CY3151

ENGINEERING CHEMISTRY

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COURSE OBJECTIVES:

To inculcate sound understanding of water quality parameters and water treatment techniques.

To impart knowledge on the basic principles and preparatory methods of nanomaterials.

To introduce the basic concepts and applications of phase rule and composites.

To facilitate the understanding of different types of fuels, their preparation, properties and combustion characteristics.

To familiarize the students with the operating principles, working processes and applications of energy conversion and storage devices.

UNIT I WATER AND ITS TREATMENT 9

Water: Sources and impurities, Water quality parameters: Definition and significance of-color, odour, turbidity, pH, hardness, alkalinity, TDS, COD and BOD, fluoride and arsenic. Municipal water treatment: primary treatment and disinfection (UV, Ozonation, break-point chlorination). Desalination of brackish water: Reverse Osmosis. Boiler troubles: Scale and sludge, Boiler corrosion, Caustic embrittlement, Priming & foaming. Treatment of boiler feed water: Internal treatment (phosphate, colloidal, sodium aluminate and calgon conditioning) and External treatment – Ion exchange demineralization and zeolite process.

UNIT II NANOCHEMISTRY 9

Basics: Distinction between molecules, nanomaterials and bulk materials; Size-dependent properties (optical, electrical, mechanical and magnetic); Types of nanomaterials: Definition, properties and uses of – nanoparticle, nanocluster, nanorod, nanowire and nanotube. Preparation of nanomaterials: sol-gel, solvothermal, laser ablation, chemical vapour deposition, electrochemical deposition and electro spinning. Applications of nanomaterials in medicine, agriculture, energy, electronics and catalysis.

UNIT III PHASE RULE AND COMPOSITES 9

Phase rule: Introduction, definition of terms with examples. One component system - water system; Reduced phase rule; Construction of a simple eutectic phase diagram - Thermal analysis; Two component system: lead-silver system - Pattinson process. Composites: Introduction: Definition & Need for composites; Constitution: Matrix materials (Polymer matrix, metal matrix and ceramic matrix) and Reinforcement (fiber, particulates, flakes and whiskers). Properties and applications of: Metal matrix composites (MMC), Ceramic matrix composites and Polymer matrix composites. Hybrid composites - definition and examples.

UNIT IV FUELS AND COMBUSTION 9

Fuels: Introduction: Classification of fuels; Coal and coke: Analysis of coal (proximate and ultimate), Carbonization, Manufacture of metallurgical coke (Otto Hoffmann method). Petroleum and Diesel: Manufacture of synthetic petrol (Bergius process), Knocking - octane number, diesel oil - cetane number; Power alcohol and biodiesel. Combustion of fuels: Introduction: Calorific value - higher and lower calorific values, Theoretical calculation of calorific value; Ignition temperature: spontaneous ignition temperature, Explosive range; Flue gas analysis - ORSAT Method. CO_2 emission and carbon footprint.

UNIT V ENERGY SOURCES AND STORAGE DEVICES 9

Stability of nucleus: mass defect (problems), binding energy; Nuclear energy: light water nuclear power plant, breeder reactor. Solar energy conversion: Principle, working and applications of solar cells; Recent developments in solar cell materials. Wind energy; Geothermal energy; Batteries: Types of batteries, Primary battery - dry cell, Secondary battery - lead acid battery and lithium-ionbattery; Electric vehicles - working principles; Fuel cells: H_2-O_2 fuel cell, microbial fuel cell; Supercapacitors: Storage principle, types and examples.

TOTAL: 45 PERIODS

COURSE OUTCOMES:

At the end of the course, the students will be able:

To infer the quality of water from quality parameter data and propose suitable treatment methodologies to treat water.

To identify and apply basic concepts of nanoscience and nanotechnology in designing the synthesis of nanomaterials for engineering and technology applications.

To apply the knowledge of phase rule and composites for material selection requirements.

To recommend suitable fuels for engineering processes and applications.

To recognize different forms of energy resources and apply them for suitable applications in energy sectors.

TEXT BOOKS:

1. P. C. Jain and Monica Jain, “Engineering Chemistry”, 17th Edition, Dhanpat Rai Publishing Company (P) Ltd, New Delhi, 2018.

2. Sivasankar B., “Engineering Chemistry”, Tata McGraw-Hill Publishing Company Ltd, New Delhi, 2008.

3. S.S. Dara, “A Text book of Engineering Chemistry”, S. Chand Publishing, 12th Edition, 2018

REFERENCES:

1. B. S. Murty, P. Shankar, Baldev Raj, B. B. Rath and James Murday, “Text book of nanoscience and nanotechnology”, Universities Press-IIM Series in Metallurgy and Materials Science, 2018.

2. O.G. Palanna, “Engineering Chemistry” McGraw Hill Education (India) Private Limited, 2nd Edition, 2017.

3. Friedrich Emich, “Engineering Chemistry”, Scientific International PVT, LTD, New Delhi, 2014.

4. ShikhaAgarwal, “Engineering Chemistry-Fundamentals and Applications”, Cambridge University Press, Delhi, Second Edition, 2019.

5. O.V. Roussak and H.D. Gesser, Applied Chemistry-A Text Book for Engineers and Technologists, Springer Science Business Media, New York, 2nd Edition, 2013

UNIT- I

Water and its treatment

- Water is the important compound for the existence of plants, animals and human beings.

- About 80% of the earth's surface is occupied by water
- Water is used for agricultural, industrial and domestic purposes.

Sources of water

a) Surface Water
b) Underground water

a) Surface Water

(i) Rain Water

- Purest form of water
- It is obtained by the evaporation of surface water.
- In the atmosphere, it dissolves industrial gases like CO_2, NO_2 and SO_2 then reaches the earth's surface.

(ii) River Water

- It has rain water
- It flows over the land and dissolves the soluble minerals present in the soil
- So river water contains chlorides, sulphates and bicarbonates of Ca, Na, Mg and Fe.

(iii) Lake Water

- It Contains less amount of dissolved minerals
- It has high organic matter.

(iv) Sea Water

- Most impure form of water
- It has more dissolved and suspended impurities.
- Due to continuous evaporation, the sea water is more saline in nature.

b) Underground Water

- It is clear in appearance due to filtering action of the soil
- The underground water contains higher dissolved salts

Ex. Well Water

The surface and underground water is used for domestic and industrial purposes.

Water Treatment

The Process of removing all types of impurities from water and making it fit for domestic and industrial purpose is called water treatment.

Types of Impurities in Water

1. Physical Impurities

a) Suspended impurities:

Sand, oil droplets, vegetable and animal matters cause turbidity in water.

b) Colloidal impurities:

They are finely divided silica, clay and organic waste products which imparts colour, odour and taste to water.

2. Chemical impurities

a) Dissolved salts:

- Bicarbonates, sulphates and chlorides of Ca and Mg - Produce hardness.
- Carbonates and bicarbonates of Na and K - makes water alkaline

b) Dissolved gases:

- Gases like O_2, CO_2, H_2S, SO_2 and CO which makes the water acidic
- They increases the rate of Corrosion.

3. Biological impurities

They are fungi, bacteria and other micro-organisms which spread harmful diseases.

Parameters of Water quality

1. Color

Materials decayed from organic matter, namely Vegetation and inorganic matter such as soil, stones and rocks impart color to water.

Colour has been used to identify the presence of potentially toxic organic materials in water

Color is graded on scale of 0 (clear) to 70 color units. Pure water is colorless.

2. Odour

Organic materials discharged directly in water, such as falling leaves and run off are sources of odour producing compounds during biodegradation.

Odour in drinking water may be indicative of some form of pollution.

3. Turbidity

Turbidity is the cloudiness of water, it is a measure of the ability of light to pass through water. It is due to the presence of clay, silt, organic material etc.

* Increase the cost of water treatment for Various uses.
* It is the hiding place for harmful organisms
* It affects the aquatic life.

4. pH

pH is a measure of how acidic or basic. It is defined as the negative log of the hydrogen ion concentration.

* As the pH decreases, water becomes more acidic. As water becomes more basic the pH increases.

5. Hardness

Hardness is the property or characteristics of water which does not give lather with soap.

* Hardness is due to the presence of bicarbonates chlorides and sulphates of Ca and Mg
* Total hardness = Temporary hardness + Permanent hardness.

6. Alkalinity

Alkalinity is a measure of the acid-neutralizing capacity of water

* The three types of alkalinity are hydroxide, carbonate and bicarbonate.

* Alkalinity is important for fish or aquatic life because it protect against rapid pH changes.

7. TDS

TDS means concentration of dissolved particles or solids in water. TDS comprises of inorganic salts such as Ca, Mg, Cl^-, SO_4^{2-}, HCO_3^- along with many more inorganic compounds that easily dissolve in water.

* The higher level of dissolved salts may not be ideal for your health, must be filtered before intake.

8. COD

COD (chemical oxygen demand) is a parameter that measures all biodegradable and non-biodegradable substances.

* Higher levels of COD will reduce dissolved oxygen levels.

9. BOD

Biological oxygen demand is a measure of oxygen consumed by bacteria and other micro organism while they decompose organic matter under aerobic conditions.

* Higher levels of BOD also reduce dissolved oxygen content in water

10. Fluoride

A moderate amount of F^- ions in water contributes to good dental health.

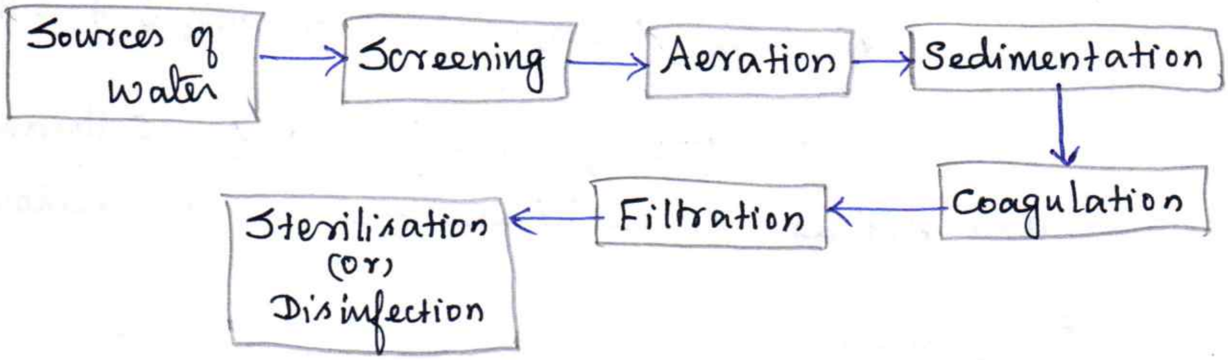
* Allowable concentration in potable water is 1.4 mg/L

* Excessive amount of F^- ion cause dental fluorosis.

11. Arsenic

Municipal Water Treatment

Rivers and lakes are the most common sources of water used by municipalities. The purification process involved the following



1. Screening

The raw water is allowed to pass through a screen, having large no. of holes, which retains the floating materials like leaves, wood pieces etc.

2. Aeration

The process of mixing water with air is called as aeration.

* remove gases like CO_2, H_2S
* remove Fe and Mn salts.

3. Sedimentation

* The water is allowed to stand undisturbed in a big tank for 2-6 hrs.
* Due to gravity, the suspended particles are settled down at the bottom, and removed.

4. Coagulation

* This process is used to remove clay, silica etc.

* The coagulants like alum, $Al_2(SO_4)_3$ are added to water

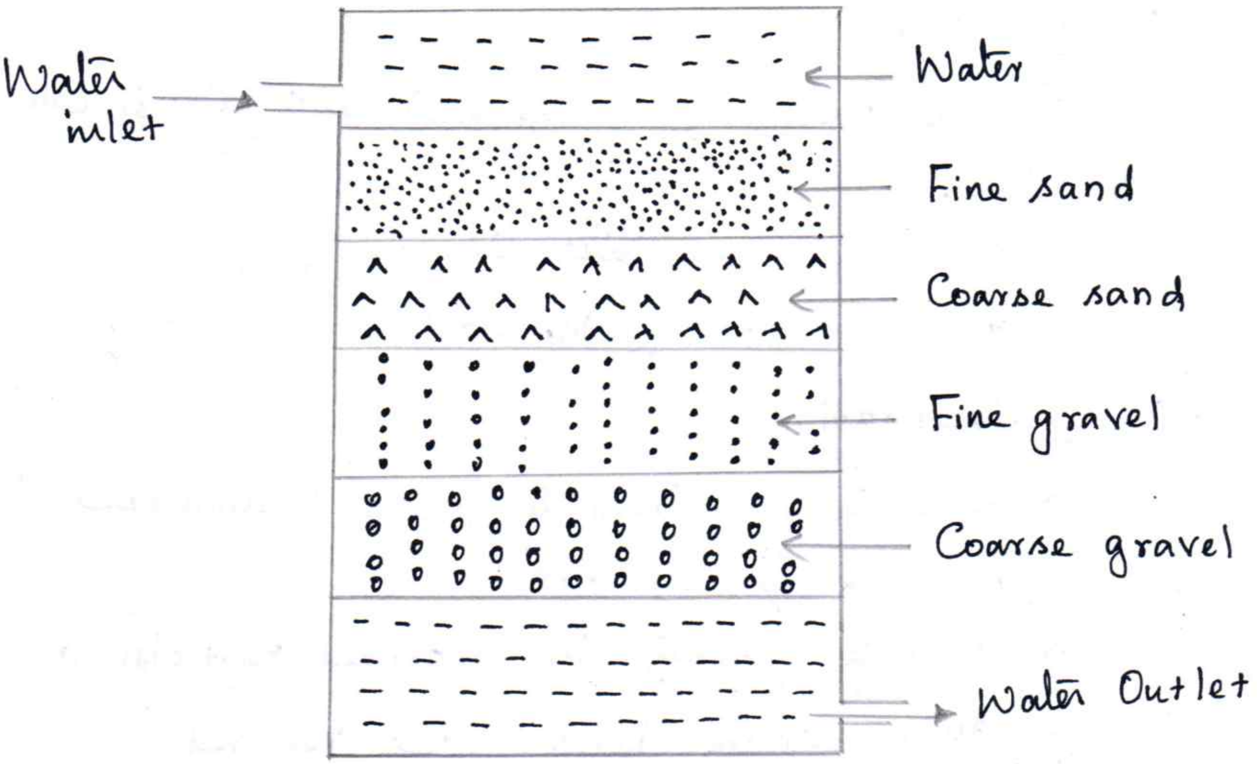
$$Al_2(SO_4)_3 + 6H_2O \longrightarrow 2Al(OH)_3 \downarrow + 3H_2SO_4$$

The ppt of $Al(OH)_3$ entraps colloidal impurities and settled at the bottom and can be removed easily.

5. Filtration

* It is the process of removing bacteria, colour, taste, and odour, by passing through the filter beds.

* The filter bed contains fine sand, coarse sand and gravel.



- When water flows through the filter bed, it moves slowly
- The rate of filtration decreases slowly due to the clogging of impurities in the pores of the sand bed.
- When the rate of filtration is very slow, it was stopped and thick layer of fine sand is scrapped off and replaced with clean sand.

6. Sterilisation (or) Disinfection

- The process of destroying harmful bacterias is known as sterilisation or disinfection.
- The chemical used for this process, known as disinfectants.

Methods

1. By ozonation (Using Ozone)

- Ozone is a powerful disinfectant
- O_3 is highly unstable and breaks down to give nascent oxygen.

$$O_3 \longrightarrow O_2 + [O]$$

The nascent oxygen kills bacterias.

Disadvantages

a) The Process is costly and cannot be used in large scale

b) Ozone is unstable, so it cannot be stored for a long time.

2. By using Ultraviolet radiations

* Uv rays produced by passing electric current through mercury vapour lamp.
* This process is useful for sterilizing water in swimming pool.

Disadvantages

* It is costly
* Turbid water cannot be treated

3. By chlorination

* The process of adding chlorine to water is called chlorination.

(a) By adding chlorine gas

Chlorine gas can be bubbled in the water, acts as a powerful disinfectant.

$$Cl_2 + H_2O \longrightarrow HCl + HOCl$$

(b) By adding chloramine.

* When chlorine mixed with ammonia in the ration 2:1 a compound chloramine is formed.

$$Cl_2 + NH_3 \longrightarrow \underset{\text{Chloramine}}{ClNH_2} + HCl$$

$$ClNH_2 + H_2O \longrightarrow \underset{\text{Disinfectant}}{HOCl} + NH_3$$

* Chloramine is a very good disinfectant and

(c) By adding bleaching powder

- When bleaching powder is added to water, it produces hypochlorous acid (HOCl)
- HOCl is a powerful germicide.

$$\underset{\text{Bleaching powder}}{CaOCl_2} + H_2O \longrightarrow Ca(OH)_2 + Cl_2$$

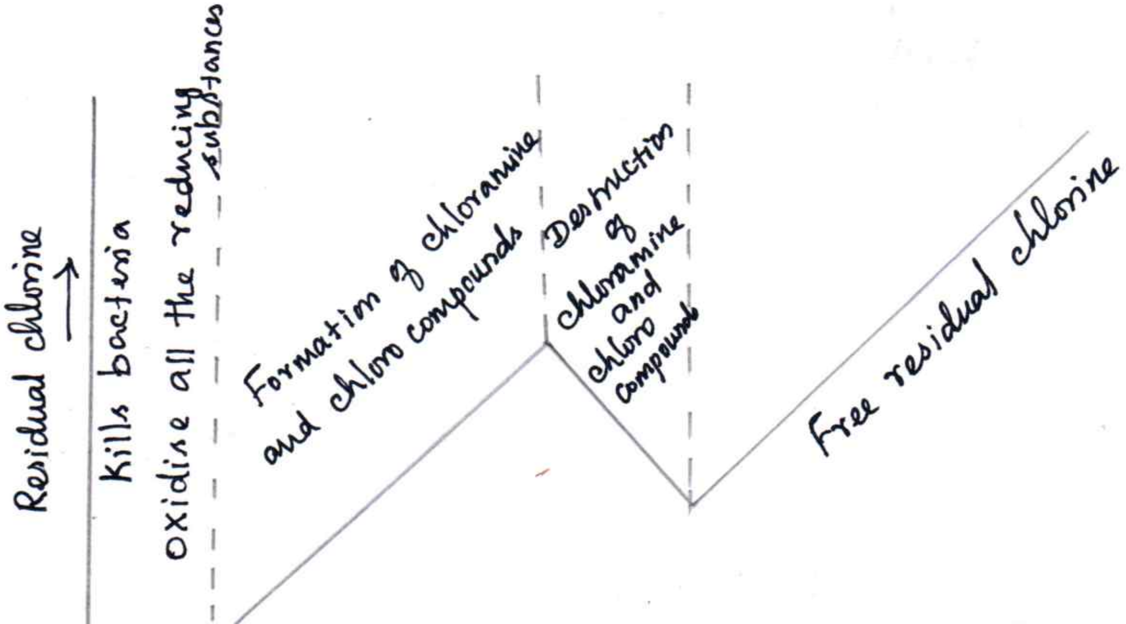
$$Cl_2 + H_2O \longrightarrow HCl + \underset{\text{hypochlorous acid}}{HOCl}$$

$$HOCl + \text{bacterias} \rightarrow \text{Bacterias are killed.}$$

Break Point Chlorination

Water contains the following impurities

(i) Bacterias
(ii) Organic impurities
(iii) Reducing substances
(iv) Free ammonia.



