel should have low content non-combustible matter, because non-combustible matter contains ash or clinkers, which also reduces the heating value.
- Products of Combustion should not be Harmful :** The products obtained during combustion of a fuel should be harmless and non polluting, CO, SO<sub>2</sub>, PH<sub>3</sub>, H<sub>2</sub>S, PbBr<sub>2</sub> etc. are very poisonous pollutants of the atmosphere.
- Moderate Velocity of Combustion :** If the rate of combustion is low, then the high temperature may be impossible because a part of the heat liberated may get radiated instead of raising the temperature. On the other hand, high combustion rate is also not required. Hence, the velocity of combustion should be moderate.
- Size :** In case of solid fuel, the size should be uniform so that combustion is regular.
- Should not Undergo Spontaneous Combustion :** In case of liquid and fuel gas, spontaneous ignition can cause fire hazards.
- Combustion should be Easily Controllable :** Combustion should be easy to start and easy to stop when required.
- Efficient Burning :** A good fuel should burn efficiently without smoke.
- Storage Cost :** The cost of storage of the fuel in bulk should be minimum.

## 1.4. CALORIFIC VALUE

Calorific value of a fuel is defined as "the total amount of heat liberated by the complete combustion of a unit weight (or volume) of fuel in the air or oxygen."

### 1.4.1 UNIT OF HEAT

Following are the units of heat in many systems.

1. **C.G.S. System (Calorie)** : Calorie is defined as "the amount of heat required to raise the temperature of one gram of water through one degree centigrade (15°C – 16°C)."  
1 calorie = 4.185 joules =  $4.185 \times 10^7$  ergs.
2. **M.K.S. System (Kilocalorie)** : Kilocalorie is defined as "the amount of heat required to raise the temperature of one kilogram of water through one degree centigrade."  
1 Kcal = 1000 cal.
3. **F.P.S. System (British Thermal Unit)** : B.Th.U. may be defined as "the amount of heat required to raise the temperature of one pound of water through 1°F (60 – 61°F)."  
1 B.Th.U. = 252 cal = 0.252 Kcal = 1,054.6 Joules =  $1,054.6 \times 10^7$  ergs  
1 Kcal = 3.968 B.Th.U.
4. **C.H.U. System (Centigrade Heat Unit)** : Centigrade heat unit may be defined as "the amount of heat required to raise the temperature of one pound (lb) of water through 1°C. Thus, 1 Kcal = 3.968 B.Th.U. = 2.2 C.H.U.

### 1.4.2 UNITS OF CALORIFIC VALUE

- (i) The calorific value of solid and liquid fuels are usually expressed as below-

Calorie/gm	(in C.G.S. System)
Kcal/kg	(in M.K.S. System)
B.Th.U./lb	(in F.P.S. System)

*Relationship* : 1 Kcal/kg = 1000 calorie/gm = 1.8 B.Th.U./lb

- (ii) Where calorific value of gases are expressed as

$$\text{Relationship : } \left[ \begin{array}{l} 1 \text{Kcal/m}^3 = 0.1077 \text{B.Th.U./ft}^3 \\ 1 \text{B.Th.U./ft}^3 = 9.3 \text{Kcal/m}^3 \end{array} \right]$$

### 1.4.3 TYPES OF CALORIFIC VALUE

#### 1.4.3.1 GROSS OR HIGHER CALORIFIC VALUE (HCV)

**Definition** : HCV is defined as "the total amount of heat liberated, when unit mass volume of the fuel is burnt completely and the products of combustion are cooled down to room temperature."

Generally all fuels contain some hydrogen. When the calorific value of hydrogen containing fuel is determined experimentally, the hydrogen undergoes combustion and is converted into steam.



When the products of combustion are condensed to room temperature (25°C or 77°F), steam is converted into liquid water and latent heat is produced. This latent heat of condensation of steam so liberated is included in the measured heat and so the value is known as higher or gross calorific value.

#### 1.4.3.2 NET OR LOWER CALORIFIC VALUE (LCV)

In actual use of any fuel, the water vapor and moisture etc. are not condensed and escape as such along with hot combustion gases. Hence, a lesser amount of heat is available.

*Definition* : LCV is defined as "the amount of heat liberated when one unit mass/volume of the fuel is burnt completely and the product of combustion are allowed to escape."

The difference between gross and net calorific value is taken to be 1,056.6 B.Th.U./lb or 587 Kcal/kg.

Thus,  $\text{LCV} = \text{HCV} - \text{latent heat of water vapors formed}$

Since, 1 part by mass of hydrogen gives 9 parts by mass of water.

$$\text{LCV} = \text{HCV} - (\text{Mass of hydrogen in fuel} \times 9 \times \text{latent heat of steam})$$

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

Where, H is the percentage of hydrogen in fuel and 587 Kcal/kg is latent heat of steam.

## **1.3 SOLID FUEL**

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Solid fuel refers to various types of solid material that are used as fuel to produce energy and provide heating, usually release through combustion. Wood and coal are important primary solid fuel, while charcoal, coke etc. are the secondary solid fuel.

### **1.3.1 Wood**

It has been used as a fuel from ancient time. The main inflammable components are resin and wax which are in small amounts (0.5-2%). The major non-inflammable constituent is water (25-50% in freshly cut wood and 10-15% in air drier wood). The variations in calorific value of different woods are due to variation in the proportions of organic matters in the wood. The calorific values of dried wood vary from about 4500 Kcal/kg to 5000 Kcal/kg. Ultimate analysis of wood on dry basis is 49-51% C, 5.9-6.2% H<sub>2</sub> and 43-45% O<sub>2</sub>.