* chlorine may be added to water directly as a gas or in the form of bleaching powder.

* Initially the applied chlorine is used to kill the bacterias and oxidises all the reducing substances present in the water.

* As the amount of chlorine increases, there is a formation of chloramine and other chloro compounds.

* On further chlorination, the oxidation of chloramines and other impurities starts.

* When the oxidation completes, the free residual chlorine begin to appear and this point is known as "break point chlorination"

Thus the break point chlorination eliminates bacterias, reducing substances, organic substances responsible for the bad taste and odour from the water.

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Desalination of Brachish Water

The process of removing sodium chloride from the water is known as desalination.

(i) Fresh water has less than 1000 ppm of dissolved salts

(ii) Brackish water has > 1000 but < 3500 ppm of dissolved salts

(iii) Sea water has > 35000 ppm dissolved salts

Reverse Osmosis (RO) Method

Osmosis

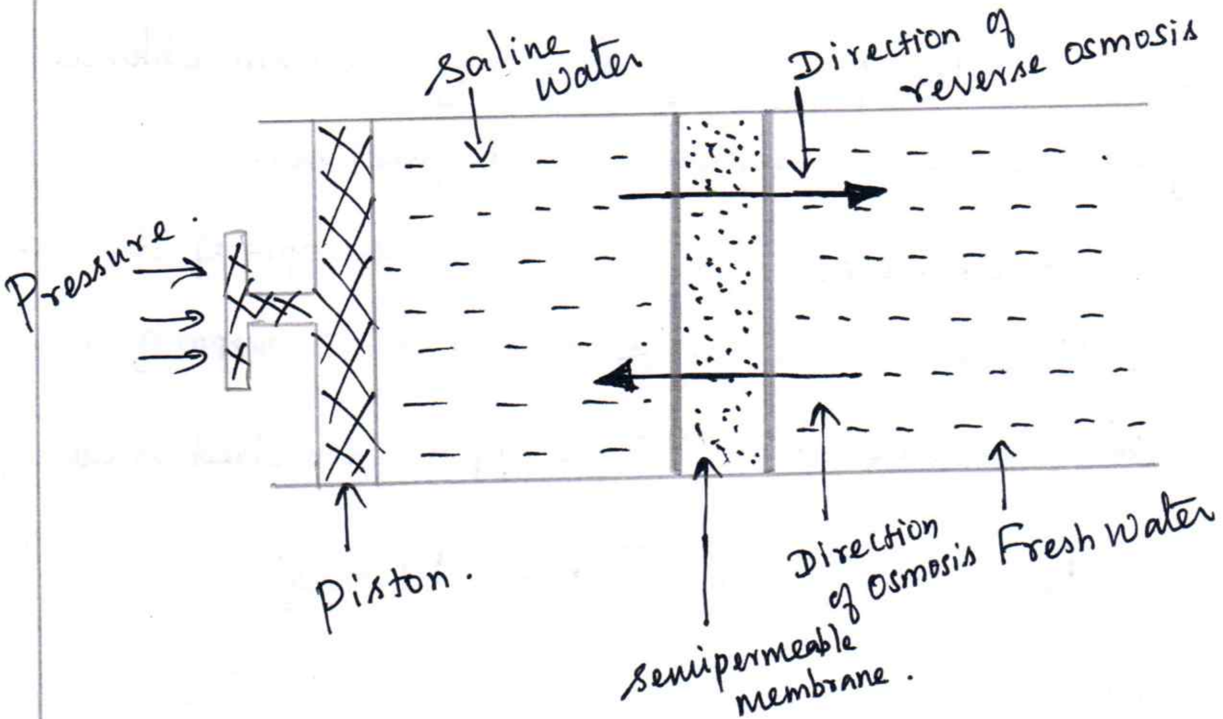
When two solutions of different concentrations are separated by a semi-permeable membrane, solvent flow from lower concentration side to higher concentration side. This process is called osmosis, the driving force is osmotic pressure.

Reverse Osmosis

If hydrostatic pressure in excess of osmotic pressure is applied on higher concentration side, the solvent flow from higher concentration to lower concentration side. This process is called Reverse Osmosis.

Thus in the process of reverse osmosis, pure water is separated from salt water.

This process is also known as super-filtration. The membranes used are cellulose acetate,



Advantages

- * The life time of membrane is high, and it can be easily replaced
- * It removes ionic, non-ionic as well as colloidal impurities.
- * Low cost
- * Sea water is converted into drinking water.

Boiler feed Water

"The water fed into the boiler for the production of steam" is called boiler feed water.

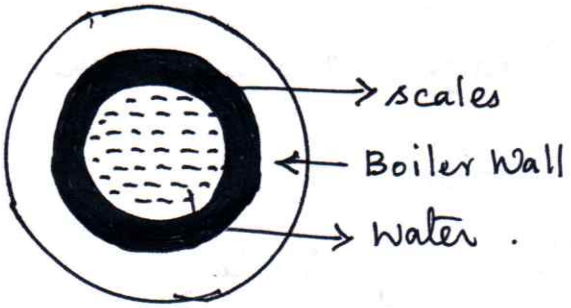
Boiler Troubles

1. Scales and Sludge.

a. Scale (Hard Deposit)

If the precipitate is hard and adherent coating on the innerwalls of the boiler, it is called scale.

Scale forming substance: $Ca(HCO_3)_2$, $CaSO_4$ & $Mg(OH)_2$.



Disadvantages:

- Scales act as thermal insulators
- Scales decreases the efficiency of boiler
- Any crack developed on the scale, leads to explosion

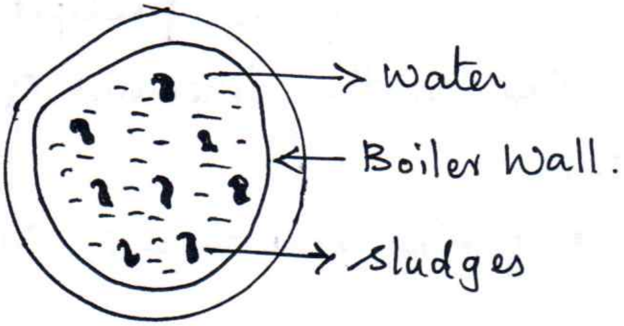
Prevention:

- By using acids like HCl, H_2SO_4
- By applying scraper, wire brush
- If scales are brittle, it can be removed by thermal shocks.

(b) Sludges (Loose Deposit)

If the precipitate is loose and slimy, it is called sludge.

Sludge forming substances : $MgCl_2$, $MgCO_3$, $MgSO_4$ & $CaCl_2$



Disadvantages

* Sludges are poor conductors of heat

* Sludges decreases the efficiency of boiler.

Prevention

* Use soft Water

* By blow-down operation - It is a process of removing a portion of concentrated Water by fresh Water.

2. Boiler Corrosion

Corrosion in boilers is due to the presence of

(i) dissolved oxygen
(ii) dissolved CO_2
(iii) dissolved salts.

(i) Dissolved Oxygen

The dissolved oxygen in water attacks the

$$4\,Fe + 6\,H_2O + 3\,O_2 \longrightarrow 4\,Fe(OH)_3 \downarrow$$

Removal of dissolved oxygen

a. chemical method

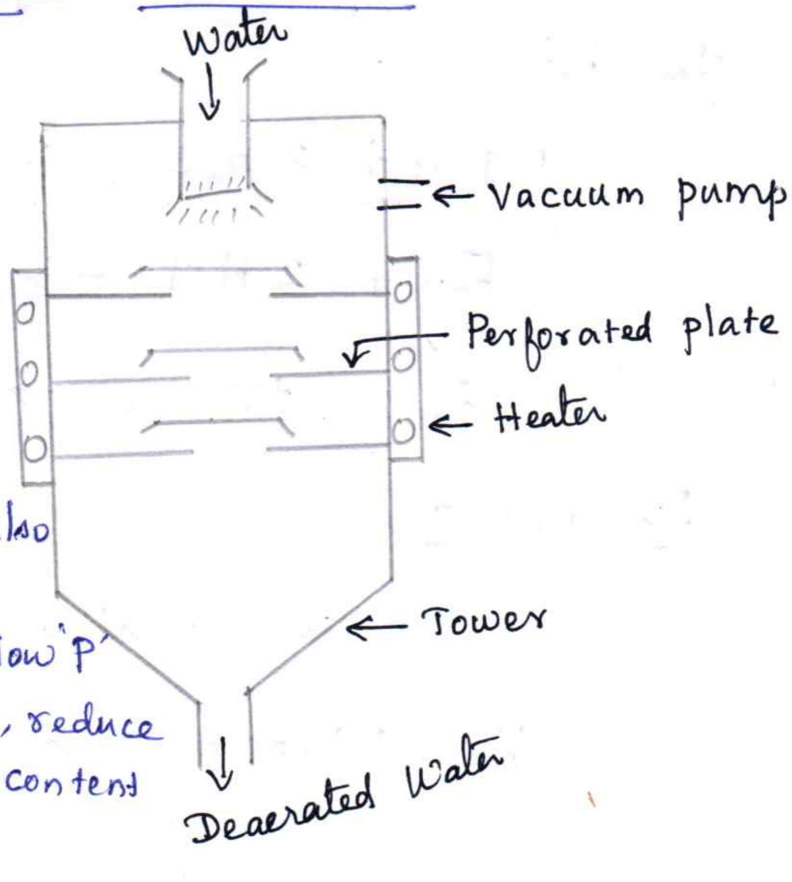
Sodium sulphite, hydrazine are some of the chemicals used for removing oxygen.

$$\underset{\text{sod. sulphite}}{2\,Na_2SO_3} + O_2 \longrightarrow 2\,Na_2SO_4$$

$$\underset{\text{Hydrazine}}{N_2H_4} + O_2 \longrightarrow N_2 + 2\,H_2O.$$

Among these, hydrazine is an ideal Compound because the products are water and inert gas (N_2).

b. Mechanical de-aeration



- * Water is allowed to fall slowly on the perforated plates
- * The sides of the tower are heated, Vacuum pump is also attached to it.
- * The high 'T' and low 'P' inside the tower, reduce the dissolved O_2 content of the water.

(ii) Dissolved CO_2

Dissolved CO_2 in water produces carbonic acid, which is acidic and corrosive in nature.

$$CO_2 + H_2O \longrightarrow H_2CO_3.$$

Removal of dissolved CO_2

- By adding NH_4OH into Water

$$2NH_4OH + CO_2 \longrightarrow (NH_4)_2CO_3 + H_2O$$

- Also removed by mechanical deaeration method.

(iii) Dissolved salts

Salts like $MgCl_2$, $CaCl_2$ undergo hydrolysis at higher temperature to give Hcl, which corrodes the boiler.

$$MgCl_2 + 2H_2O \longrightarrow Mg(OH)_2 \downarrow + 2HCl.$$

$$Fe + 2HCl \longrightarrow FeCl_2 + H_2 \uparrow$$

$$FeCl_2 + 2H_2O \longrightarrow Fe(OH)_2 + 2HCl.$$

Removal of acids

- By the addition of alkali to water

$$HCl + NaOH \longrightarrow NaCl + H_2O.$$

3. Caustic Embrittlement (Intercrystalline Cracking)

Caustic Embrittlement means intercrystalline cracking of boiler material.

* Boiler water contains small amount of Na_2CO_3

* In high 'P' ~~pe~~ boilers,

$$Na_2CO_3 + H_2O \longrightarrow 2NaOH + CO_2.$$

* This NaOH flows into the minute cracks in the boiler material, by capillary action and dissolved the surroundings (Fe) as sodium ferroate.

$$Fe + 2NaOH \longrightarrow Na_2FeO_2 + H_2\uparrow$$

This causes brittlement in bends, joints of the boiler parts, causing even failure of the boiler.

Prevention

* ~~B~~ Using sod. phosphate instead of Na_2CO_3.
* By adding tannin, lignin which blocks the hair cracks.

4. Priming and foaming (carry over)

a. Priming

The process of production of ~~weat~~ wet steam is called priming. It is caused by

* High Steam Velocity
* Very high water level in the boiler

Prevention

- Control the velocity of steam
- keeping the water level lower.
- Good boiler design
- Using treated water.

b. Foaming

The formation of stable bubbles above the surface of water is called foaming.

It is caused by

- Presence of oil and grease
- Presence of finely divided particles.

Prevention

- Adding coagulants like sodium aluminate, $Al(OH)_2$
- Adding anti-foaming agents like synthetic polyamides.

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Treatment of Boiler Feed Water

Internal Treatment

1. Phosphate Conditioning

- Scale formation can be avoided by adding Na_3PO_4 to the boiler.
- Used in High Pressure boilers.

$$3CaSO_4 + 2Na_3PO_4 \rightarrow Ca_3(PO_4)_2 + 3Na_2SO_4.$$

Generally 3 types of phosphates are used.

(i) Na_3PO_4 (Trisodium phosphate)

Too alkaline – Used for too acidic water

(ii) Na_2HPO_4 (Disodium hydrogen phosphate)

Weakly alkaline - Used for weakly acidic water

(iii) NaH_2PO_4 (sodium dihydrogen phosphate)

Acidic - Used for alkaline water

2. Colloidal Conditioning

* Scale formation can be avoided by adding agents like kerosene, agar-agar, gelatin etc.
* Used in low pressure boilers.
* The colloidal substance converts scale forming particles into sludges, which can be removed by blow down operation.

3. Calgon Conditioning

Calgon - Sodium hexa meta phosphate

$Na_2[Na_4(PO_3)_6]$

It is used to remove scale forming salt.

$$2CaSO_4 + Na_2[Na_4(PO_3)_6] \rightarrow Na_2[Ca_2(PO_3)_6] + 2Na_2SO_4$$

The complex $Na_2[Ca_2(PO_3)_6]$ is soluble in water, so the sludge disposal is easy.

4. Sodium aluminate Conditioning

Sodium aluminate ($NaAlO_2$) undergoes hydrolysis in boiler water to give gelatinous white ppte of aluminium hydroxide and sodium hydroxide.

$$NaAlO_2 + 2H_2O \longrightarrow Al(OH)_3 + NaOH$$

The NaOH reacts with Mg forms $Mg(OH)_2$.

Then the ppt of $Al(OH)_3$ and $Mg(OH)_2$ entraps finely divided solids and settled down. This can be easily removed by blow down operation.

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EXTERNAL TREATMENT

Ion - Exchange Process (Or) Demineralization Method.

This process removes almost all the ions (both anions and cations) present in hard water.

Soft water - does not contains hardness producing Ca^{2+}, Mg^{2+} ions but contain Na^+, Cl^-, K^+ ions.

Demineralized Water (D.M. Water) - does not contain both anions and cations.

So soft water is not a demineralized water, but demineralized water is soft water.

Process

* It is carried out by using ion-exchange resins.
* Ion exchange resins - Long chain, crosslinked, insoluble organic polymers.

* The functional groups are responsible for ion-exchange properties.
* Two types of ion exchange resins are used
  1. Cation exchange resin
  2. Anion exchange resin.

1. Cation exchange resin (RH_2)

* Resins containing acidic functional groups ($-COOH, -SO_3H$)
* These are capable of exchanging their H^+ ions with other cations of water

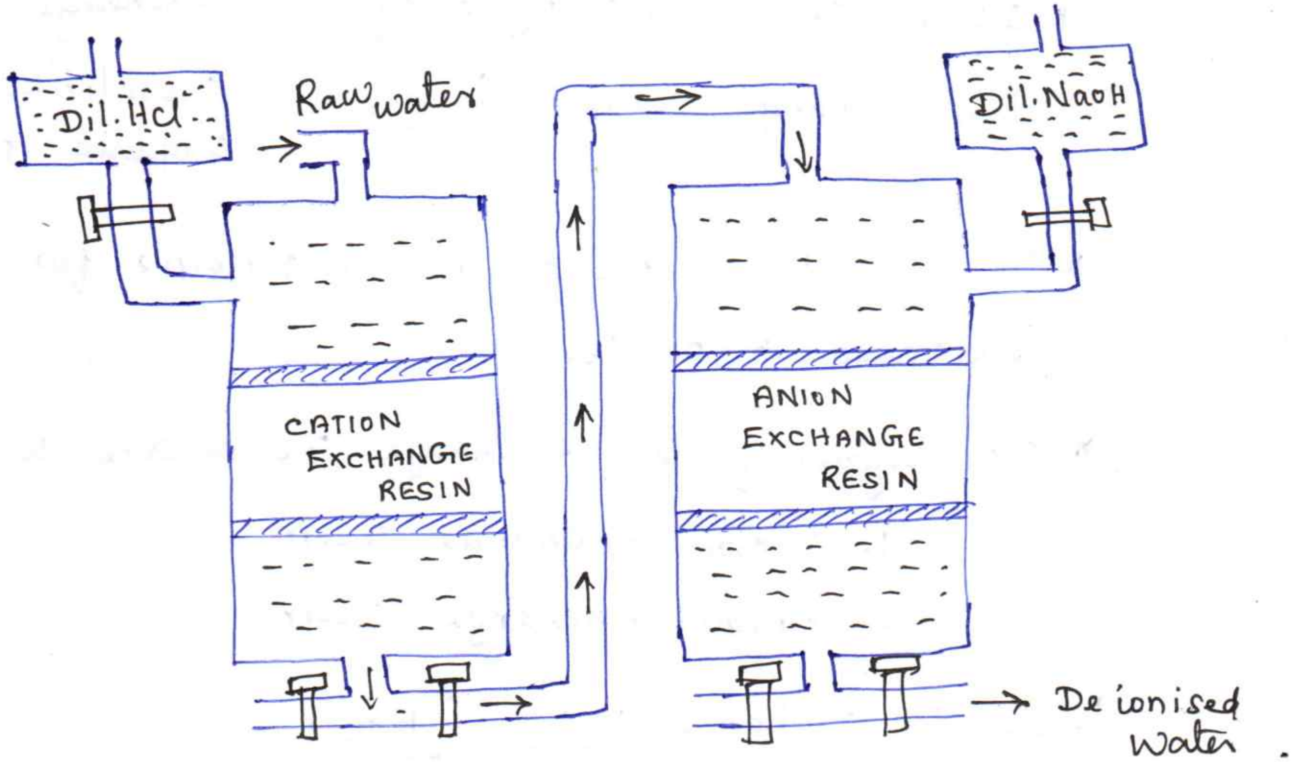
Ex. Sulphonated Coal, Sulphonated polystyrene.

2. Anion exchange resin ($(R'-OH)_2$)

* Resins containing basic functional groups ($-NH_2, -OH$)
* These are capable of exchange their anions with other anions of hard water.

Ex. Urea-formaldehyde resin.

Process of ion exchange resins



* The hardwater is first passed through cation exchange Column which absorb all the cations like Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} etc present in the hard water.

$$RH_2 + CaCl_2 \rightarrow RCa + 2HCl$$
$$RH_2 + MgSO_4 \rightarrow RMg + H_2SO_4.$$

* The cation free water is then passed through anion exchange column which absorb all the anions like Cl^-, SO_4^{2-} etc.

$$R'(OH)_2 + 2HCl \rightarrow R'Cl_2 + 2H_2O$$
$$R'(OH)_2 + H_2SO_4 \rightarrow R'SO_4 + 2H_2O$$

The water coming out from anion exchange resin is free from all the anions and cations, this is known as DM water (or) de ionised water.

Regeneration

* Cation Exchange resin – By using dil. Hcl (or) dil. H_2SO_4.

$$RCa + 2HCl \longrightarrow RH_2 + CaCl_2$$

$$RMg + H_2SO_4 \longrightarrow RH_2 + MgSO_4$$

* Anion Exchange resin – By using dil. NaOH.

$$R'Cl_2 + 2NaOH \longrightarrow R'(OH)_2 + 2NaCl.$$

Advantages

* Highly acidic (or) alkaline water can be treated
* The water obtained having hardness less than 2 ppm.

Disadvantages

* Water contain turbidity, Fe, Mn cannot be treated.
* Equipment is costly and chemicals are expensive.

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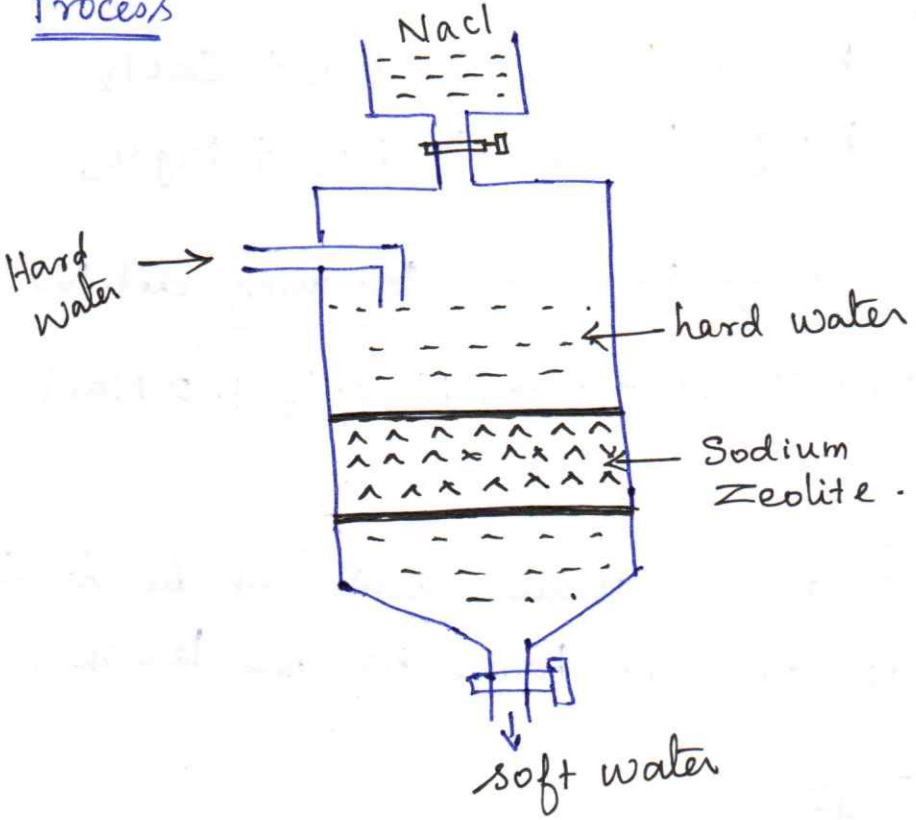
Zeolite Process (or) Permutit Process

* Zeolites – hydrated sodium alumino silicate.
* General Formula – $Na_2O . Al_2O_3 . x SiO_2 . y H_2O$
  $(x = 2 \text{ to } 10, y = 2 \text{ to } 6)$
* Natural Zeolites – Green sand and non-porous
* Synthetic Zeolite (Permutit) – Porous and having gel like structure.
* Synthetic Zeolites are represented by Na Ze.

The sodium ions are replaced by Ca^{2+} and Mg^{2+} ions present in the water.

Process



When hard water is passed through a bed of sodium zeolite (Na_2Ze) kept in cyclinder, exchanges its Na^+ ions with Ca^{2+} and Mg^{2+} ions present in hard water.

$$Ca(HCO_3)_2 + Na_2Ze \longrightarrow CaZe + 2\,NaHCO_3$$
$$Mg(HCO_3)_2 + Na_2Ze \longrightarrow MgZe + 2\,NaHCO_3$$
$$CaSO_4 + Na_2Ze \longrightarrow CaZe + Na_2SO_4$$
$$MgSO_4 + Na_2Ze \longrightarrow MgZe + Na_2SO_4$$
$$CaCl_2 + Na_2Ze \longrightarrow CaZe + 2\,NaCl$$
$$MgCl_2 + Na_2Ze \longrightarrow MgZe + 2\,NaCl.$$

The softened water contain large amount of sodium salts, it does not produce any hardness but cannot be used in boilers.

Regeneration

By using 10% Nacl solution.

$$CaZe + 2NaCl \longrightarrow Na_2Ze + CaCl_2$$

$$MgZe + 2NaCl \longrightarrow Na_2Ze + MgCl_2.$$

Advantages

- This method is cheap
- The water obtained having hardness 1-2 ppm.
- It's operation is easy.

Disadvantages

Turbid water, acidic water, water having Fe, Mn cannot be treated.

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UNIT – 2

NANO CHEMISTRY

Nano – 1×10^{-9} m

Nanoparticles

- Size = 1 to 50 nm
- They obtained as colloids
- Nanoparticles exhibit electronic behaviour, they are also called as quantum dots.

Nanomaterials

- Size < 100 nm
- 1 D Nanomaterials – thin films.
- 2 D Nanomaterials – Nanotubes, Nanowires
- 3 D Nanomaterials – colloids, quantum dots.

Distinction Between Nanoparticles, Molecules and Bulk Materials

1. Size :

   Nanoparticles < 100 nm
   Molecules – picometers
   Bulk materials – Micron size.

2. Molecule – Collection of atoms
   Nanoparticles – Collection of few molecules (< 100 nm)
   Bulk materials – thousands of molecules.
3. Surface area of nanoparticles is more than the bulk material.

4. Hardness of nanomaterial is 5 times more than the bulk material

5. Strength of nanomaterial is 3-10 times higher than bulk materials.

6. Nano particles has size dependent properties.
   Bulk materials has physical properties

7. Nanomaterials has corrosion resistant properties than bulk materials.

8. Nanoparticles posses some optical properties

   Ex. * Gold nanoparticles appear deep red to black colour in solution

   * ZnO Nanoparticles has superior UV blocking property compared to bulk material.

9. Nanoparticles - Lower melting point than bulk material

   Ex Gold nano particle - 300°c
   Gold slab - 1064°c.

10. Electrical properties of nanoparticles are increased by three times.

11. Because of high surface area, suspension of nanoparticles is possible.

12. The wear resistance of nanoparticles are 170 times higher than the bulk material.

Properties of Nanomaterials

1. Electrical Properties

- Electrical Conductivity decreases with a reduced dimension due to increased surface scattering. However, it can be increased, due to better ordering in micro-structure.

  Ex. Polymeric fibres

- Nanocrystalline materials can hold more energy, so they can be used as separator plates in batteries.

  Ex Nickel-metal hydride batteries (made of nanocrystalline nickel) Works longer.

2. Optical Properties

Reduction of materials dimensions has great effects on the optical properties.

- The quantum confinement of electrons within the nano-particles increases the energy level spacing.

- The surface plasma resonance, which is due to smaller size of nano-particles ~~shifts to a short wavelength~~, ~~due to an increased band gap~~ than the wavelength of incident radiation.

Ex The colour of metallic nano-particles may change with their sizes due to surface plasma resonance.

3. Mechanical Properties.

The nano materials have less defects compared to bulk materials, which increases the mechanical strength.

- Mechanical properties of polymers can be increased by the addition of nano-fillers.
- Nanomaterials are harder, stronger and corrosion resistant.

Ex Nano-crystalline carbides are used in micro drills.

4. Magnetic Properties

- Magnetic properties of nanomaterials are different from that of bulk materials.
- Ferromagnetic behaviour of the bulk materials disappear, when the particle size is reduced and transfers to super-paramagnetics.

x — x

Types of Nanomaterials

1. Nanoparticles

- Size - 1 to 100 nm
- They are smaller than their crystals
- They have 3D structure.

Eg TiO_2, gold, ZnO etc.

Applications

- TiO_2 - used in cosmetics (absorb UV rays)

2. Nano clusters

- Size - 0.1 to 10 nm
- Nano clusters are smallest size nano materials

Ex CdS, ZnO etc.

- They bound together by metallic, covalent, ionic and vanderwaals forces of attraction.
- Nano clusters are more stable

Magic Number - It is the no. of atoms present in the clusters of critical sizes with higher stability.

Properties

- Atomic or molecular clusters are formed by the nucleation of atoms or molecules.
- The reactivity of nanoclusters are decreased with their size.
- Melting point was low.
- Electronic structure of clusters are more confined than bulk materials.

Applications

- Used as catalysts
- Used in nano based chemical sensors
- Used as a light emitting diode in quantum computers.

3. Nanorods

Nano rod is 2D cylinderical solid material have length to width ratio less than 20.

Ex ZnO, CdS nanorods.

Properties of nanorods.

- * These are two dimensional materials
- * It exhibits optical and electrical properties.

Applications

- * Used in display technologies
- * Used in the manufacturing of micro mechanical switches.
- * Used in energy harvesting and light emitting devices.
- * Used as cancer therapeutics.

4. Nanowires

Nanowires are 2D cylindrical solid material having length to width ratio greater than 20.

Diameter of the nanowire ranges from 10-100 nm.

Ex

Metallic nanowires - Au, Ni, Pt
Molecular nanowires - DNA

Properties

- * These are 2D material
- * It has less conductivity
- * Silicon nanowires show strong photoluminescence characteristics.

Uses

- * Used for enhancing mechanical properties of composites.
- * Play a important role in future of digital computing
- * It replace Conventional Cu wires in computer, television etc

5. Nanotubes

* Size 1 to 100 nm (diameter),
Few nm to microns (length).

* Nanotubes may be organic (or) inorganic.

Ex
Carbon nanotube, silicon nanotube, DNA nanotube.

Properties of CNT's

* CNTs are very strong, withstand extreme strain in tension and posses elastic flexibility

* The atoms in a nano-tube are continuously vibrating back and forth.

* It is highly conducting like metallic materials.

* It has very high thermal conductivity and kinetic properties.

Uses of CNTs

* Used in battery technology

* Used as catalyst

* Used as light weight shielding materials for protecting electronic equipments

* Used for drug delivery

* It acts as a very good biosensor.

* It is used to detect many molecules present in the blood

* Used in water softening process as a filter.

x — x

Preparation of Nanomaterials

1. Sol-gel Process

* It's a wet chemical technique, also known as chemical solution deposition.

* This method used for the fabrication of metal oxides.

* In this process,

monomers ⟶ colloidal solution (sol)
[acts as the precursor]
⟶ Gel-like system

It involves the following steps

(i) Hydrolysis and polycondensation
(ii) Gelation
(iii) Aging
(iv) Drying
(v) Densification
(vi) Crystallization

* The significant amount of fluid need to be removed for the gel-like properties to be recognized. It is done in two ways.

(a) Sedimentation

The solution is allowed to keep for some time for sedimentation to occur and then pour off the remaining liquid.

(b) Centrifugation

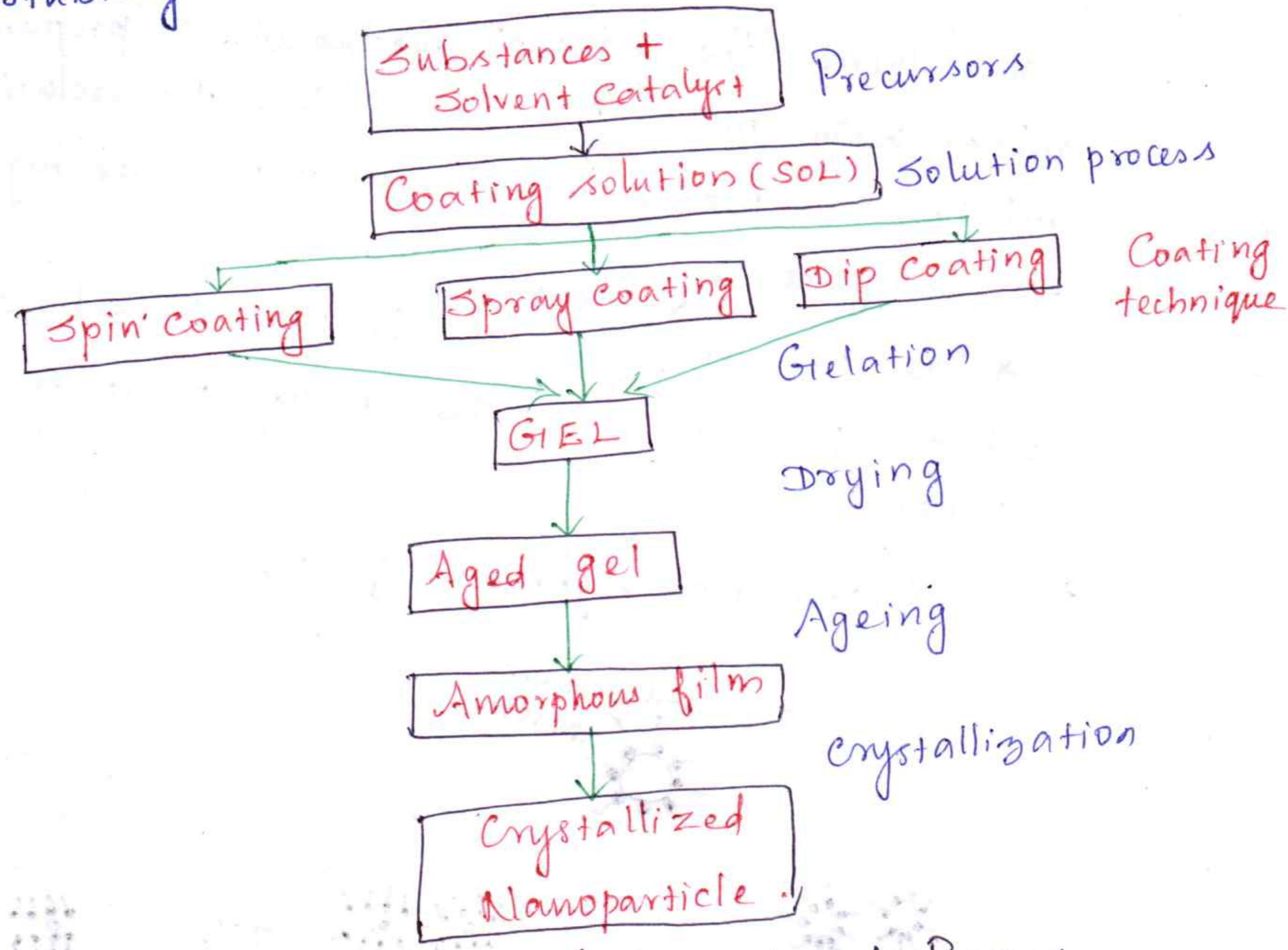
It is used to accelerate the process of phase

Drying and densification

Removal of the remaining liquid (solvent) is done by drying process, which accompanied by shrinkage and densification.

Firing (or) Crystallization

A thermal treatment (firing) is necessary to enhance mechanical properties and structural stability.



Various Steps of Sol-Gel Process.

2. Solvothermal Synthesis

This process is done under,

* high temperature (100°c to 1000°c)

* high pressure (1 to 10,000 atm)

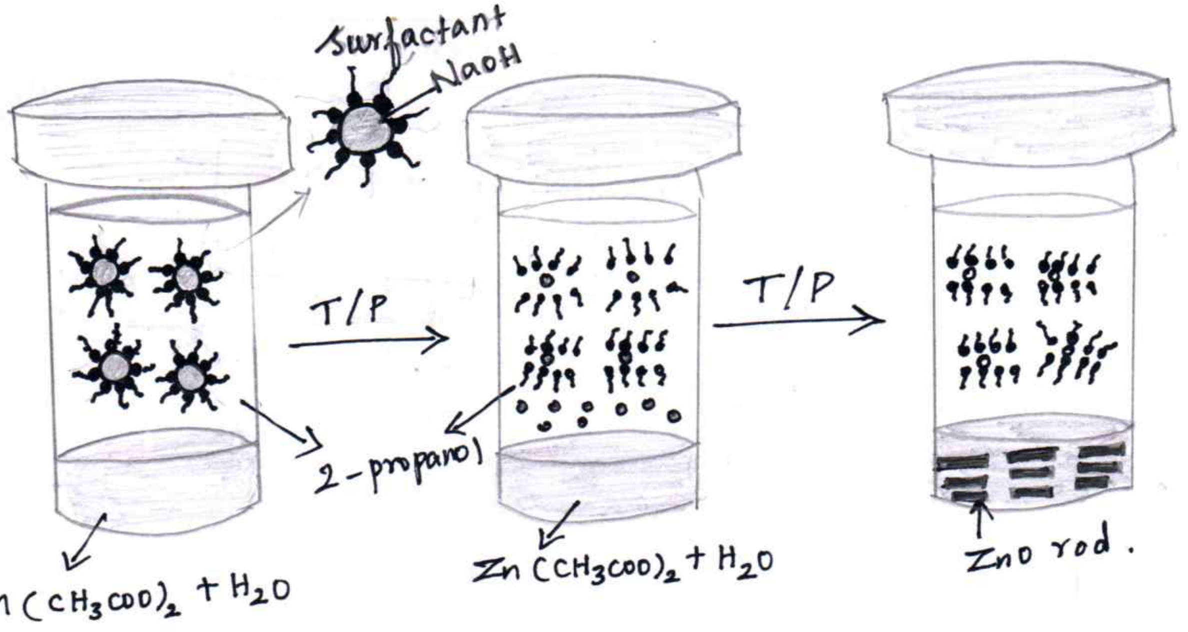
this facilitates the interaction of precursors during synthesis.