### **1.3.2 COAL**

Coal is readily combustible black or brownish black sedimentary rock normally occurring in rock strata in layers or veins called coal beds or coal streams. Coal is primarily of carbon along with variable quantities of other elements, chiefly sulphur hydrogen, oxygen and nitrogen. Coal is a very important fuel since give many other useful products on carbonisation in addition to its use as a fuel in a large number of industries and as reducing agent in many chemical process like during iron processing.

### **1.3.3 ORIGIN OF COAL**

Two theories viz. insitu theory and drift theory have been proposed by geologist to explain the coal formation. The insiter theory explains the formation of coal at the site of vegetation itself.



In drift theory or transportation theory, the vegetable is believed to have been transported from the site or growth and buried underground which subsequently transformed into peat under an aerobic condition.

Coal is formed by the combined action of high temperature and high pressure on degraded vegetable matter over geological period of time. The vegetable matter mainly composed of cellulose  $(C_6H_{10}O_5)_n$ . During conversion to coal, the proportion of hydrogen and oxygen decrease while that of carbon increase.

### 1.3.4 CLASSIFICATION OF COAL

Commercially coal can be classified as steam coals, coking coals, non-coking coals etc., depending on their suitability for specific purpose and physical properties. However, the most common method of coal classification is according to their rank, i.e., peat, lignite, sub bituminous, bituminous and anthracite. The ranking classification is primarily based on the each content of coal or we can say that the rank of a coal is a measure of its degree of maturity. The increasing order of rank during coal formation is as:

Vegetation, debris → Peat → lignite → sub-bituminous → bituminous → semi-anthracite → anthracite → graphite.

- ① Decrease in moisture content, H, O, N, S-content and volatile matter →  
 Increase in carbon content, calorific value, hardness →

← Moisture content, H, O, N, S content and V.M. →  
 ← Carbon content, calorific value, hardness →

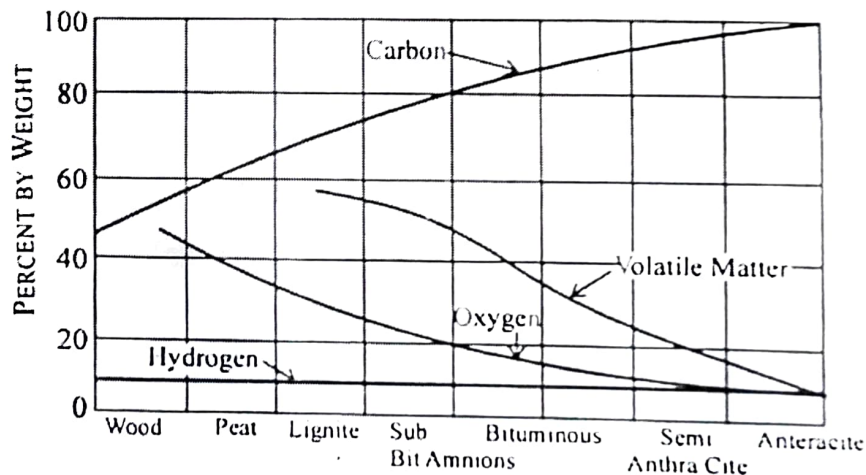


Fig.1.1 : Progressive changes during the coalification

- (i) **Peat** : According to oxford dictionary of geography "Peat is a mass of dark brown or black plant material produced when the vegetation of a wet area is partly decomposed. Peat forms where the land is waterlogged and where temperature are low enough to slow down the decomposition of plant residue. It is a first stage of coalification. In fact,

peat is not used as coal for industrial purposes. The main difficulties in use of peat are:

- (a) Uneconomical production of the deep buried peat, and
- (b) Large amount of water associated with peat.

The average composition of air dried peat is: C=57%, H=6%, O=35%, ash=2.5-6% and its calorific value is about 5400 Kcal/kg.

- (ii) **Lignite (Brown coal)** : Lignite often referred to as brown coal or Rosebud coal [by Northern Pacific Railroad], is a soft brown coal with characteristics that put it in between coal and peat. It is the next stage of coalification after peat. Dry lignite is powdered and pressed into small briquettes and employed as a household and boiler fuel. Air dried lignite contains C = 60-70%, O = 20%. Its calorific value is about 6500-7100 Kcal/kg.
- (iii) **Bituminous coal** : Bituminous coal and **black coal** is a relatively soft coal contain in a tar like substance called bitumen. It is of higher quality than lignite coal but of poorer quality than anthracite coal. It is most widely used. Carbon contents of bituminous coal varies from 75-90% and their calorific value is about 8000 Kcal/kg. They are widely used in industries for making metallurgical coke, coal gas and for steam preparation as well as domestic heating. They are further subclassified as follows (on the basis of carbon contents) :
  - (a) **Sub-bituminous coal**: Carbon content varies from 75-83%, O = 10-20 and calorific value is about 7000 Kcal/kg.
  - (b) **Semi-bituminous coal**: These are rich in carbon contents 83-90%. Their calorific value is about 8500-8600 Kcal/kg. These are used in coke manufacturing.
- (iv) **Anthracite coal**: These are the product with maximum transformation and are the highest in rank. Their carbon content is more than 90% and volatile matter less than 8%. These coals are black in colour, hard and brittle and do not produce much fine powder on crushing. These coals are non-caking and burn without smoke and with a short non-luminous flame giving intense heating. Air dried anthracite contains, C = 93%, H = 3%, N = 0.7% and O = 3% and calorific value is 8800 Kcal/kg.