Method

* Solvent like ethanol, methanol, 2-propanol is mixed with metal precursors, then the solution mixture is placed in an autoclave (at high T & P) to carryout crystal growth.

* The pressure generated in the vessel, due to solvent vapour, elevates the boiling point of the solvent.

Ex Solvothermal synthesis of ZnO .



- Zinc acetate dihydrate is dissolved in 2-propanol at 50°c
- Then the solution is cooled to 0°c and NaOH is added to precipitate ZnO.
- Then the solution is heated to 65°c to allow ZnO growth for some period of time.
- Then a capping agent (1-dodecanethiol) is injected into the suspension to arrest the growth.
- The rod shaped ZnO nano-crystal is obtained.

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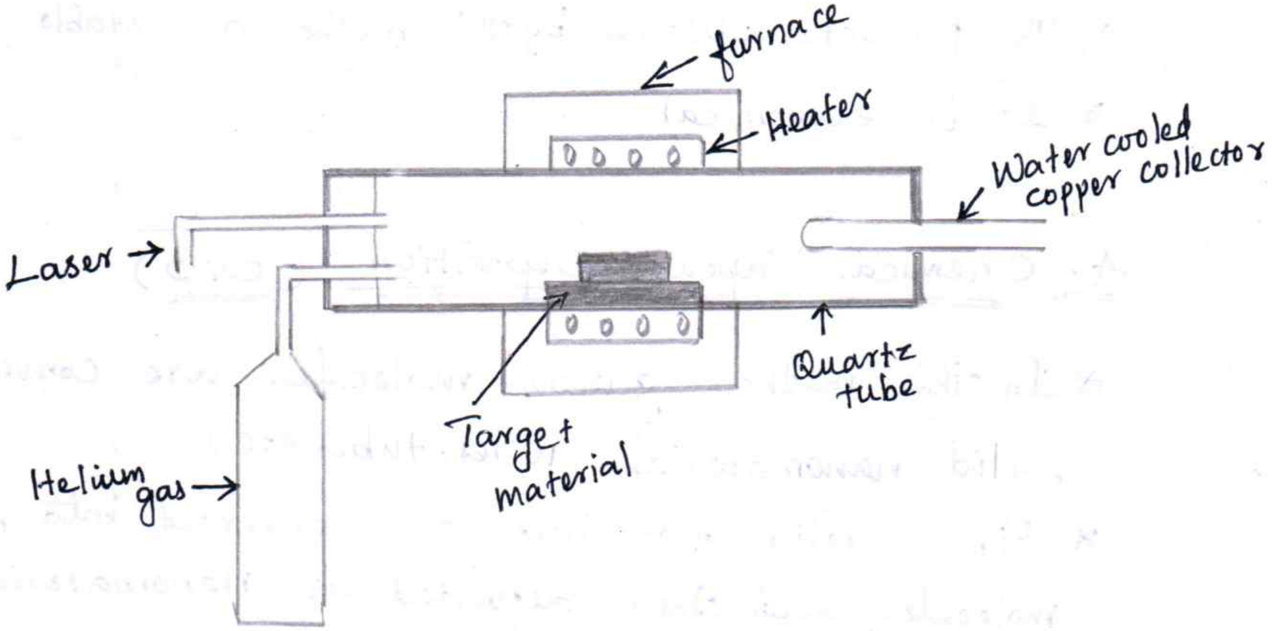
3. Laser Ablation Method

In this method, high-power laser pulse is used to evaporate the material from the target. The total mass ablated from the target per laser pulse is referred to as the ablation rate.



* The vapourisation of target material containing small amount of catalyst (Ni (or) Co) by passing an intense pulsed laser beam at high tempe (120°c) in a quartz tube reactor was takes place.
* Simultaneously, an inert gas such as Ar, He is allowed to pass through a reactor to sweep the evaporated particles from the furnace to the colder collector.

Uses

* Nanotubes (diameter 10 to 20 nm, 100 μm) can be produced.
* ceramic particles and coating can be produced.
* Si, C can also be converted into nanoparticles.

Advantages

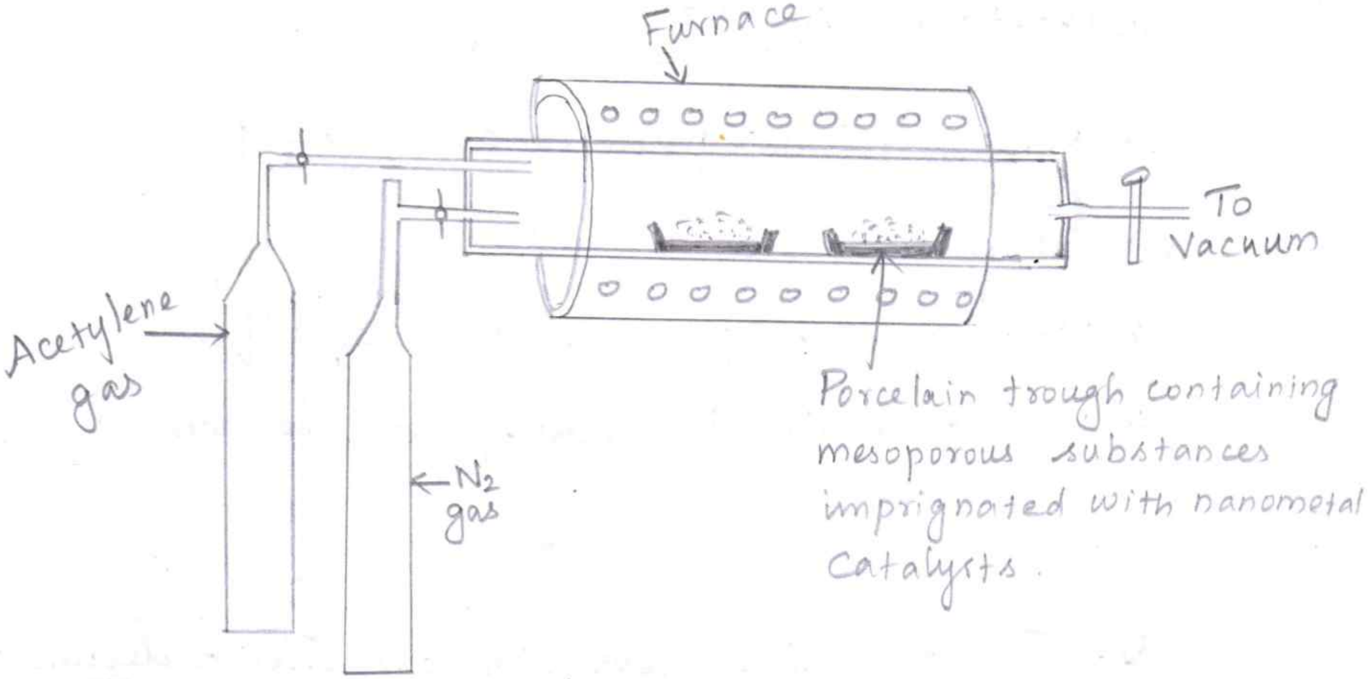
* Easy to operate
* Amount of heat required is less.
* It is eco-friendly method
* The products obtained by this method are stable.
* It is economical.

4. Chemical Vapour Deposition (CVD)

* In this method, gaseous molecules are converted into solid nanomaterials (wires, tubes etc)
* First solid materials are converted into gaseous molecules and then deposited as nanomaterials.

CVD reactor

- * has high 'T' vacuum furnace maintained at inert atmosphere.
- * Inside the furnace, the substrate material like silica, quartz are kept along with catalyst like Ni, Co and Fe.
- * The hydrocarbons such as ethylene, acetylene and nitrogen cylinders are connected to the furnace.
- * Carbon atoms produced at 1000°c, condense on the Cooler surface of the catalyst.
- * By this process CNT is produced continuously.

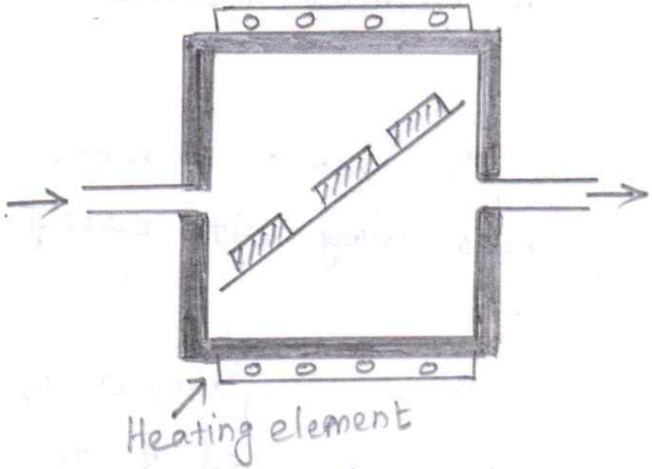


<u>Types of CVD Reactor</u>

(a) Hot wall CVD

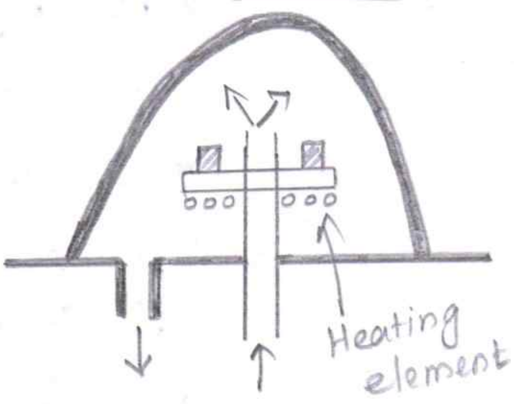
(b) Cold wall CVD

Hot-Wall CVD



* Tubular in form
* Heating is done by surrounding the reactor with resistance elements.

Cold-Wall CVD



* substrates are directly heated while chamber walls are air (or) water cooled.

Advantages of CVD

* Nanomaterials produced are highly pure
* It is economical
* Nanomaterials produced are defect free
* Mass production in industry can be done.

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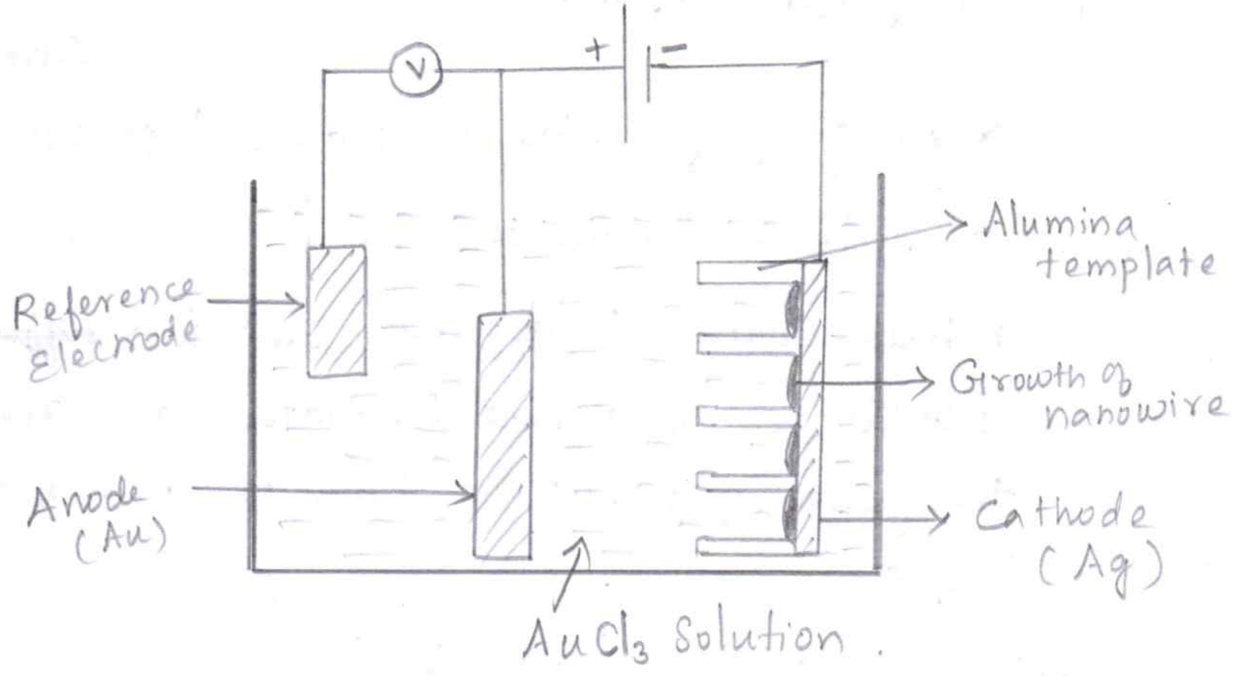
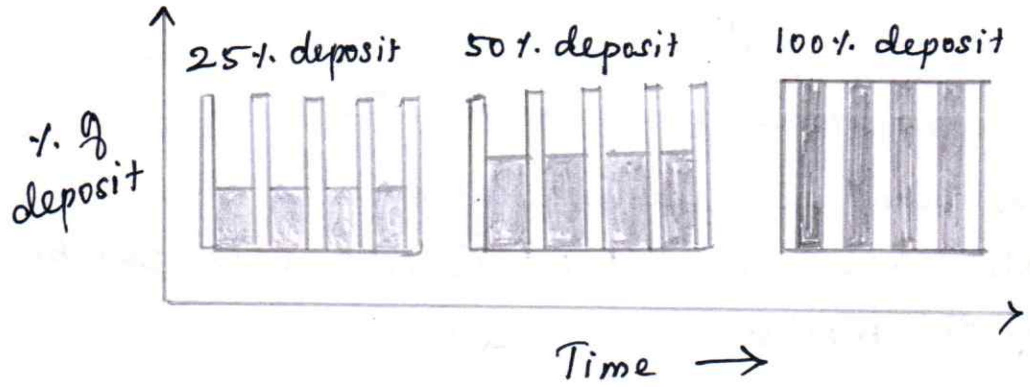
5. Electrochemical deposition (or) Electro deposition

* By this method ions from the solution are deposited at the surface of cathode
* Metallic nanomaterials with controlled shaped and size was synthesized by template assisted

* By using active template as a cathode, nano-structured materials with specific arrangements can be prepared.

Electrodeposition Method





* A cell consists of a reference electrode, cathode and anode.

* All these electrodes were connected through an voltmeter and dipped in an electrolytic ($AuCl_3$)

* When the current is passed through the electrodes, the metal ions from the solution get reduced at the cathode, hence nanowires are grown inside the pores of the template.

Ex Electrodeposition of gold on silver.

* Preparation of nanostructured gold - Goldsheet (anode)
  Silverplate (cathod
* An array of alumina template is kept over the cathode
* $AuCl_3$ - Electrolyte.
* When current is applied, Au^+ ions ~~diffuse~~ diffuse into the pores of alumina templates, and resulting in the growth of nano wires inside the pores of the alumina template.

Advantages of Electro-deposition

* cheap and fast
* Complex shaped object can be coated
* The wire obtained is uniform
* Metal nanowires like Ni, Co, Cu and Au can be fabricated by this method.

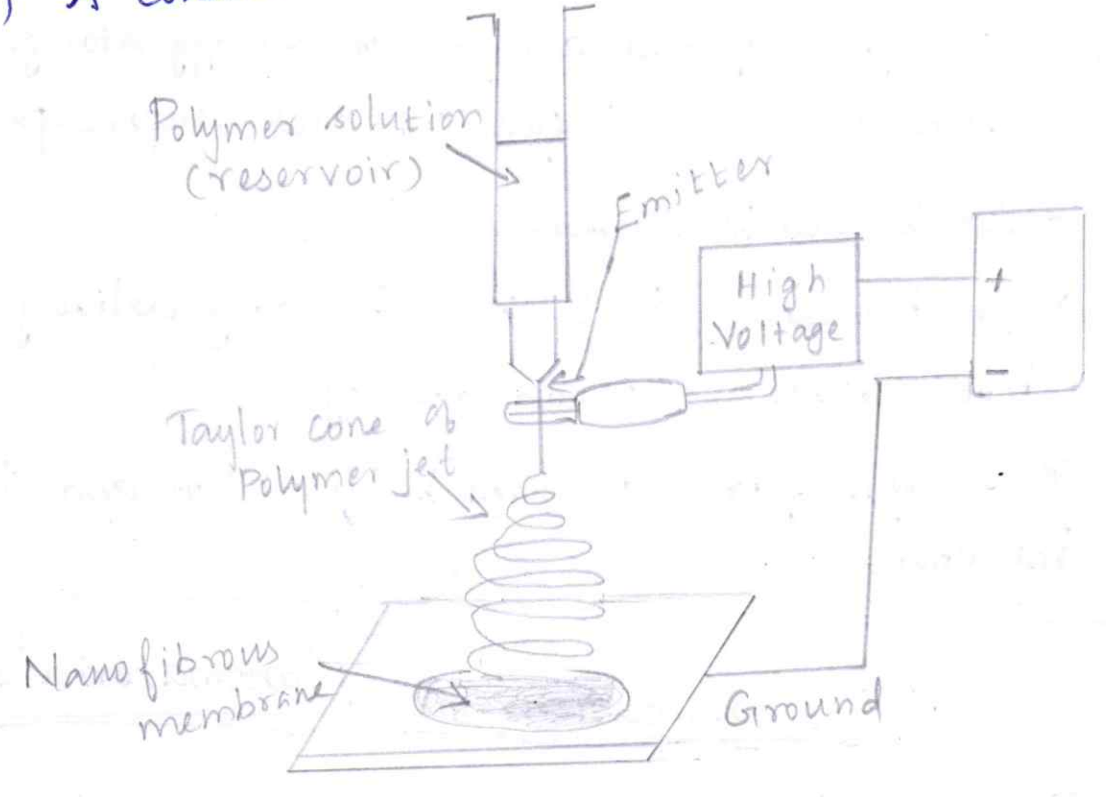
—

6. Electrospinning

It is a method of producing ultrafine fibres by charging and ejecting a polymer solution through a spinner under a high-voltage electric field and to solidify (or) coagulate it to form a filament.

Components

(i) High Voltage power supply.
(ii) Polymer reservoir (maintain constant flow rate of sol^n)
(iii) Conductive needle
(iv) A conductive collector.



Process

* Polymer is dissolved in a suitable solvent and filled in the reservoir
* High Voltage is applied to create an electric field between the needle tip and the collector,

* When the electrostatic repulsion is higher than the surface tension the liquid meniscus deformed into conically shaped structure known as taylor cone.

* Then the liquid jet is ejected towards the collector.

* Then the solid fibre will be formed as the solvent evaporates.

Applications

* Used in the treatment of diabetes

* The fibres formed are used in energy storage devices such as solar cell, fuel cell and supercapacitors.

* It is used in sensors.

* In biomedical, it is used in drug delivery, artificial blood vessel and wound dressing.

* e-spun fibres are used in filtration and thermal insulation.

Applications of Nanomaterials

I. Medicine

1. Nano drugs

Nanomaterials are used as nano drugs for the cancer and TB therapy.

2. Laboratories on achip

Nano technology is used in the production of

3. Nano-medibots

As nano-medibots, nanoparticles used as anti-cancer drug and treat cancer.

4. Gold-coated nanoshells

These used in the destruction of tumours.

5. Gold nanoparticles as sensors

Gold nanoparticles undergo colour change during the transition of nanoparticles.

6. Protein analysis

It can be done by nanoparticles.

7. Gold nanoshells for blood immuno assay

Gold nano shells are used for blood immuno assay.

8. Gold nano shells in imaging

Gold nano shells are used for both imaging and therapy.

9. Targeted drug delivery using gold nanoparticles

It involves slow and selective release of drugs to the targeted organs.

10. Repairing work

Nanotechnology is used to partially repair ~~neuro~~ neurological damage.

II. In Agriculture

1. Nanomaterials poepared by eco-friendly and green method could increase agricultural potential for improving fertilization process and plant growth.
2. Used to minimige the use of harmful chemicals.
3. Identification of diseases in crops can be done by using nanosensors.
4. Nanomaterials are used in plant disease diagnostics.
5. It is also used in postharvest management
6. Silver nanoparticles are used as antimicrobial agents in food packing.
7. Nanoparticle based pesticides are used to protect crops from various diseases.

III. In Energy

1. Power generation

Nanoparticles can be used in running power plants

2. Generating hydrogen from sea water

Nanostructured film of nickel selenide used as a catalyst for the electrolysis of hydrogen from sea water.

3. Producing high efficiency light bulbs

Nano engineered polymer matrix is used for the production of high efficiency light bulbs.

4. Increasing the electricity generated by wind mills

Nanotubes in wind mills as blades, increases the amount of electricity.

5. Generating electricity from waste heat

Sheets of nanotubes used to build thermocells, that generates electricity.

6. Storing hydrogen for fuel cell powered cars

Graphene layers are used in fuel tank for storing hydrogen.

7. Reducing the cost of solar cell

Nanotech solar cells are manufactured at lower cost than the conventional solar cells.

8. Nanobattery and fuel cell

Nanomaterials, used in batteries and fuel cell, increases their efficiency.

IV. Electronics

1. Quantum wires are found to have high electrical Conductivity.
2. The integrated memory circuits with nanomaterials are effective devices.
3. A transistor, called NOMFET (Nanoparticle Organic Memory Field Effect Transistor) is the combination of

4. Nano wires are used to build transistors without p-n junctions.

5. Using carbon nanotubes, nano radios are prepared.

6. MOSFET (Metal oxide Semiconductor Field Effect Transistor) performs both as switches and as amplifiers.

V. In Catalysis

Nanoparticle catalysts are highly effective due to (i) huge surface area
(ii) enhanced reactivity.

1. Water Purification

Nanosilver catalyst used in controlling microbes in water.

2. Bio-diesel production

Solid base nanocatalyst KF/CaO can be used for biodiesel production with yield more than 96%.

3. Fuel cell application

Carbon supported electro-catalyst play an important role in fuel cell.

4. In drug delivery

CNT's are suitable for drug delivery systems.

5. Gold nanoparticles

It is used as a catalyst in co-oxidation

6. Titania- based nanocatalysts are used in photocatalysis.

7. Nanocrystalline MgO particles acts as an effective catalyst for dehydrogenation.

x — x

UNIT – III

Phase Rule and Composites

Phase Rule

General Phase rule.

$$\boxed{F = C - P + 2}$$

F → No. of degree of freedom

C → No. of components

P → No. of phases.

1. Phase (P)

"Any homogeneous physically distinct and mechanically separable portion of a system which is separated from other parts of the system by definite boundaries"

Ex (a) Gaseous phase – All gases are completely miscible, so single phase

(b) Liquid Phase –

* Two liquids are immiscible – two liquid phase one vapour phase. (Benzene – Water)

* Two Liquids are miscible – one liquid phase, one vapour phase (Alcohol - Water

(c) Solid phase – Every solid constitutes a separate phase.

2. Component (C)

"The smallest number of independently variable constituents, by means of which the composition of each phase can be expressed in the form of chemical equation"

Ex (a) Consider a Water system.

$$Ice_{(S)} \rightleftharpoons Water_{(L)} \rightleftharpoons Vapour_{(G)}$$

It has 3 phases, but the chemical composition of all the 3 phases is H_2O. So no. of Component is 1.

(b) Thermal decomposition of $CaCO_3$.

$$CaCO_{3\,(s)} \rightleftharpoons CaO_{(s)} + CO_{2\,(g)}$$

It has 3 phases. But it is a one Component system. Because the composition can be expressed by using two of the three components. $CaCO_3$ & CaO considered as components.

Phase	Components
$CaCO_3$	$CaCO_3 + 0\ CaO$
CaO	$0\ CaCO_3 + CaO$
CO_2	$CaCO_3 - CaO$

3. Degree of freedom (F)

"The minimum no. of independent variable factors such as T, P and Concentration, which must be fixed in order to define the system completely.

Ex Ice (s) $\rightleftharpoons$ Water (l) $\rightleftharpoons$ Vapour (g)

These 3 phases is in equilibrium only at a particular Temp. and pressure. So degree of freedom = 0.

One Component System

Water system

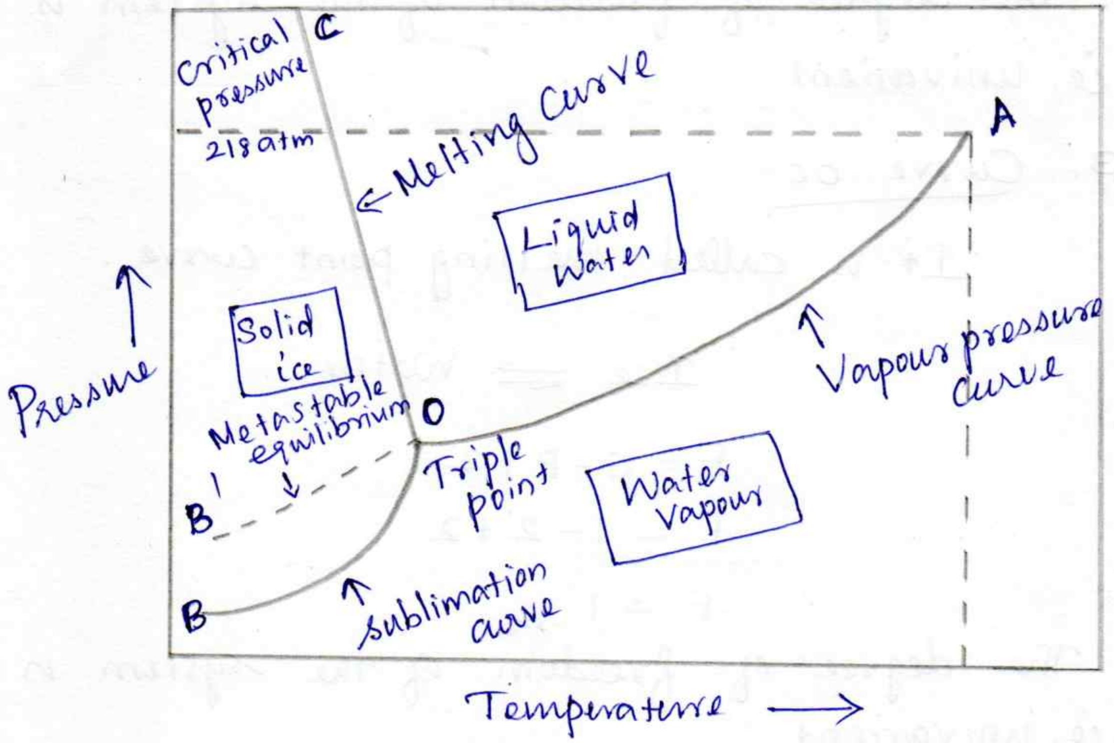
Water exists in 3 phases namely solid, liquid and vapour. So 3 forms of equilibria.

$$\text{Solid} \rightleftharpoons \text{Liquid}$$

$$\text{Liquid} \rightleftharpoons \text{Vapour}$$

$$\text{Solid} \rightleftharpoons \text{Vapour.}$$

The phase diagram has curves, areas and triple point.



1. Curve OA

It is called vapourisation curve.

$$\text{Water} \rightleftharpoons \text{Water Vapour}$$

The Phase rule is, $F = C - P + 2$

$$F = 1 - 2 + 2$$

$$F = 1$$

The degree of freedom of the system is one, ie, univarient.

2. Curve OB

It is called sublimation curve

$$\text{Ice} \rightleftharpoons \text{Vapour}$$

The phase rule is,

$$F = C - P + 2$$
$$F = 1 - 2 + 2$$
$$F = 1$$

The degree of freedom of the system is one, ie, univarient.

3. Curve OC

It is called melting point curve.

$$\text{Ice} \rightleftharpoons \text{Water}$$

$$F = C - P + 2$$
$$F = 1 - 2 + 2$$
$$F = 1$$

The degree of freedom of the system is one, ie, univarient.

4. Point 'O' (Triple point)

Here all the three phases namely solid, liquid and vapour are in equilibrium.

$$\text{Ice}_{(s)} \rightleftharpoons \text{Water}_{(L)} \rightleftharpoons \text{Vapour}_{(g)}$$

$$F = C - P + 2$$

$$F = 1 - 3 + 2$$

$$F = 0$$

The degree of freedom of the system is zero, ie, non-variant.

5. Curve OB' (Metastable equillibrium)

Here super cool water and vapour are in equillibrium.

$$\text{Super-Cool Water} \rightleftharpoons \text{Vapour}$$

Sometimes water can be cooled below 0°c without formation of ice, this water is called super-cooled water.

6. Areas

Area AOC, BOC and AOB represents water, ice and vapour respectively.

$$F = C - P + 2$$

$$F = 1 - 1 + 2$$

$$F = 2$$

The degree of freedom of the system is two ie, bivarient

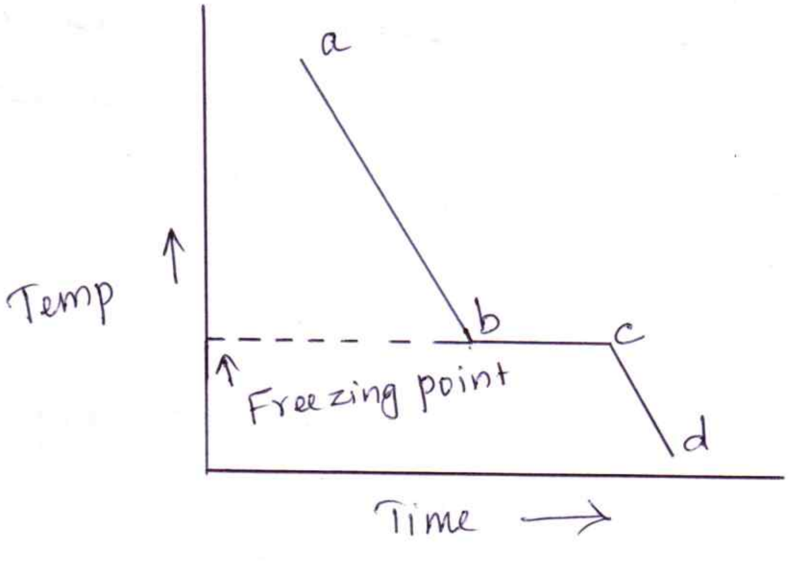
x—x

Thermal Analysis (or) Cooling Curves

This method used to study cooling curves of various compositions of a system during solidification. The shape of freezing point curves for any system can be determined by thermal analysis.

Ex.1 Cooling curve of a pure solid

Pure solid in the fused state is allowed to cool slowly and temperature is noted at different time interval.

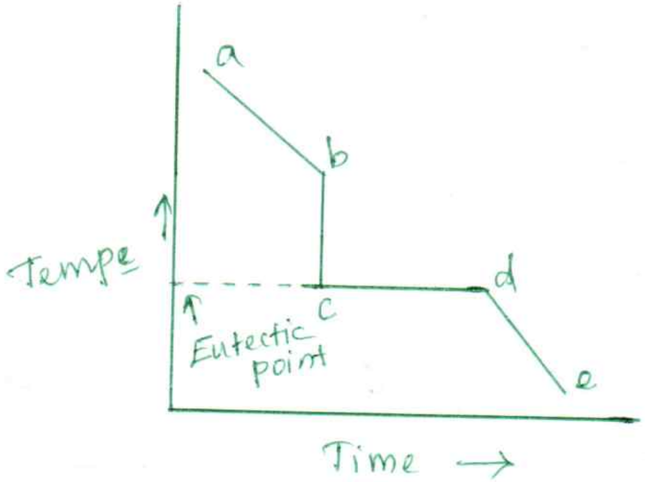


Initially the rate of cooling is continuous, at point 'b' solid begins to appear, now the temperature remains constant until all the liquid melt is solidified. Solidification completes at point 'c'. After the point 'c' temperature decreases along the curve 'cd'.

Example 2 Cooling Curve for a Mixture.

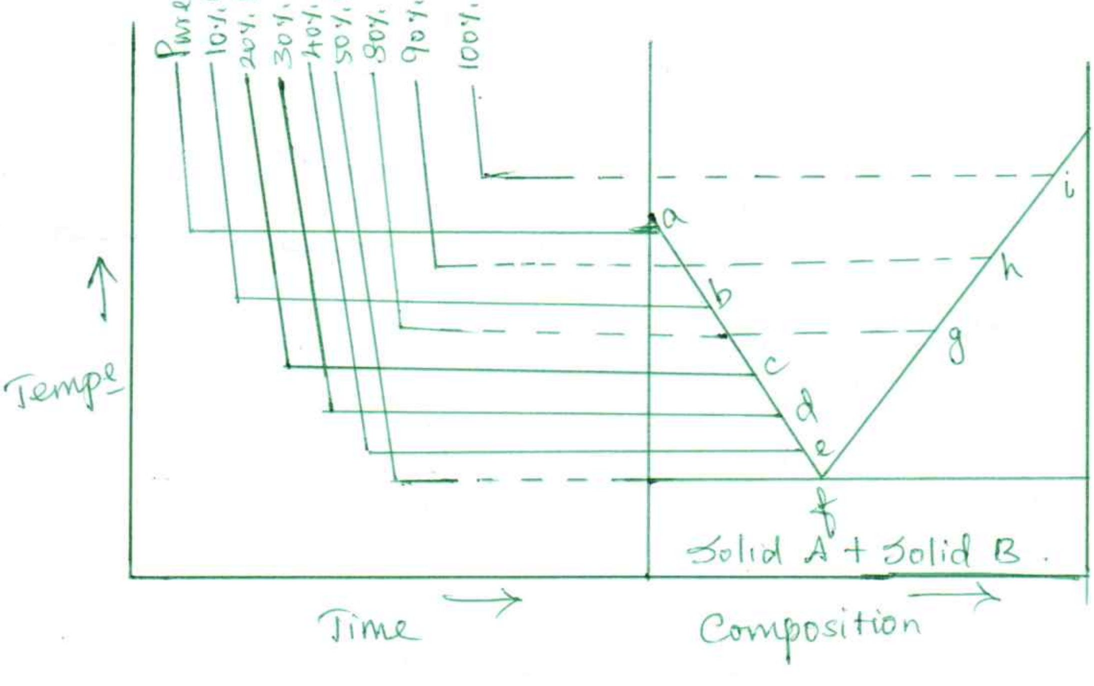
Mixture of two substances (A & B) in the fused state is allowed to cool slowly and temperature is noted at different time interval.

Initially the rate of cooling is continuous. At point 'b' one substance (A or B) begins to solidify.



On further cooling, at point 'c' the second substance also begins to solidify. Now the temperature remains constant until all the liquid melt is solidified. The temperature at 'cd' line gives the eutectic temperature.

The experiment is repeated for different compositions of A & B, various cooling curves obtained.



Uses of Cooling curves

- Melting point and eutectic temperature can be noted from the Cooling curve.
- Purity of Compounds can be noted.
- The behaviour of the Compounds can be clearly understood from the cooling curve.

Two Component Systems

Reduced Phase Rule

In order to represent the Conditions of equilibrium graphically, it requires P, T and C. It requires 3-D diagram, which cannot be represented on paper. Therefore one must be kept Constant (P or T or C).

In a Solid-Liquid equilibrium, no gaseous phase. So the experiment can be conducted at constant pressure. So the phase rule becomes,

$$\boxed{F' = C - P + 1}$$

This equation is called reduced phase rule (or) Condensed phase rule.

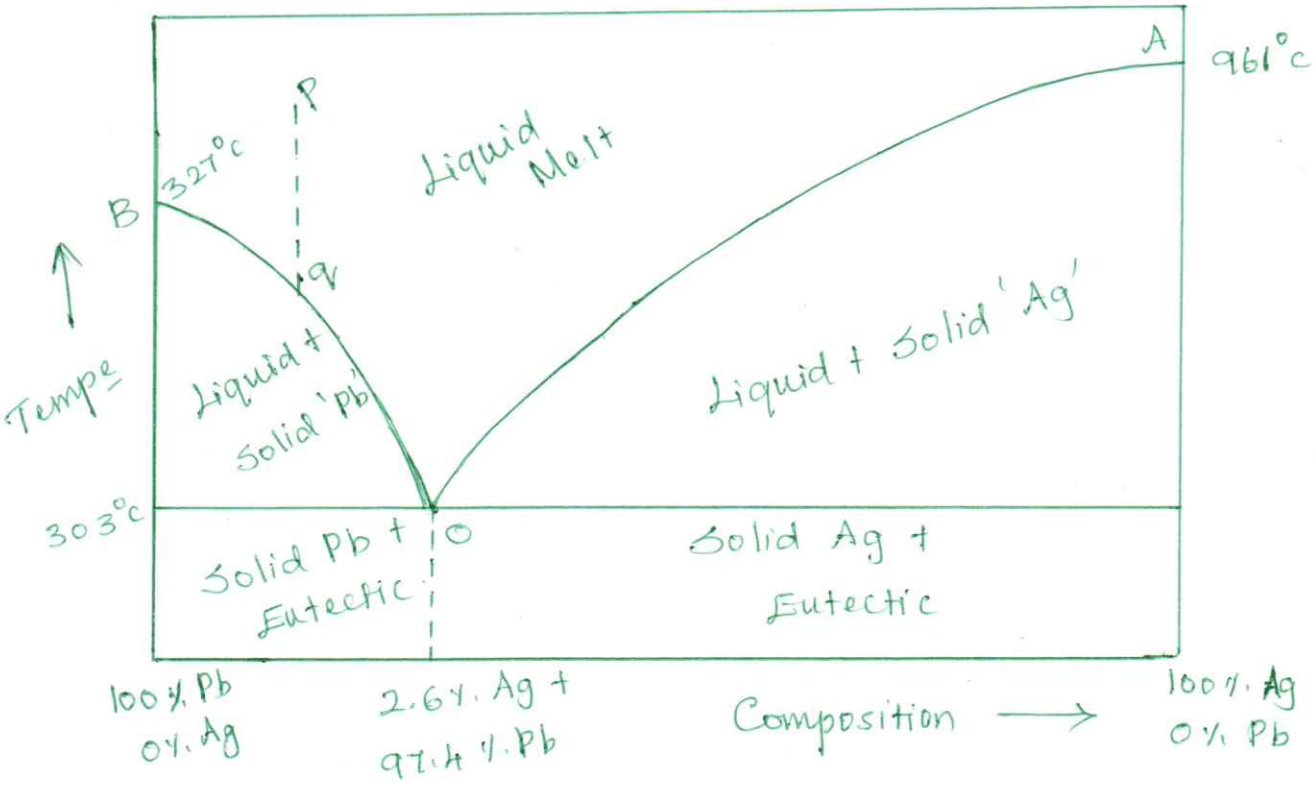
x — x

Two Component System (or) Binary alloy system (or) Simple Eutectic system

Lead - Silver System

The system is studied at Const 'P', so reduced phase rule is used.

$$F' = C - P + 1$$



1. Curve AO

It is the freezing point curve of silver. Point 'A' is the melting point of pure Ag (961°c)

$$\text{Solid Ag} \rightleftharpoons \text{Melt}$$

According to reduced phase rule

$$F' = C - P + 1$$
$$F' = 2 - 2 + 1 = 1$$

The system is univariant.