**Table 2 : Average composition from wood to anthracite on coalification**

Fuel	Moisture at 40° and 60% relative humidity	Volatile matter	C	H	N	O	Calorific value (KCal/kg)
Wood	25	75	50	6	0.5	43.5	4600
Peat	25	65	57	5.7	2.0	35.3	5400
Lignite	18	50-56	67	5.0	1.5	26.5	6600
Sub-bituminous coal	11	45-50	77	5.0	1.8	16.2	7200
Bituminous coal	4	20-45	83	5.0	2.0	10.0	8500
Semi-bituminous coal	1	9-20	90	4.5	1.5	4.0	8600
Anthracite	1.5	5.6	93	3.0	0.7	3.0	8750

### 1.3.5 SELECTION OF COAL

The following factors are taken into consideration, for selection of coal for various uses:

- (i) **Calorific value:** The coal with high calorific value is preferred, so that the larger quantity of heat can be obtained from the small amount of coal.
- (ii) **Ash content:** The coal with low ash contents is preferred. It does not take part in combustion and lowers the heating value of coal. It poses problem of storage, handling and pollution.
- (iv) **Calorific intensity:** The coal having a high calorific intensity, is always preferred. It may be defined as "the maximum temperature attainable on complete combustion of coal with theoretical amount of air".

As a fuel burns without any flame, the heat liberated can be considered to be used in heating up the fuel bed and the fuel is then turned to burn with high calorific intensity. But, fuel containing volatile matter burn with a flame and the total heat is liberated over a larger area and thus the heat is less localized. Hence fuel burning with a flame have a lower calorific intensity. The calorific intensity depends on the nature, quality, quantity and specific heat of gaseous products obtained on combustion of coal. Mostly, the heat liberate on combustion preheats the air and hence calorific intensity becomes low.

**Calorific intensity can be calculated as flame temperature**

$$\text{Flame temperature} = \frac{\text{Heat of combustion} + \text{Specific heat of C}}{\Sigma(\text{Combustion Product} \times \text{specific heat})}$$

The flame temperature is never attained in general, but it represents the theoretically attained maximum temperature to which a fuel could be heated under ideal conditions.

- (v) **Caking quality:** It is a very important factor for preparing metallurgical coke. Depending on the type of product/residue formed on heating the coal in the absence of air, it may be caking coal or coking coal.

Coal	Caking coal, if it produces soft, plastic coherent mass on heating.
	Caking coal, if it produces porous, hard and strong residue on heating.

Only bituminous coals have caking properties.

- (vi) **Size of coal:** It should be uniform to facilitate easy handling and regulation of the combustion process.
- (vii) **Sulphur and phosphorous contents:** The coal used for metallurgical purpose must have least amount of sulphur and phosphorus. Because, these badly affect the properties of the metal. The gases produced from such coal are corrosive to equipments and also pollute the environment.

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### 1.3.6 PULVERISED COAL

The rate of combustion of a solid fuel can be increased by bringing the air into intimate contact with the fuel. This can be achieved by pulverising the coal in powdered form (75-85% below 74  $\mu\text{m}$ ). The pulverised coal is sent along with air into suitable burners where the air fuel mixture burns just like gaseous fuel.

The coal having a high volatile matter content are used for making pulverised coal. As soon as it is fired, the volatile matter liberates quickly and starts burning which helps the combustion of fixed carbon.

### 1.4 COKE

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Coke is an important secondary fuel of industrial importance and is produced by strongly heating the coal out of contact with air. **This process of heating the coal in absence of air to form coke is called carbonisation of coal.** The properties and efficiency of coal improve on carbonisation.

#### Requisites of a metallurgical coke:

- (i) **High Purity:** The best metallurgical coke should contain lowest possible percentage of moisture (<4%), ash (<6%) sulphur (<0.5%) and phosphorous (<0.1%).
- (ii) **Porosity:** The metallurgical coke should be porous to provide intimate contact between the carbon and oxygen to ensure efficient combustion of fuel.
- (iii) **Strength:** The coke should be strong enough to withstand the abrasion and pressure due to arc, flux etc.
- (iv) **Uniformity:** The coke should be uniform and medium in size for uniform combustion.
- (v) **Calorific value:** The coke should possess a high calorific value.
- (vi) **Cost:** Cost should be low.
- (vii) **Calorific intensity:** The calorific intensity of the fuel should be high enough to melt metal.
- (viii) **Combustibility:** The coke should burn easily but at the same time should not be very reactive.

#### 1.4.1 PROCESS OF CARBONISATION

Coal can not be used as a metallurgical fuel (except in reverberatory furnaces) because it does not have the necessary purity, porosity and strength. During process of carbonisation, when bituminous coal is slowly heated, moisture and gases are driven out first. At 270°C, some  $\text{H}_2\text{S}$  olefine gases are evolved. At 350°C, active decomposition of coal substance take place with brisk evolution of gas and tarry vapours. Below 450°C, the liberated gases mainly comprise of hydrocarbons. At about 700°C, amount of liberated  $\text{H}_2$  increases.

The properties of coke produced mainly depend on the type of coal used, the temperature of carbonisation and the rate of carbonisation. These factors control the porosity, reactivity and the amount of volatile matter retained in the coke.

### 1.4.2 TYPES OF CARBONISATION

Depending on the temperature of carbonisation, the following three types of carbonisation are usually performed:

(1) **Low temperature carbonisation (LTC) [at 500-700°C]:** This type of carbonisation is carried out mainly for the manufacture of domestic fuel. The coke produced is called low temperature coke and the yield is about 75-80%. The coke thus produced contains 5-15% volatile matter and is not sufficiently strong to be used as a metallurgical fuel. Since it is easily ignited, it is a valuable, smokeless, domestic fuel. Its calorific value is about 6300 to 9500 Kcal/kg, depending on the coal and the process used. However this process has several disadvantages as follows:

- (i) Produces heavy air pollution
- (ii) Poor quality of the soft coke produced
- (iii) Loss of liquid and gaseous by products formed

An important practical difficulty for low temperature carbonisation of coals is the poor transmission of heat through the coal charge. In order to overcome this difficulty modern commercial plants employ either externally heated metal or refractory retorts of narrow width or internally heated stationary or rotary retorts or a combination of two. Some such processes developed at commercial scale include:

- (i) Fuel research board (UK) vertical retorts.
- (ii) CFRI (India) vertical retort with gas circulation.
- (iii) Rexco process.

(2) **Medium temperature carbonisation [at 700-900°C] [MTC]:** This type of carbonisation is carried out at 700-900°C. The yield of total light oils and phenols are more in MTC than HTC. The tar obtained by this method has different properties than the tar obtained from HTC. Light oil obtained in this process has more paraffinic and diolefinic hydrocarbons. Thus MTC is done to obtain greater yield of particular type of by products.

(3) **High temperature carbonisation [HTC] [ $>900^{\circ}\text{C}$ ]:** High temperature carbonisation is used for the production of pure, hard, strong and porous metallurgical coke. The yield of coke is 65-75%, and the volatile matter is 1-3%. The calorific value is lower (5000-6000 Kcal/m<sup>3</sup>) than that produced in LTC.

**Table 3 : Differences between low and high temperature carbonization**

S.No.	Low temperature carbonization	High temperature carbonization
1.	Heating temperature: 500-700°C	900°-1200°C or above
2.	Yield of coke: 75-80%	65-75%
3.	% of volatile matter in coke produced: 5-15%	1-3% volatile matter
4.	Mechanical strength: not mechanically strong.	Hard and have good mechanical strength.
5.	Use: Good for domestic purpose.	Good for metallurgical process
6.	Quantity of by product gases: 130-150m <sup>3</sup> /tonne.	300-390 m <sup>3</sup> /tonne
7.	Calorific value: 6500-9500 Kcal/m <sup>3</sup>	5400-6000 Kcal/m <sup>3</sup>
8.	% of aromatic hydrocarbons in gases : lower	Higher
9.	Hardness of coke : soft	Hard
10.	Smoke produced on burning coke: Smokeless	Smoky
11.	% of straight chain hydrocarbon: smaller	Higher
12.	Steel retorts are required for this purpose	Retorts made of refractor bricks are used for this purpose.
13.	Coking rate is very slow	Coking rate is high than LTC
14.	Less fuel consumption and less temperature is required.	More amount of fuel is required to attain high temperature.

# UNIT - II

## PART - B (iii)

### 10.1 Natural Gases :

Natural gas is an important primary gaseous fuel. It is a mixture of methane, ethane, propane, butane, pentane and traces of other gases like carbon dioxide, nitrogen, hydrogen sulphide, mainly found in the vicinity of coal mines or oil fields. It is also associated with petroleum deposits. When natural gas occurs along with petroleum in oil wells, it is called wet gas. When natural gas is associated with crude oil, it is called dry gas. To use the wet gas as LPG, it is treated to remove propane, propane butane and butane since wet gas has large amount of the heavier unsaturated hydrocarbons than that of dry gas. It is having greater calorific value about 12000–14000 kcal/m<sup>3</sup>. The approximate composition of natural gas is CH<sub>4</sub> = 70–90%, C<sub>2</sub>H<sub>6</sub> = 5–10%, H<sub>2</sub> = 3%, traces of other gases like CO and CO<sub>2</sub>.

- (a) It is an excellent domestic fuel and can be conveyed over very long distances through pipe-lines.
- (b) It is used for the synthesis of number of chemicals.

### 10.2 Manufacture of Gaseous Fuels :

Under this group, the important gases produced are producer gas, water gas or blue gas coal gas, oil gas etc.

(i) **Producer Gas** : It is a secondary gaseous fuel. It is a mixture of combustible carbon monoxide and non-combustible nitrogen gas. It also contains small amount of H<sub>2</sub>, CH<sub>4</sub> and CO<sub>2</sub>. Producer gas is prepared by passing air mixed with steam over a red hot coal or coke bed maintained at about 1100°C in special type of reactor called producer. The composition of producer gas depends on (a) nature of fuel used, (b) temperature of operation, and (c) amount of moisture or steam. High-volatile bituminous coals give a richer gas with small amounts of methane, whereas

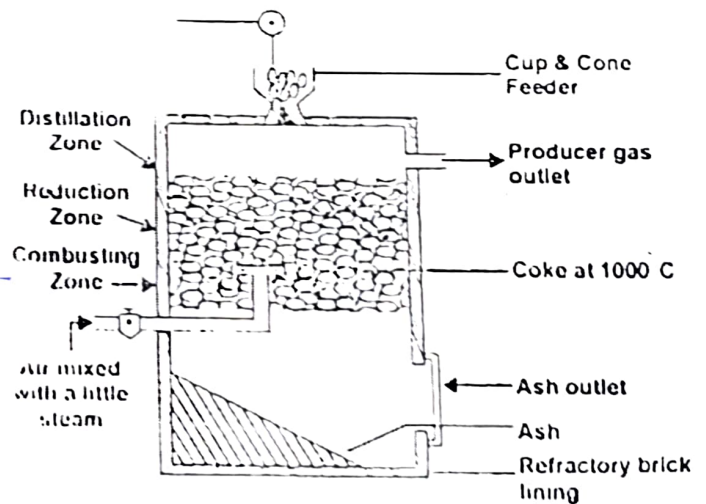


Fig. 20 : Production of producer gas

coke gives poor gas deficient in methane. Low temperatures favour high production of  $\text{CO}_2$  whereas high temperatures favour high production of  $\text{CO}$ .