2. Curve BO

It is the freezing point curve of lead. Point 'B' is the melting point of pure lead (327°c).

$$\text{Solid Pb} \rightleftharpoons \text{Melt}$$

$$F' = C - P + 1$$

$$F' = 2 - 2 + 1 = 1$$

The system is univariant.

3. Point 'O' (Eutectic Point)

Here all the 3 phases (solid Ag, Solid Pb and liquid melt) are in equillibrium.

$$\text{Solid Pb} + \text{Solid Ag} \rightleftharpoons \text{Melt}$$

$$F' = C - P + 1$$

$$F' = 2 - 3 + 1 = 0$$

The system is non-variant.

4. Areas

The area above the line AOB, has a single phase (molten Pb + Ag)

$$F' = C - P + 1 = 2 - 1 + 1$$

$$F' = 2$$

The system is bivariant.

The area below the line Ao (Solid Ag + Melt) below the line Bo (Solid Pb + Melt) and below the point (Eutectic Compound + solid Pb (or) Solid Ag) have two phas

So,
$$F' = C - P + 1$$

$$F' = 2 - 2 + 1 = 1$$

So the system is univariant.

Application of Pattinson's process for the desilverisatio of Argentiferous lead

The argentiferous lead having small amount o silver (0.1%), is heated to a temperature above its melting point, so the system only consists of liquid phase represented by a point 'p'. It is then allowed to Cool. The temperature falls down along the line 'pq'. As soon as point 'q' is reached, Pb is crystallised out so the solution contains increasing amount of 'Ag'

On further cooling more and more 'Pb' is separated along the line 'BO'. So the percentage of silver increases in the melt. At point 'O' the percentage of Ag rises to 2.6%.

Thus the process of raising the percentage of Ag in the alloy is known as Pattinson's process.

× — ×

COMPOSITES

Definition

"A material system consisting a mixture of two (or) more micro-constituents, which are mutually insoluble differening in form (or) Composition and forming distinct phases"

Need for Composites

- Composites never rust
- To reduce maintenance cost
- To ensure long-term stability
- According to the needs, the properties of composites can be modified
- Composites are essential in telecommunication industries, because here power transmission along with data transmission was used.
- Because of its lower weight, it reduces fuel Consumption and emission.
- As carbon fibre is much stronger and stiffer than steel and aluminium, Composites were essential.

Constituents of Composites

1. Matrix phase (or) Matrix resin
2. Dispersed phase (or) Reinforcement.

1. Matrix Phase (or) Matrix resin

Matrix phase is a Continuous body Constituent, Which encloses the Composite. Matrix phase may be metal, ceramics (or) polymers.

(i) Metal Matrix Composites (MMC)
(ii) Ceramic Matrix Composites (CMC)
(iii) Polymer Matrix Composites (PMC)

2. Dispersed phase (or) Reinforcement

Dispersed phase is the structural constituent, which determines the internal structure of Composite.

Ex. Fibres, Particulates, Flakes, Whiskers.

Reinforcement – * It means addition of plastic matrix with some reinforcing agents (organic or inorganic) to improve the characteristics
* The reinforcing agents may be in the form of powder, flakes, fibres.
* These reinforcing agents are highly resistance to corrosion and posses high strength and ease of fabrication.

1. Fibres

Fibres are long and thin filament of any macromolecu substance such as polymer, metal (or) ceramic having high length to diameter ratio at least 100 : 1

Characteristics of Fibre

(i) Fibre possesses high tensile strength
(ii) Have high stiffness
(iii) Lowers overall density.

Classification of fibres

* Natural fibres – derived from naturally available sources
Ex. Cotton, wool, silk etc.

* Semi-synthetic fibres - produced by modifying natural fibres
Ex. Rayon

* Synthetic Fibres - made in laboratory
Ex. Polyester, glass fibre

* Aramid Fibres - aromatic polyamides
Ex. kevlar

(A) Important Natural Fibres

(a) Cotton fibre → It is a vegetable fibre and is made of cellulose molecule

(b) Wool fibre → It is an animal protein fibre, these are made of α-aminoacids.

(c) Silk → Natural protein fibre derived from insect, silkworm. These fibre posses qualities such as softness, strength, elongation etc

(d) Sisal → Low-cost fibrous material

(e) Jute and Coir → Low-cost fibrous material, it can be used as woven cloth.

(B) Synthetic fibres

(a) Polyethylene Terephthalate (PET) → produced by the condensation of ethylene glycol and terephthalic acid.

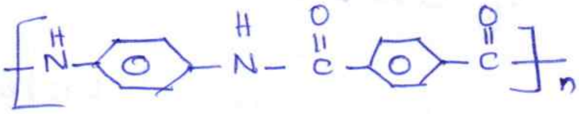
(b) Polypropylene – produced by the polymerisation of propylene. They posses better hardness, strength and used in making carpets, blankets, bags etc.

(c) Carbon fibres – At high temperature they posses good strength and stiffness.

(d) Nylon – Used as reinforcements for epoxide resin to give flexible laminates with abrasion and chemical resistance.

(C) Aramid fibres

The aromatic polyamides are called as aramids.



kevlar.

Properties
- * posses high tensile strength
- * Stable at higher temperatures
- * Excellent toughness.

Uses
- * Used in reinforcements
- * bullet proof clothing.
- * astronauts suits

2. Particulates

These are small pieces of hard solid materials. They may be metallic (or) non-metallic.

Effect of particulate in Composite.
- * Surface hardness gets increased
- * Wear and abrasion resistance are increased
- * performance at elevated temperature is improved.
- * Electrical, thermal Conductivities are modified.

3. Flakes

These are Very thin solid like materials.

Ex. Mica flakes

- * They imparts equal strength in all directions in a plane
- * Flakes can be packed more efficiently than fibres
- * Mica flakes can be used in electrical and thermal insulating appliances.

4. Whiskers

It is a strong fibre like material.

Ex. Graphite, silicon carbide, Silicon nitride.

- * perfect Whiskers possess high strength
- * they possess high elastic modulus and high degree of crystallinity
- * These are costly and difficult to incorporate in matrix, so they find limited ~~used~~ use.

×—×

Properties and Applications

1. Polymer Composites (or) Fibre Reinforced Polymer (FRP) Composites

These are widely used Composites in Various industries.

Properties and Applications

	Properties	Applications
(i) Glass FRP	* Lower densities and dielectric constants. * Higher tensile strength * Excellent corrosion and chemical resistance.	Automobile parts, pipes, storange tanks etc.

	Properties	Applications
2. Boron-FRP	* Excellent stiffness and strength * Manufacturing of B-FRB is difficult.	Horizontal and Vertical tail in aeroplane, stiffening spares, ribs etc.
3. Carbon-FRP	* Light density * Resist corrosion * Retention of desired properties even at higher temperature.	Structural Components of aircraft and helicopters, sports materials, solar panal etc.
4. Aramid-FRP	* they are ductile * stable at Compressive stresses.	Structeral Component in aircraft, helicopter parts
5. Alumina-FRP	* Good abrasion resistance, creep resistance. * possess dimensional stability	Used in making engine parts and Components of turbine engin

2. Metal Matrix Composites

Properties

- exhibit good thermal stability, high strength and good stiffness.
- They are ductile and exhibit good performance at elevated temperature
- They can withstand at elevated temperatures in corrosive environment than polymer composites.

Applications

- MMCs are suitable alternatives with Al, Ti, Ni alloys as one of the matrix material
- Used in engine blades, combustion chambers etc.
- Al and Mg MMCs are used in automotive industry.
- They improve fuel efficiency because of weight reduction
- MMCs are also used in biomedical and sports equipment industry.

3. Ceramic Matric Composites

Properties

- they possess good corrosion resistance, stable at elevated temperatures.
- possess good oxidation resistance.
- The matrixes used are glass, ceramics, carbides, nitrides, oxides and borides, the reinforcements are Al_2O_3, B, C, SiC and SiO_2.

Applications

- Used as thermal shields in space vehicles, pump seal, brake linings etc.

x — x

Hybrid Composites

Hybrid composites are new class of materials Composed of a suitable polymer matrix reinforced with two different fibres.

Properties

- They possess strong, tough and higher impact resistance
- They possess balanced strength and stiffness
- They exhibit superior mechanical properties.

Types

1. Structurally hybridized composites
2. Materials hybridized in chemical bond
3. Functionally hybridized Composites.

Uses

- Used in light-weight transparent structural Components
- Used in light Weight sports goods
- Used to make furniture (chair, table, bath tubs)
- Used in railway Coach interiors.

x — x

Unit - IV.

Fuels and Combustion

Proximate Analysis of Coal.

Determination of % of

- Moisture Content
- Volatile Matter
- Ash Content
- Fixed Carbon.

(i) Moisture Content

$$1\text{ g of air-dried coal} \xrightarrow[\text{1 hr, electric hot-air oven}]{100-105^\circ\text{c}} \text{Loss in weight of Coal is calculated.}$$

$$\%\text{ of moisture in Coal} = \frac{\text{Loss in weight of the Coal}}{\text{Weight of air-dried Coal}} \times 100$$

(ii) Volatile matter

$$\left.\begin{array}{r}\text{Moisture removed Coal}\\ \text{Covered with lid}\end{array}\right\} \xrightarrow[950 \pm 20^\circ\text{c}]{\text{Muffle furnace, 7 min}} \text{Loss in weight of Coal is noted}$$

$$\%\text{ of Volatile matter in coal} = \frac{\text{Loss in weight of the Coal}}{\text{Weight of moisture free Coal}} \times 100$$

(iii) Ash Content

$$\left.\begin{array}{r}\text{Moisture \& Volatile matter}\\ \text{removed Coal without lid}\end{array}\right\} \xrightarrow[700 \pm 50^\circ\text{c}]{\frac{1}{2}\text{ hr}} \text{Loss in weight of coal is noted.}$$

$$\%\text{ of ash Content in coal} = \frac{\cancel{\text{Loss in}}\text{ weight of }\overset{\text{ash formed}}{\cancel{\text{the Coal}}}}{\text{Weight of air-dried Coal}} \times 100$$

(iv) Fixed Carbon

$$\left.\begin{array}{l}\text{\% of fixed Carbon} \\ \text{in coal}\end{array}\right\} = 100 - \text{\% of (Moisture Content + Volatile matter + Ash content)}$$

Significance of Proximate Analysis

S.No	Contents	Significance.
1	High Moisture	(i) Reduces the calorific value of Coal (ii) Consumes more heat
2	High Volatile matter	(i) Reduces calorific value of coal (ii) Burns and produces high smoke
3	High Ash Content	(i) Reduces calorific value of Coal (ii) Blocks the air supply through the fuel.
4	More fixed carbon	(i) Greater calorific value (ii) Helps in designing the furnace.

x — x

Ultimate Analysis of Coal

Determination of % of

- Carbon & Hydrogen
- Nitrogen
- Sulphur
- Ash
- Oxygen.

(i) Carbon & Hydrogen Content

$$\left.\begin{array}{l}\text{A known amount}\\ \text{of Coal}\end{array}\right\} \xrightarrow[\text{Combustion apparatus}]{O_2} \text{Formation of } CO_2 \text{ \& } H_2O$$

Reactions

12 C 6

1 H

16 O 8

$$C + O_2 \longrightarrow CO_2 \uparrow$$

$$H_2 + \tfrac{1}{2} O_2 \longrightarrow H_2O \uparrow$$

KOH Tube

- CO_2 is absorbed
- Increase in weight of KOH Tube = Weight of CO_2.

Anhydrous $CaCl_2$ Tube

at.wt
C - 12
O - 16
H - 1

- H_2O Vapour is absorbed
- Increase in weight of $CaCl_2$ Tube = Weight of H_2O.

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

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

(ii) Nitrogen Content

Kjeldahl's method

Johan

$$\text{Powdered Coal} \xrightarrow[K_2SO_4]{\text{Con } H_2SO_4} \begin{array}{c}\text{Ammonium}\\ \text{sulphate}\end{array} (\text{Clear sol}^{n})$$

$$\Big\downarrow \text{NaOH}$$

$$\begin{array}{c}\text{Neutralisation}\\ \text{takes place}\end{array} \xleftarrow{\text{Std. } N/10 \text{ HCl}} NH_3$$

Reactions

$$2N + 3H_2 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$$

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

$$NH_3 + HCl \longrightarrow NH_4Cl.$$

methyl orange indicator

$$\%\ \text{of } N_2 \text{ in Coal} = \frac{1.4 \times \text{Volume of } \overset{HCl}{\text{acid}} \text{ Consumed} \times \overset{HCl}{\text{Normality}}}{\text{Weight of Coal sample}}.$$

(iii) Sulphur Content

$$\text{A known amount of Coal (g)} \xrightarrow[\text{Bomb Calorimeter (instrument)}]{\text{Burnt in}} \text{Sulphate} \xrightarrow[\text{with water}]{\text{Extracted}} \text{Extract}$$

$$\text{Extract} \xrightarrow{BaCl_2} BaSO_4 \longrightarrow \text{Filtered, dried and weighed.}$$

$$S + 2O_2 \longrightarrow SO_4^{2-} \xrightarrow{BaCl_2} BaSO_4 \downarrow$$

$$\%\ \text{of sulphur in coal} = \frac{\overset{(S.\ at\ wt)}{32} \times \text{Weight of } BaSO_4 \text{ obtained}}{\underset{BaSO_4}{233} \times \text{Weight of Coal sample}} \times 100$$

O = 16

Ba 137
S 32
4(O) 64
233

Ba = 137

(iv) Ash content

$$\text{Moisture \& Volatile matter removed Coal without lid} \xrightarrow[700 \pm 50^\circ c]{\frac{1}{2}\ hr} \text{Loss in weight of coal is noted.}$$

$$\%\ \text{of ash Content} = \frac{\text{Weight of ash formed}}{\text{Weight of air dried Coal}} \times 100.$$

(v) Oxygen Content

% of O_2 in Coal = 100 − % of (Carbon + Hydrogen + Sulphur + Nitrogen + ash Content

Significance of Ultimate analysis of Coal.

S.No	Contents	Significance
1	High C & H_2	(i) Increases calorific Value of Coal (ii) Helps in the classification of Coal
2	High Nitrogen	No calorific value.
3	High Sulphur	(i) It produces SO_2, NO_3 and Corrosion takes place
4	High ash Content	Reduces calorific Value of Coal
5	High Oxygen	(i) Reduces Calorific Value of Coal (ii) Increases moisture holding capacity of the coal.

x — x

Manufacture of Metallurgical Coke

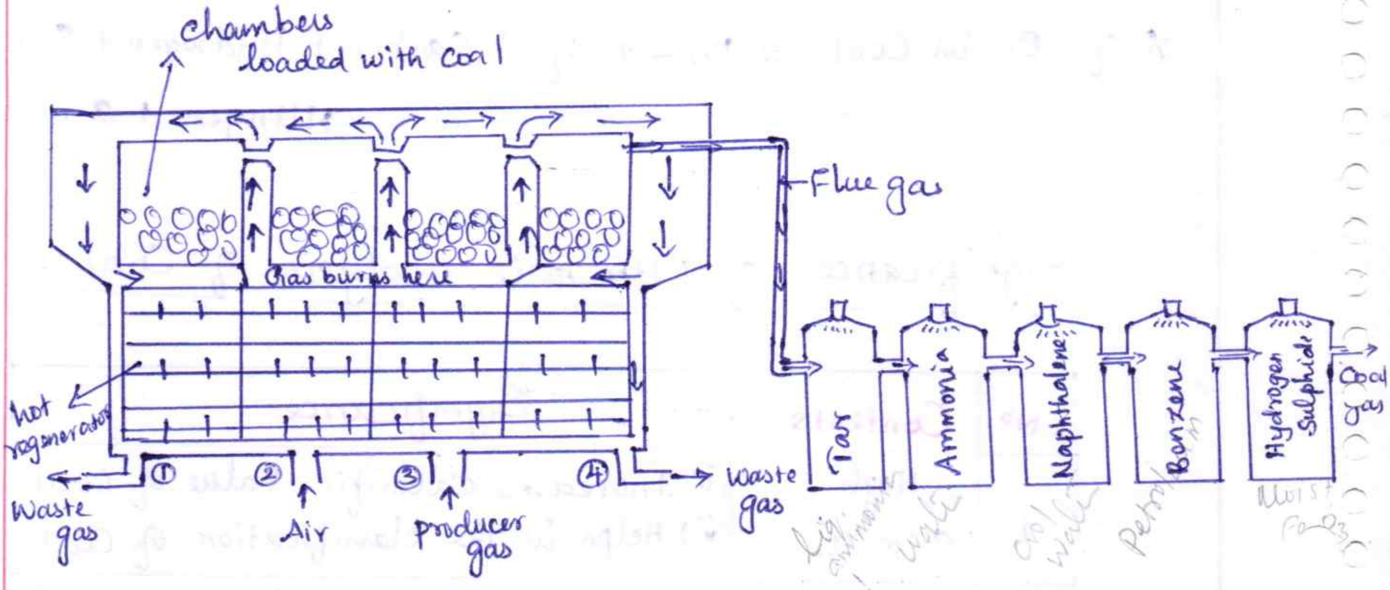
Otto-Hoffman's by-product oven

Significance

(i) Increase the thermal efficiency of the Carbonisati process

(ii) Recover Value by-products.

Construction



⇒ The oven consist of a number of silica chambers.