When steam is added to the blast, it increases the proportion of  $\text{H}_2$  and  $\text{CO}$  in the producer gas. This raises the calorific value of producer gas due to decreased amount of  $\text{N}_2$ . However, if excessive amounts of steam are used, more  $\text{CO}_2$  will be formed due to decrease in temperature.

### Construction :

A typical producer with various reaction zones is shown in Fig. 20.

The producer consists of an air-tight cylindrical furnace made of fireclay refractory bricks. A water seal provided at the base facilitates the removal of ash. The coal or coke is fed from the top. The air, or a mixture of air and steam is blown through a pipe at the bottom. At the top an outlet is provided for the discharge of producer gas.

### Working :

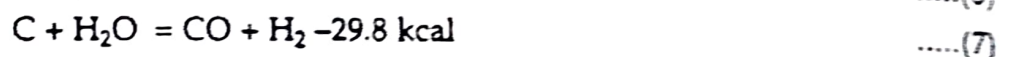
To start the production of producer gas, the cylindrical furnace is filled with fuel (coal or coke) and it is ignited. Then the air is forced through the hot fuel and in the lower zone, known as oxidation zone, carbon burns to  $\text{CO}_2$  and  $\text{CO}$  which are highly exothermic reactions :

#### Oxidation Zone :

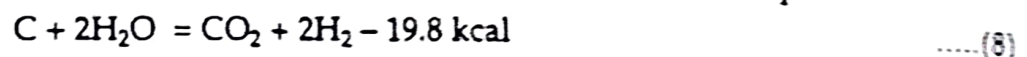


#### Reduction Zone :

The  $\text{CO}_2$  so produced and steam ( $\text{H}_2\text{O}$ ) of blast pass upwards through the bed of fuel where these are reduced to  $\text{CO}$  and  $\text{H}_2$  by the endothermic reactions in the reduction zone :



Other secondary reactions of steam ( $\text{H}_2\text{O}$ ) with carbon and  $\text{CO}$  also take place



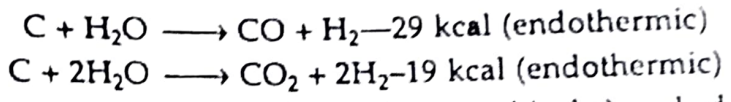
In the top portion of the producer, there is fresh fuel which is at much lower temperature and no reaction takes place, but the fuel gets preheated and volatile matter distills out. The producer gas produced from efficient plants and without use of steam, contains mainly  $\text{CO}$  (33%) and  $\text{N}_2$  (64%) with small amount of  $\text{CO}_2$ . If air alone is blown through producer, the combustion of carbon in air heats the lower part excessively resulting in formation of clinkers which are difficult to remove.

The calorific value of producer gas is low ( $1000\text{--}1200 \text{ kcal/m}^3$ ) and comes out at relatively higher temperature, and thus, it is used at the place of generation to make full use of its sensible heat. The main uses of producer gas are in heating of coal gas retorts, in furnaces and gas engines.



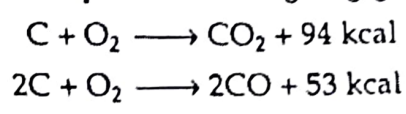
**Water Gas :** Water gas is also called blue gas because it burns with blue flame. Water gas is a mixture of carbon monoxide and hydrogen (50% along with small amount of non combustible gases such as carbon dioxide and nitrogen). The equipment used for production of water gas is identical to that used in production of producer gas. This consist two operation cycles i.e., alternatively air blowing and steam blowing.

**Reactions involved :** When steam (H<sub>2</sub>O) reacts with red hot coke at about 1000°C, the following reactions take place



As both above reactions are endothermic, the fuel bed (coal/coke) cools down.

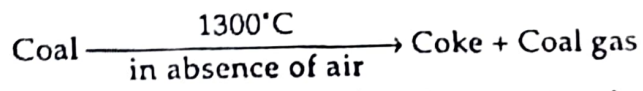
The above endothermic reactions cause a fall in temperature of coal bed. In order to raise the temperature, steam supply is withdrawn and in its place only air is introduced. The following exothermic reactions take place. The outgoing gases generated in this cycle are



A mixture of CO<sub>2</sub> and N<sub>2</sub> can not be used as fuel but there is a rise in temperature to about 1000°C. It is properly maintained by alternatively sending steam and air. Average composition of water gas is CO = 41%, H<sub>2</sub> = 51%, CO<sub>2</sub> 4% and N<sub>2</sub> 4% and it has calorific value of about 2,800 kcal/m<sup>3</sup>. It is enriched with some gaseous hydrocarbon. This is so called **Corburretted water gas** contains CO = 25%, H<sub>2</sub> = 35%, hydrocarbons = 35%, N<sub>2</sub> = 5% and CO<sub>2</sub> = 5%.

It is used as (a) source of hydrogen and (b) illuminating gas. Its flame is short but very hot.

**Coal Gas :** It is produced during the carbonisation of coal i.e., when coal is heated in the absence of air at about 1300°C in coke ovens or gas retorts. The heating is carried out by burning producer gas



The gas coming out from the retort is first scrubbed by passing through a hydraulic main (Fig. 22). Much of the tar is then removed by cooling the gas in a big water cooled heat exchanger called exchanger. Any remaining tar and ammonia present in the gas are removed by scrubbing with water in scrubber. The cooled gas is then scrubbed with creosote oil which dissolves benzol, naphthalenes etc. Sulphur compounds such as H<sub>2</sub>S can be removed by passing it over a column of moist ferric oxide (Fe<sub>2</sub>O<sub>3</sub>).

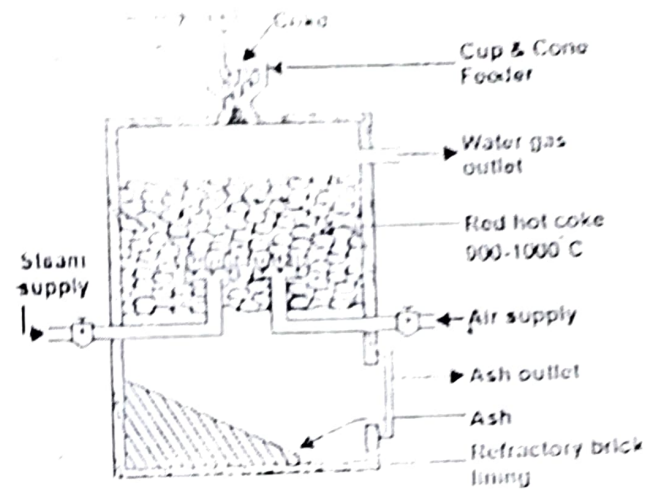


Fig. 21 : Production of water gas

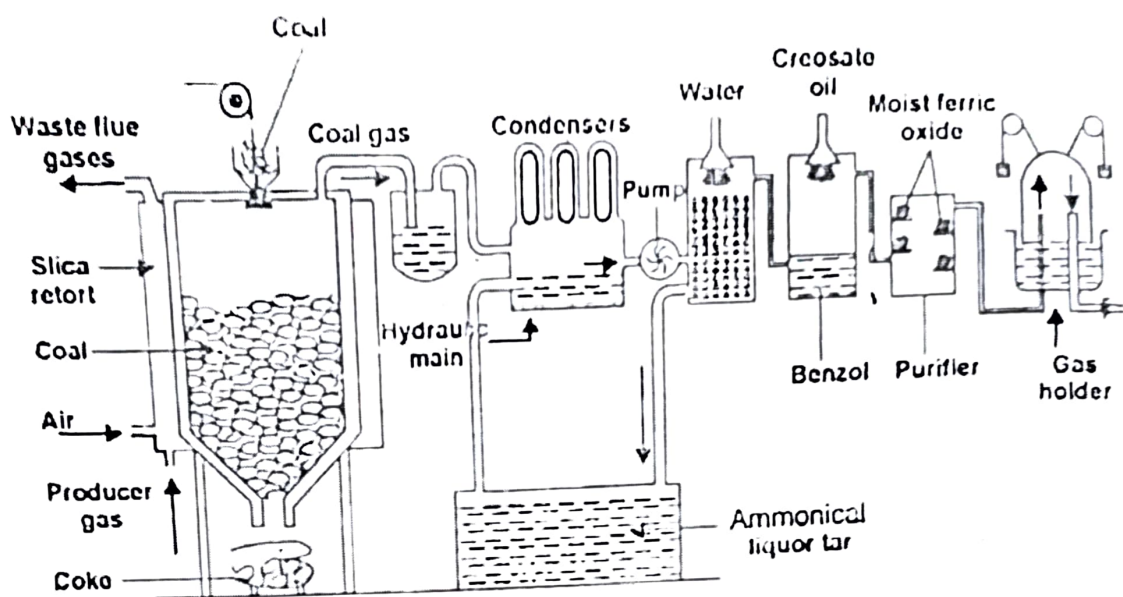


Fig. 22 : Manufacture of Coal Gas

When ferric oxide of the purifier is exhausted, it is taken out for regeneration and exposed to air when it gets oxidised to ferric oxide.



The purified coal gas is finally stored over water in gas holder.

The average composition of coal gas is  $\text{CH}_4 = 32\%$ ,  $\text{H}_2 = 40\%$ ,  $\text{CO} = 7\%$ ,  $\text{C}_2\text{H}_2 = 2\%$ ,  $\text{N}_2 = 4\%$ ,  $\text{C}_2\text{H}_4 = 3\%$ ,  $\text{CO}_2 = 1\%$ . Calorific value is about  $4,900 \text{ kcal/m}^3$ . Coal gas is used (i) for illumination purpose, (ii) in metallurgy for providing reducing atmosphere and (iii) as fuel.

## UNIT - II

### PART - C

## 1.7 LIQUID FUELS

The main largest source of liquid fuel is "Petroleum" or "Crude oil" and almost the liquid fuels are derived from petroleum. The petroleum is mined and is subjected to fractional distillation to obtain a wide range of fuels. The liquid fuels are characterized by low flash point, higher calorific value, low viscosity at ordinary temperature and low moisture and sulphur contents.

The liquid fuels are also obtained synthetically from the hydrogenation of coal. Low boiling fractions of petroleum are used in petrol engines while higher boiling fractions of petroleum are used in diesel engines and oil fired furnaces. Kerosene is used for heating and cooking liquid fuels, find extensive use in domestic and industrial field.

### *Advantages*

- (i) They have higher calorific value per unit mass than solid fuels.
- (ii) They burn without forming dust, ash, clinkers etc.
- (iii) They are easy to transport through pipes.
- (iv) They require less amount of air for complete combustion.
- (v) They can be used as internal combustion fuels.
- (vi) They require less volume for storage as compared to solid and gaseous fuels.
- (vii) They are clean in use and economic in labor.
- (viii) Combustion can be started or stopped at any time resulting in economic use of fuel.