⇒ Each chamber (10-12 m long, 3-4 m height, 0.4-0.45 m wide) with charging hole at top and iron door at each end.

→ Coal is taken in chambers is heated by preheated air and producer gas at 1200°c.

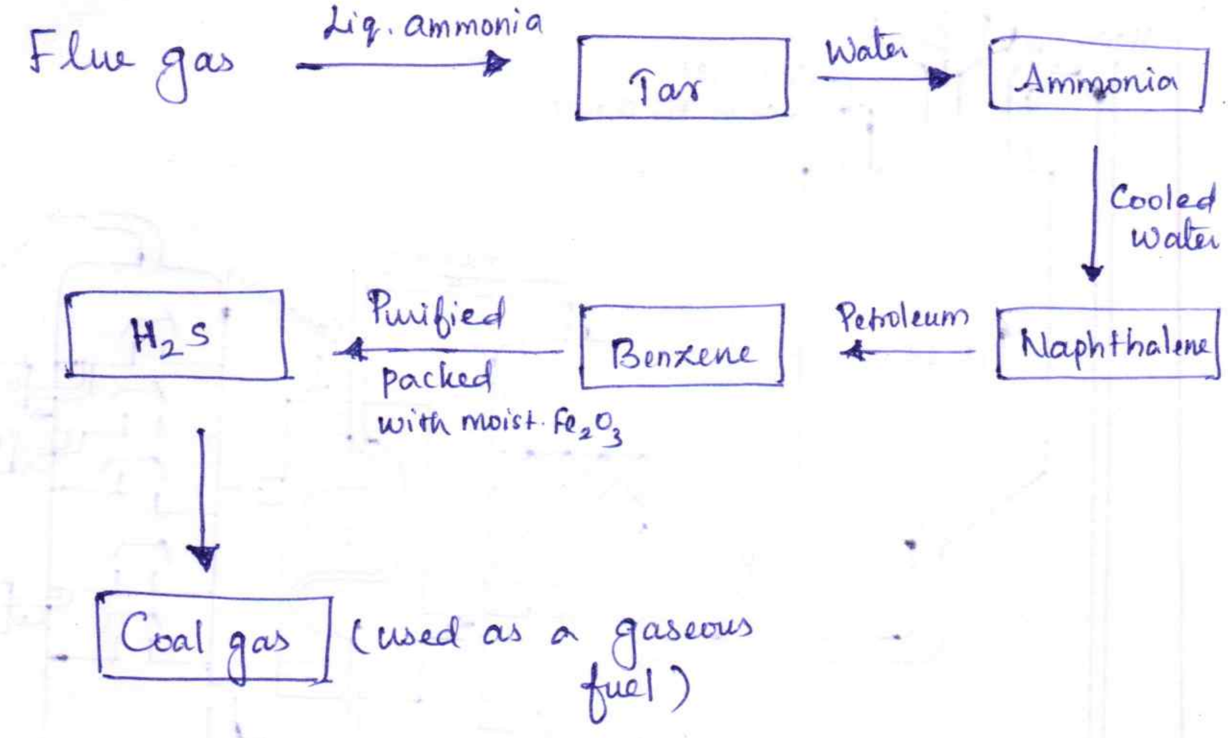
→ Hot flue gas produced, is passed through 1st and 4th regenerators upto 1000°c.

⇒ The system of recycling of flue gases to produe heat energy is known as the "regenerative system of heat economy".

⇒ After 24 hours, when the process is complete the coke is removed and quenched with water.

⇒ Yield is about 70% and the valuable by products can be recovered from flue gas.

Recovery of by-products



Advantages

- * The carbonisation time is less.
- * Heating is done externally by producer gas
- * Valuable by-products (Tar, ammonia etc) are recovered.

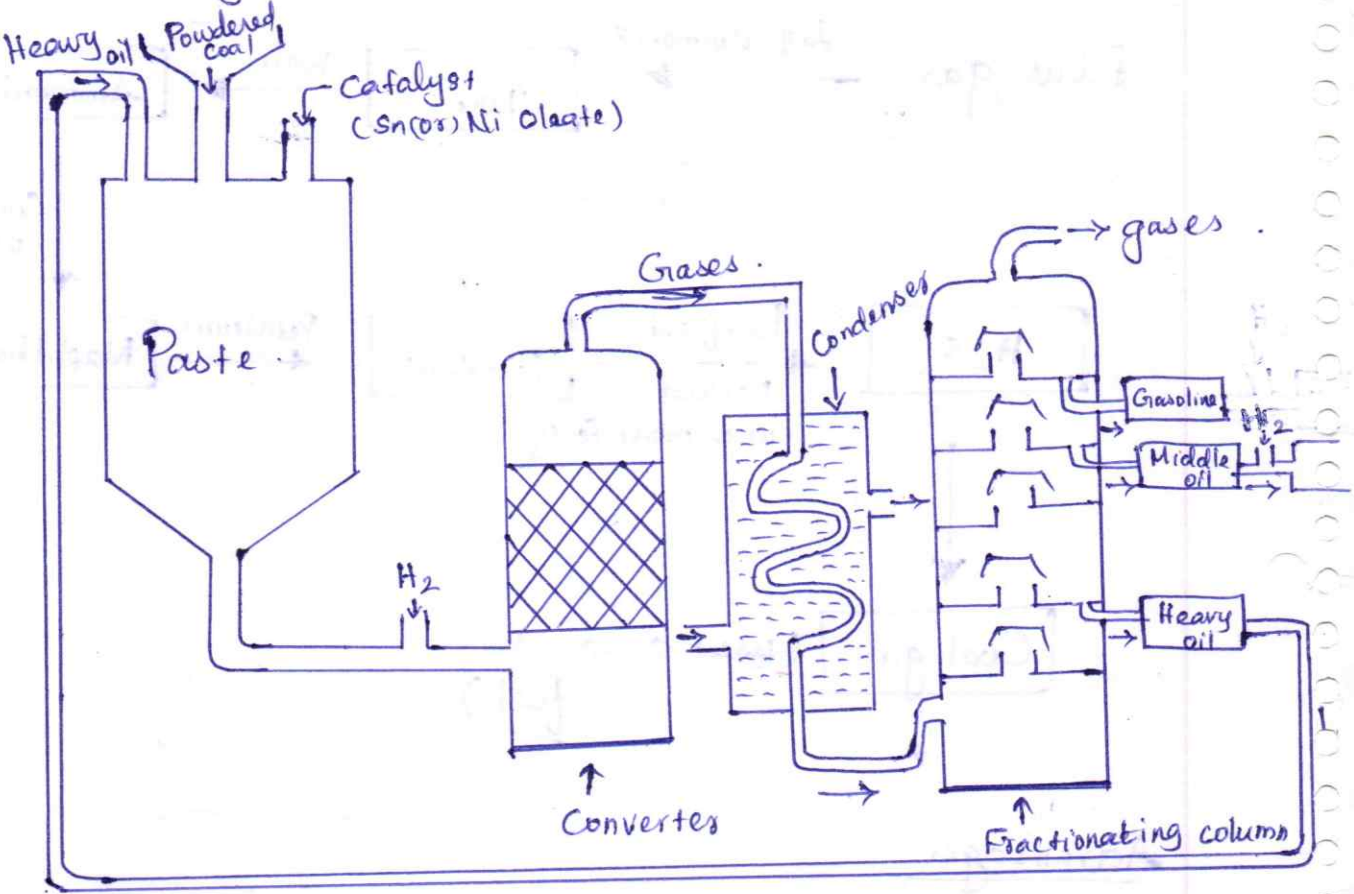
× —— ×

Hydrogenation of Coal
(or)
Manufacture of synthetic Petrol

$$\text{Coal} + H_2 \xrightarrow[\text{High Pressure}]{\text{High Temp } \Delta} \text{Gasoline.}$$

"The preparation of liquid fuels from solid coal" is called hydrogenation of coal.

Bergius Process (Direct Method)



Process

- Finely powdered coal + heavy oil + catalyst powder (tin (or) nickel oleate) is made into a paste and pumped along with H_2 gas into the converter.

- Converter – Paste (400-450°c , pressure – 200 to 250 atm)

- H_2 + Coal $\longrightarrow$ $\left(\begin{array}{c}\text{Saturated higher}\\\text{hydrocarbons}\end{array}\right)$ $\xrightarrow[\text{High Temp}]{\text{decomposition}}$ $\left(\begin{array}{c}\text{Mixture of}\\\text{lower}\\\text{hydrocarbon}\end{array}\right)$

  no double (or) triple bond

- The mixture led into the condenser, where the crude oil is obtained.

  (or) petroleum

- The crude oil is then fractionated to yield (i) Gasoline (ii) Middle oil (iii) Heavy oil.

* The middle oil + H_2 ⇒ More gasoline

* The heavy oil is recycled for making paste with fresh coal dust

* The gasoline yield – 60%.

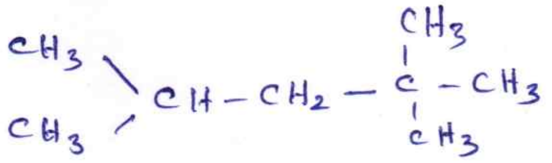
x — x

Knocking

"It is a kind of explosion due to rapid pressure rise occurring in an IC (diesel, petrol) engine.

Octane number

"The percentage of iso octane present in a mixture of iso-octane and n-heptane"



$$\begin{matrix} CH_3 \diagdown & & & CH_3 & \\ & CH-CH_2 & - & \overset{|}{\underset{|}{C}} & -CH_3 \\ CH_3 \diagup & & & CH_3 & \end{matrix}$$

Iso octane (oct. no = 100)

$CH_3-CH_2-CH_2-CH_2-CH_2-CH_2-$

n-heptane

(oct. no = 0)

Cetane number

"The percentage of n-cetane present in a mixture of n-cetane and 2-methyl naphthalene, Which has same ignition lag as the fuel under test"

$CH_3-(CH_2)_{14}-CH_3$

n-cetane

(cetane no = 100)

2-methyl naphthalene

(Cetane no = 0)

Power Alcohol

"When ethyl alcohol is blended with petrol at concentration of 5-10%, it is called Power alcohol."

Absolute alcohol (100% Ethyl alcohol) is also called as power alcohol.

Manufacture

Step I - Manufacture of ethyl alcohol

$$\underset{\text{Glucose (sugar)}}{C_6H_{12}O_6} \xrightarrow{\text{Yeast}} \underset{\text{Ethyl alcohol (20\%)}}{2\,C_2H_5OH} + 2\,CO_2$$

Concentration of alcohol can be increased upto 97.6% by fractional distillation.

Step II - Conversion of ethyl alcohol into Power alcohol

(i) $\underset{\text{(with trace of water)}}{\text{Alcohol}} \xrightarrow[\text{with Benzene}]{\text{Distillation}} \text{Power alcohol}$

Properties

- * It has high calorific value
- * It has high octane number (90)
- * It's anti knocking properties are good.

Uses

Good fuel

Advantages	Disadvantages
* cheap	* It may undergo oxidation
* Emission of CO, HC reduced	* It cause starting trouble.

Bio-diesel

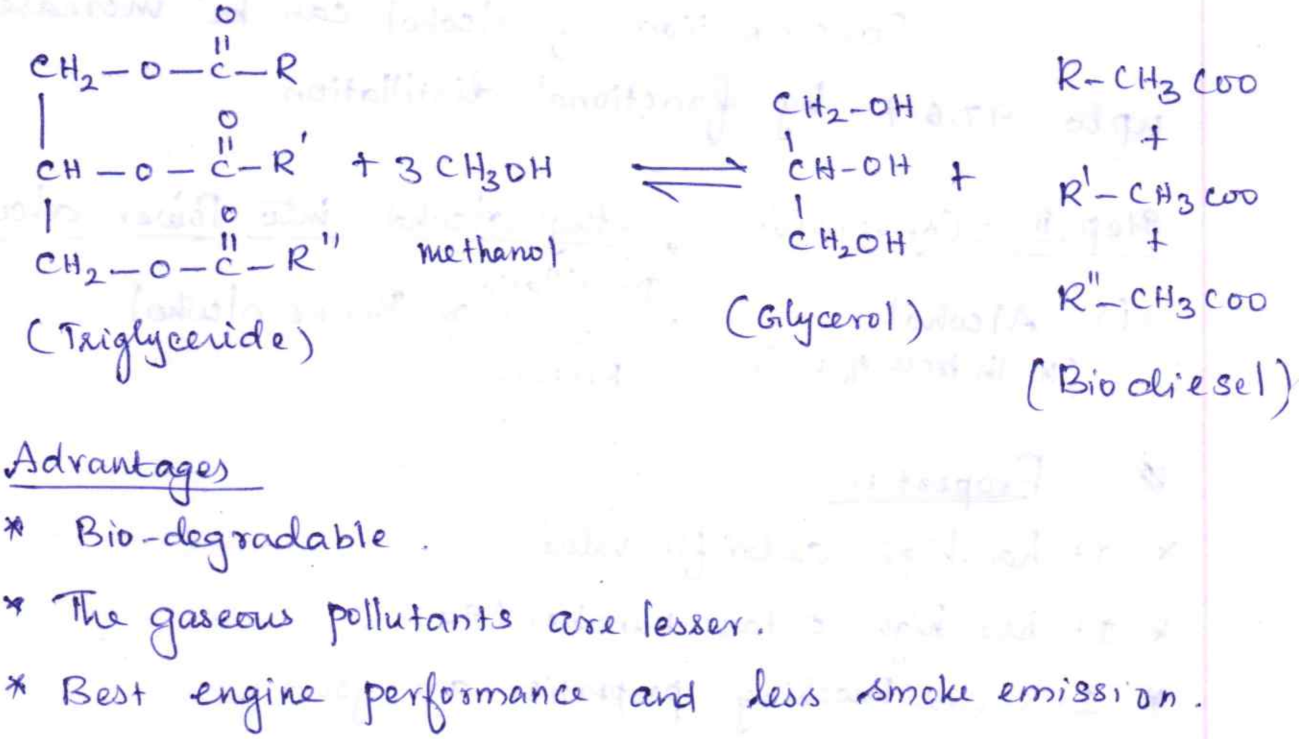
Problems in using Vegetable oils directly.

1. Viscosity of Vegetable oil is high - incomplete combustion.
2. High viscosity - misfire and ignition delay.
3. For using vegetable oil, we should modify diesel engine design.

Manufacture of bio diesel.

Alcoholysis (or) Trans-esterification

"Displacement of alcohol from an ester by another alcohol".



Advantages

- * Bio-degradable.
- * The gaseous pollutants are lesser.
- * Best engine performance and less smoke emission.

Disadvantages

- * Biodiesel gels in cold weather.
- * It decreases the horse power of the engine.
- * Bio-diesel absorb water from the atmosphere.

x—x

Ignition Temperature.

"The lowest temperature to which the fuel must be heated, so that it starts burning smoothly".

Spontaneous Ignition Temperature

"The minimum temperature at which the fuel catches fire spontaneously without external heating".

Explosive range.

Lower limit – Smallest proportion of combustible gas (fuel)

Upper limit – Largest proportion of Combustible gas.

The range covered by these limits is termed as explosive range of the fuels.

x——x

Flue gas Analysis

(ORSAT method)

"The mixture of gases (like CO_2, O_2, CO etc) coming out from the combustion chamber is called flue gases".

Flue gas analysis give an idea about the complete or incomplete combustion process.

Description

- It consist of a horizontal tube.
- One end of the tube – 'U' tube with fused $CaCl_2$
  other end – graduated burette.
- The lower end of burette connected with water reservoir
- The horizontal tube is also connected with different absorption bulbs 1, 2 and 3 for absorbing CO_2, O_2 and CO.

Bulb	Reagent	Function.
1	Potassium hydroxide solution	Absorbs only CO_2
2	Alkaline pyrogallol solution	Absorbs CO_2 and O_2
3	Ammoniacal cuprous Chloride solution	Absorbs CO_2, O_2 and CO.

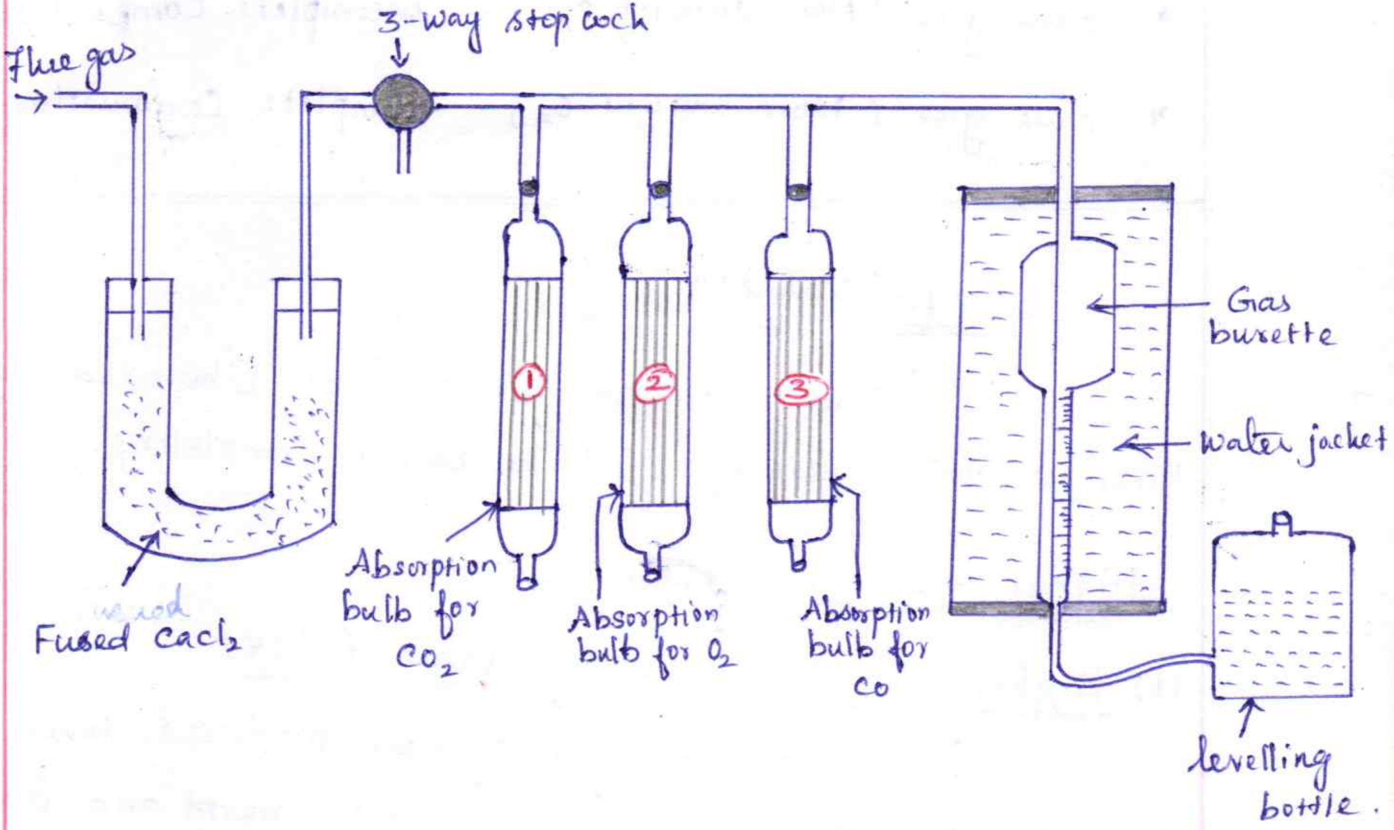
Working

→ The 3-way stop cock is opened to the atmosphere, reservoir is raised, so that air is excluded from the burette

→ Then the 3-way stop cock is connected to flue gas supply. (100 cc)

(i) Absorption of CO_2

- Bulb 1 – KOH solution
- It absorbs CO_2 present in flue gas.
- The decrease in the volume of flue gas in the burette – volume of CO_2 in 100 cc of flue gas.