However, they are highly inflammable and give unpleasant odor during incomplete combustion. The cost of liquid fuel is relatively much higher as compared to solid fuels. There is greater risk of fire hazards, particularly in case of highly inflammable and volatile liquid fuel.

### 1.7.1 PETROLEUM

'Petroleum' or crude oil (In Latin, *petra* = rock, *oleum* = oil) means rock oil. It is a source of many liquid fuels like gasoline, diesel, kerosene etc. that are in current use. It is also a very good source of *petrochemicals*. These petrochemicals like alkane, alkene, benzene etc. are converted into raw materials like **ethanol**, acetic acid etc. which find extensive applications in industries for the production of **drugs**, **detergents**, **polymers** etc. It is also named as *mineral oil* because it occurs beneath the **earth**. It is a dark greenish-brown, viscous oil found deep in

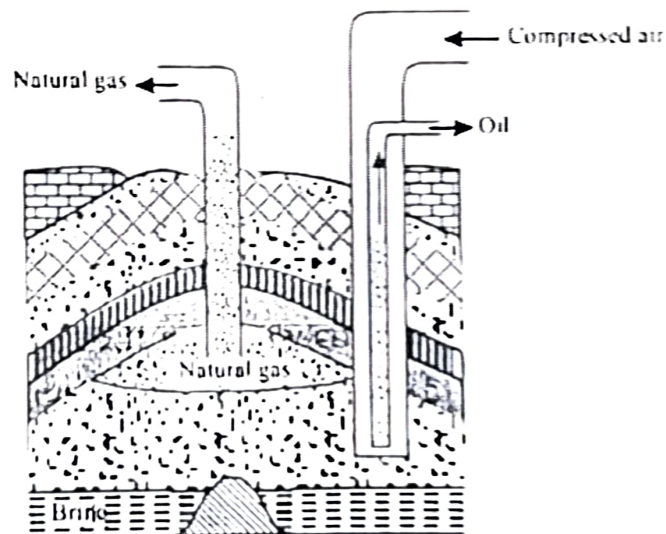
### 1.7.1.2 CLASSIFICATION OF CRUDE PETROLEUM

Crude petroleum may be classified into three classes, depending on the nature of hydrocarbons.

- (i) **Paraffinic base petroleum** : It is mainly composed of the saturated hydrocarbons from  $\text{CH}_4$  to  $\text{C}_{35}\text{H}_{72}$ , the hydrocarbons from  $\text{C}_{18}\text{H}_{38}$  to  $\text{C}_{35}\text{H}_{72}$  are semi solids called "Waxes."
- (ii) **Asphalt base petroleum** : It is mainly contains cycloparaffines and naphthalenes.
- (iii) **Mixed base petroleum** : It contains both paraffinic as well as asphaltic hydrocarbons.

### 1.7.1.3 MINING OF PETROLEUM

The crude oil is found well deep below the earth. The oil is found deep below the impervious rock floating over salty water (brine). It is often associated with natural gas (mainly methane) which exerts pressure on the oil surface and drives it out with high velocity through natural openings.



**Fig.1.4 : Mining of Crude Oil and Use of Air-lift Pump**

Mining of petroleum is done by drilling hole in the earth's crust and sinking pipes upto the oil bearing porous rocks. Usually oil rushes out by itself due to the hydrostatic pressure of the natural gas or it may be pumped up using an air-lift pump or a lift pump.

The air-lift pump is a device containing two co-axial pipes, lowered into the oil well. Compressed air is forced through the outer pipe causing the oil to flow up the inner one and can be conveyed through pipe lines to refinery and processed.

#### 1.7.1.4 REFINING OF CRUDE PETROLEUM

As already mentioned, petroleum coming out from ground is dark colored, thick liquid and mixture of various hydrocarbons containing a lot of impurities (sand, brine etc.). It is therefore separated into a number of useful fractions by fractional distillation.

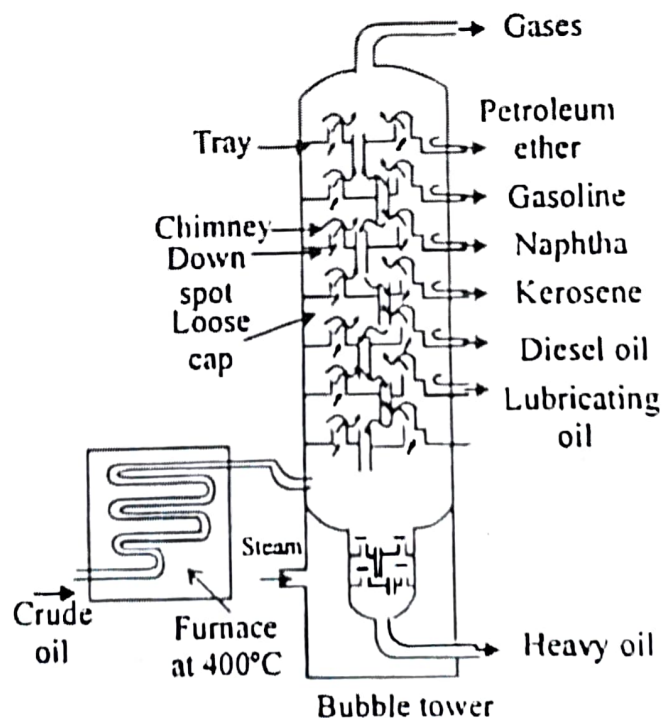
"The process of separation of crude oil into various fractions by *fractional distillation* and desired specific products can be obtained from these fractions by removing objectionable impurities is known as *refining of petroleum* and the plants set up for this purpose are called *refineries*."

The process of refining involves the following steps :

- (i) **Removal of Water by Cottrell's Process :** Crude oil coming out from the earth crust is an emulsion of oil and brine (salt water). The crude oil is allowed to flow between two highly charged electrodes where colloidal water droplets coalesce to form large drops and separates out from the oil.
- (ii) **Removal of Sulphur Compounds :** The crude oil is allowed to be treated with copper oxide, where sulphur is converted into insoluble copper sulphide which may be removed by filtration.

They exhibit bad odor and color, cause corrosion of metal parts of ICE and lower the response to the anti-knocking agent.

- (iii) **Fractional Distillation :** The crude oil is heated first in an iron retort at about  $400^{\circ}\text{C}$ . The most of oil is evaporated (except asphalt or coke).



**Fig.1.5 : Fractional Distillation of Crude Petroleum**

The hot vapors are then passed into the long fractionating column. Fractionating column is a long cylindrical tower containing a series of horizontal stainless steel trays at short distances. Each tray is provided with small chimney which are covered with loose cap called bubble tower. As the vapors go high, they become cooler and condense. The higher boiling fraction (300°C) condenses first at the bottom while lower boiling fractions will condense later near the top of the tower. The outlets in tower are provided in the side of the column to withdraw a number of fractions. Various fractions are collected at intermediate points, depending upon their boiling points. High boiling fractions, getting collected at the bottom, can be further subjected to cracking to get more useful low boiling fractions.

Various principal fractional products and their uses are given in table 1.7.

**Table 1.7 : Fractions by Distillation of Crude Oil**

S.No.	Name of fraction	Boiling range (°C)	Approximate composition in terms of hydrocarbon containing C atoms	Applications
1.	Uncondensed (refinery) gas	Below 30°C	C <sub>1</sub> to C <sub>4</sub>	Gaseous fuel (LPG)
2.	Petroleum ether	30-70°C	C <sub>5</sub> -C <sub>7</sub>	As extracting solvent, in dry-cleaning
3.	Gasoline (petrol)	40-120°C	C <sub>8</sub> -C <sub>9</sub>	Motor fuel, solvent and in dry-cleaning
4.	Naphtha or solvent spirit	120-180°C	C <sub>9</sub> -C <sub>10</sub>	As solvent and in dry-cleaning
5.	Kerosene	180°C-250°C	C <sub>10</sub> -C <sub>16</sub>	Domestic fuel, jet fuel, tractor fuel, for preparing laboratory gas, as illuminate
6.	Diesel oil or fuel oil or gas oil	250°-320°C	C <sub>10</sub> -C <sub>15</sub>	Diesel engine fuel, feed stock for cracking
7.	Heavy oil (on further fractional distillation gives following) (a) Lubricating oil (b) Vaseline  (c) Grease (d) Paraffin wax	320°-400°C	C <sub>17</sub> -C <sub>30</sub>	To obtain gasoline by cracking  As lubricants In cosmetics and medicine to prepare ointments As lubricant In candles, wax paper, boot polish, tarpolin cloth etc.
8.	Residue may be either : (a) Asphalt (b) Petroleum coke	above 400°C	C <sub>30</sub> and above	Water proofing of roofs and road making As electrodes and fuel

The most important liquid fuels obtained from petroleum are gasoline, kerosene oil and diesel oil.

- Petrol :** This fraction is obtained between temperature range 40–120°C. It consists of a mixture of hydrocarbons such as  $C_5H_{12}$  (pentane) to  $C_8H_{18}$  (octane). Its calorific value is about 11,250 Kcal/kg. It is highly volatile and inflammable. The approximate composition of petrol is : C = 84%, H = 15%; N,S,O = 1%.  
It is used as a fuel for internal combustion (IC) engines of automobiles and aeroplanes.
- Kerosene Oil :** This fraction is obtained between 180-250°C. It consists of a mixture of hydrocarbons such as  $C_{10}H_{22}$  (decane) to  $C_{16}H_{34}$  (hexadecane). Its calorific value is 11,100 Kcal/kg. The crude kerosene oil is slightly colored while a good and pure variety of kerosene oil is colorless. Due to high boiling point range (200–300°C), kerosene does not vaporize easily.  
The approximate composition of kerosene oil is : Carbon (C) = 84%; H = 16%; S = Less than 0.1%. It is used as a domestic fuel in stove, as jet engine fuel and for making oil gas.
- Diesel Oil :** This fraction is obtained between 250 – 320°C. It consists of a mixture of hydrocarbons such as  $C_{15}H_{32}$  to  $C_{18}H_{38}$ . Its calorific value is about 11,000 Kcal/kg. Its density is 0.86 to 0.95. It is used as a diesel engine fuel.

**Table 1.8 : Comparison of Important Liquid Fuels**

S.No.	Factor	Petrol (gasoline)	Kerosene	Diesel
1.	Distillation range	40–120°C	180°–250°C	250–320°C
2.	Hydrocarbons	$C_5H_{12}$ to $C_8H_{18}$	$C_{10}H_{22}$ to $C_{16}H_{34}$	$C_{15}H_{32}$ – $C_{18}H_{38}$
3.	Calorific value	11250 kcal / kg	11,100 kcal/kg	11,000 kcal/kg
4.	Use	Internal combustion engine fuel	Domestic fuel and for making oil gas	Diesel engine fuel
5	Cost	Costliest	Cheap	Costlier