(ii) Absorption of O_2

- Bulb 2 – Alkaline pyrogallol solution
- It absorbs O_2 present in flue gas
- The decrease in the volume of the flue gas in the burette indicates the volume of O_2.

(iii) Absorption of CO

- Bulb 3 – Ammoniacal cuprous chloride
- It absorbs CO present in flue gas.
- The decrease in the volume of the flue gas in the burette indicates the volume of CO.

Significance of flue gas analysis

- It gives an idea about complete (or) incomplete combustion process.

- Flue gas (More amount CO) – incomplete Combustion.
- Flue gas (More amount O_2) – Complete Combustion.

Calorific Value

"The total amount of heat liberated, when a unit mass of fuel is burnt completely"

Higher and Lower Calorific Value

(i) Higher (or) Gross calorific Value (GCV)

"The total amount of heat produced, when a unit quantity of the fuel is completely burnt and the products of combustion are cooled at room temperature".

(ii) Lower (or) Net Calorific Value (NCV)

"The net heat produced, when a unit quantity of the fuel is completely burnt and the products of combustion are allowed to escape"

NCV = GCV – Mass of hydrogen × 9 × Latent heat of Condensation of water vapour

$$\begin{array}{ccccc} H_2 & + & O & \longrightarrow & H_2O \\ 2\,gm & & 16\,gms & & 18\,gms \\ 1 & & 8 & & 9 \end{array}$$

$$\therefore \quad NCV = GCV - \frac{9}{100} H \times 587$$

$$= GCV - 0.09\,H \times 587$$

Where,

H = % of H_2 in the fuel.

Fuels

A fuel is a combustible substance containing carbon as the main constituent, which on burning gives large amount of heat. During combustion, carbon, hydrogen etc combine with O_2 ~~with~~ and liberate heat.

$$C + O_2 \longrightarrow CO_2 + 94 \text{ kcal.}$$

$$2H_2 + O_2 \longrightarrow 2H_2O + 68.5 \text{ kcal.}$$

Characteristics of a good fuel

* It should be cheap, readily available
* High calorific value
* Combustion should be controllable
* Low moisture content.
* should be safe.

Classification of fuels

I. Classification based on occurrence.

1. Primary fuels - It occurs in nature as such.
   Eg. Coal, petroleum, natural gas
2. Secondary fuels - derived from primary fuels.
   Eg. Coalgas, coke, gasoline.

II Classification based on their Physical state

1. Solid fuels. Eg. Coal, Coke
2. Liquid fuels. Eg. gasoline, diesel
3. Gaseous fuels. Eg. Coal gas, natural gas.

Comparison of Solid, Liquid and Gaseous fuels.

Property	Solid fuels	Liquid fuels	Gaseous fuels
1. Calorific Value	Low	Higher	Highest
2. Combustion	Slow	Quick	Rapid
3. Control of Combustion	Cannot be Controlled.	Can be Controlled	Can be Controlled.
4. Thermal efficieny	Least	Higher	Highest
5. In IC engine	Cannot be used	Can be used	Can be used.
6. Handling Cost	More	Less	Lesser.
7. Ignition temp	Highest	Moderate	Low
8. Cost of production	Low	High	High
9. Pollution	Release dust, smoke	Clean	Clean
10. Fire hazard	Least risk.	Greater risk	Highly inflammable

Gaseous Fuels

1. Natural Gas

Composition.

Constituents	Percentage (%)
Methane	88.5
Ethane	5.5
Propane	4
Butane	1.5
Pentane	0.5

Calorific Value = 12,000 to 14.000 kcal/m^3.

Natural gas → having lower hydrocarbons (Methane, ethane) ⇒ lean or dry gas

↳ having higher hydrocarbons (propane, butane with methane) ⇒ rich or wet gas.

Uses

* Domestic and industrial fuel
* raw material for the manufacture of carbon black and hydrogen.
* Produce electricity

2. Compressed Natural Gas (CNG)

When the natural gas is compressed, it is called Compressed Natural Gas (CNG).

Composition

Constituents	Percentage (%)
Methane	88.5
Ethane	5.5
Propane	3.7
Butane	1.8
Pentane	0.5

properties

* Cheapest, cleanest, environmetally safe fuel
* Less expensive than petrol and diesel
* Ignition temp = 550°c
* It requires more air for ignition.

Uses

Used to run automobiles.

Advantages of CNG over LPG.

* CNG produces less pollutants than LPG.
* CNG is cheaper and cleaner than LPG
* Thermal efficiency of CNG is more
* CNG does not evolve sulphur and nitrogen gas
* Noise level is much less than diesel.

3. Liquified Petroleum Gas (LPG)

Composition

Constituents	Percentage (%)
n-Butane	38.5
Iso butane	37
Propane	24.5

Calorific value - 25,000 kcal /m^3

Uses

- Domestic and industrial fuel
- Motor fuel

Advantages of LPG over other gaseous fuels

- It burns cleanly
- Higher calorific value.
- High Thermal efficiency and heating rate.
- Needs little care for maintenance
- Free from CO, so it is less hazardous.

Disadvantages of LPG over other gaseous fuels

- Leakage cannot be easily detected
- Octane value is low
- Handling must be done under high pressure.

x — x

Ⓟ

Unit - 5

Energy Sources and Storage Devices

Stability of Nucleus

Mass Defect

Definition

The difference between the calculated and experimenta masses of nucleus is called mass defect. It is denoted by Δm.

$$\Delta m = \left\{ \begin{array}{l} \text{Total mass of the} \\ \text{protons, neutrons} \\ \text{and electron} \end{array} \right\} - \left\{ \begin{array}{l} \text{Experimental mass} \\ \text{of the nucleus} \end{array} \right\}$$

Calculation of mass defect

Consider an isotope,

Let its atomic number = Z

Mass number = A

If its atom contains,

Z-protons, Z-electrons and $(A-Z)$ neutrons

Let, m_p = mass of proton, m_n = mass of ~~electron~~ neutron

m_e = mass of electron.

$\therefore$ Calculated mass of isotope

$$M' = Zm_p + Zm_e + (A-Z)m_n = Zm_H + (A-Z)m_n$$

M = Actual experimental mass of nucleus

$(\because m_p + m_e = m_H$ & mass of H atom

Then the mass defect (Δm),

$$\Delta m = M' - M$$

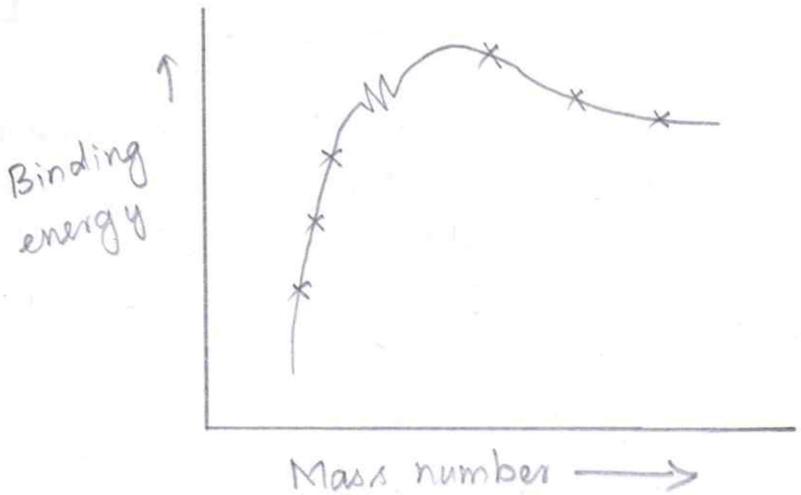
$$\boxed{\Delta m = Zm_H + (A-Z)m_n - M}$$

Binding Energy

Definition

"The energy released when a given number of protons and neutrons come together to form nucleus"

Binding energy Vs Nuclear Stability



- From the graph, the stability of nucleus increases upto a mass number of 65 and decreases thereafter.
- Some subsidiary peaks in the plot at ${}_2He^4$, ${}_6C^{12}$ and ${}_8O^{16}$ indicating stable nuclear configurations.
- This is probably due to the presence of equal number of protons and neutrons.

Calculation of binding energy

It is calculated from the mass defect using the relation,

$$E = \Delta m c^2$$

$$E = [Z m_H + (A-Z)m_n - M] \times c^2$$

Where,

$E \rightarrow$ binding energy of the nucleus
$\Delta m \rightarrow$ mass defect
$c \rightarrow$ Velocity of light

x — x

Nuclear Energy

"The energy released by the nuclear fission (or) nuclear fusion reaction, is called nuclear energy".

Nuclear Reactor (or) Pile

"The arrangement (or) equipment used to carry out fission reaction under controlled manner is called a nuclear reactor"

Light water Nuclear Power plant.

Components of a nuclear reactor

1. Fuel Rods

The fuel (fissionable material) used in the reactor in the form of rods (or) stripes.

Eg. U^{235} ; Pu^{239}

Function

* It produces heat energy and neutrons.

2. Control Rods

To control the fission reaction, movable rods are placed between fuel rods. These rods can be raised (or) lowered and control the fission reaction.

$$Cd^{113}_{43} + {}_0n^1 \longrightarrow Cd^{114}_{43} + \gamma\text{-ray}$$

$$B^{10}_5 + {}_0n^1 \longrightarrow B^{11}_5 + \gamma\text{-ray}$$

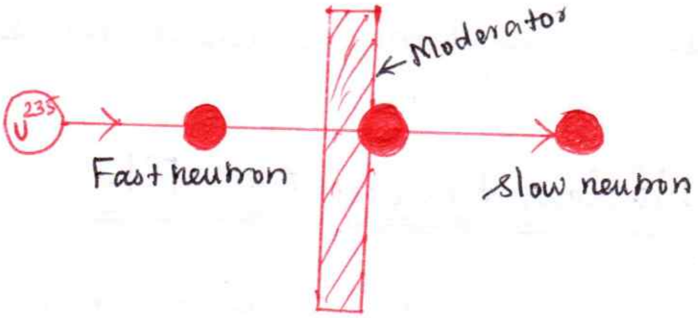
Eg. Cd^{113}, B^{10}

Function

* It controls the nuclear chain reaction.

3. Moderators

These are substance used to slow down the neutrons.



Eg

H_2O, D_2O (heavy water)

Function

- The kinetic energy of fast moving neutrons (1 meV) is reduced to 0.25 meV.

4. Coolant

The liquid (used to absorb heat produced) is circulated in the reactor core is known as coolant.

Eg

H_2O, D_2O

Function

- It Cools the fuel core.

5. Pressure Vessel

It enclose the reactor core and provide entrance and exit for the passage of coolant.

Function

It withstand the pressure as high as 200 kg/cm^2.

6. Protective shield

The nuclear reactor enclosed with a Concrete shield (more than 10m thick)

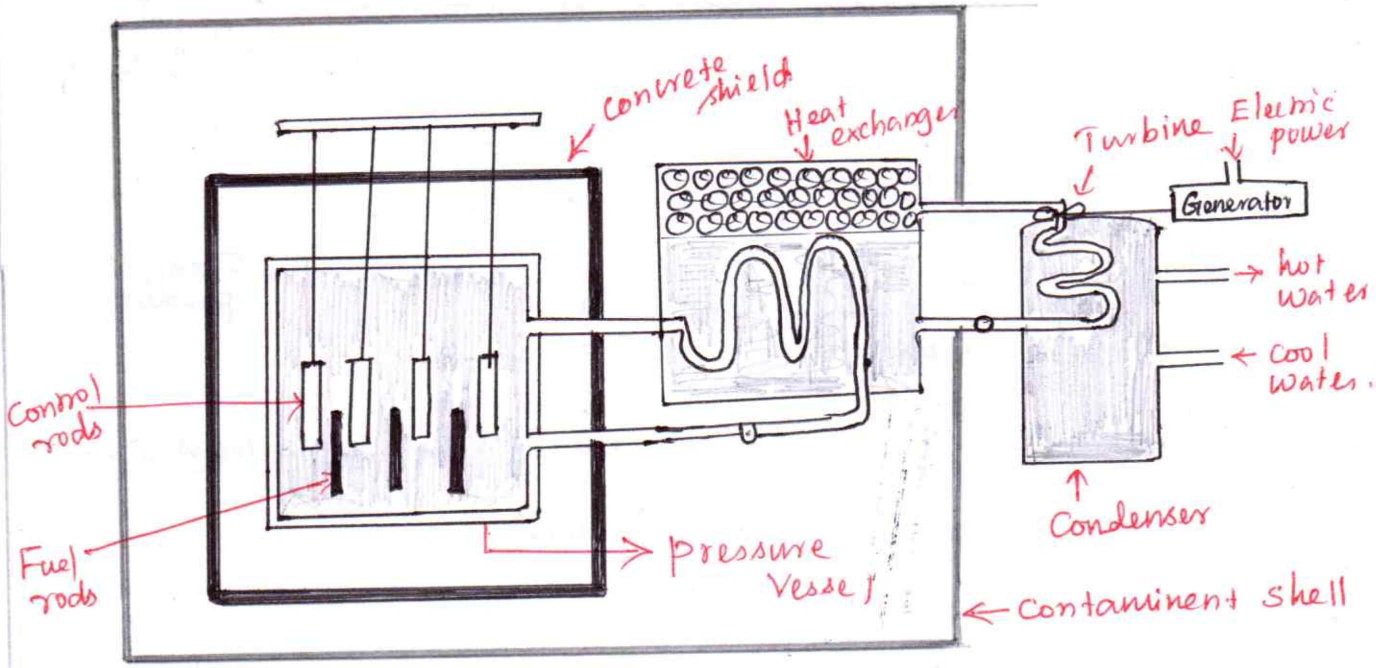
Function

Used to protect environment from radiation.

7. Turbine

The steam is used to operate steam turbine which drives a generator to produce electricity.

"In Light water nuclear power plant U^{235} fuel rods are submerged in water. Here water acts as coolant and moderator".



Working

- * The fission reaction is controlled by inserting (or) removing control rods of B^{10}
- * The heat produced from nuclear fission reaction is absorbed by the coolant (water).
- * The heated coolant (Water at 300°c) then goes to the heat exchanger containing sea water
- * The coolant here, transfers heat to sea water, which is converted into steam.
- * The steam drives the turbine, generate electricity.

Problem on disposal of reactor waste.

The fission products are radioactive. They emit dangerous radiation for several hundred years. So the waste is packed in concrete barrels, which are buried deep in the sea.

Breeder Reactor

" Breeder reactor is the one which converts non-fissionable material (U^{238}, Th^{232}) into fissionable material (U^{235}, Pu^{239}).

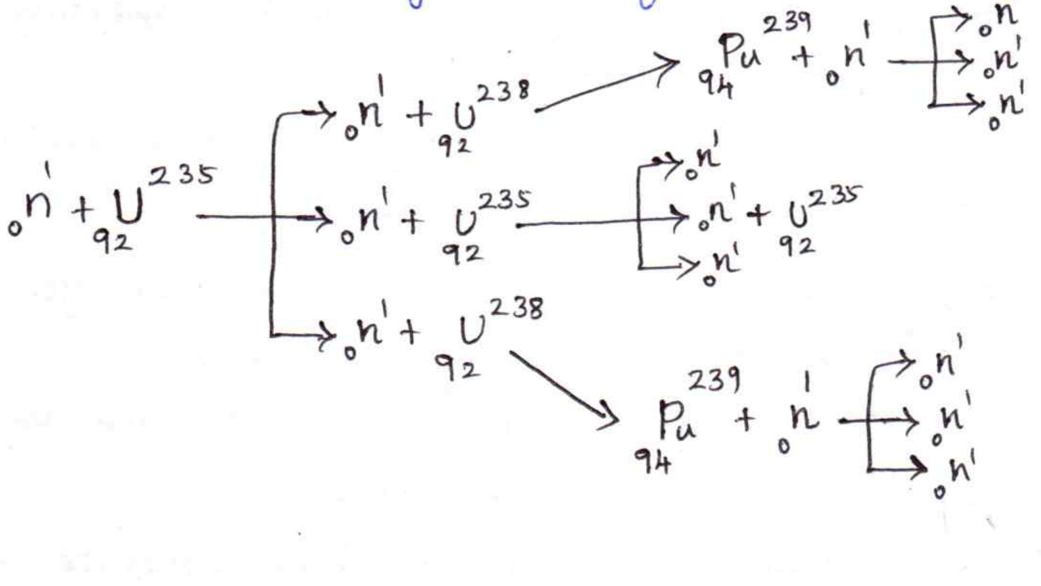
$$ {}_{92}U^{238} + {}_0n^1 \longrightarrow {}_{94}Pu^{239} + 2e^- \xrightarrow{{}_0n^1} \left.\begin{matrix}\text{Fission}\\ \text{product}\end{matrix}\right\} + 3\,{}_0n^1 $$

Non-fissionable Fissionable.

In breeder reactor, of the 3 neutrons,

one is used to react with U^{235}
two is used to react with U^{238}

P^{239} is a man made nuclear fuel, and it is known as secondary nuclear fuel.



Significance

* The non-fissionable nucleides (fertile nucleides) like U^{238}, Th^{232} Converted into fissile nucleides like U^{235} & Pu^{239}
* The efficiency of fissile nucleides are greater.

x—x

Solar Energy Conversion

It is the process of Conversion of direct sunlight into more useful forms.

* Thermal conversion
* Photo conversion.

Methods of Thermal Conversion.

1. Solar heat Collectors

These consist of natural materials like stones, bricks (or) glass, which can absorb heat during the daytime and release it slowly at night.

Uses

Used in Cold places.

2. Solar Water Heater.

* It Consist of an insulated box (painted in black colour
* At the top, there is a glass lid (receive and store solar heat)
* Inside it black painted Cu coil, through which Cold water is allowed to flow in, which gets heated and stored in a storage tank.
* Then the water is supplied through pipes.

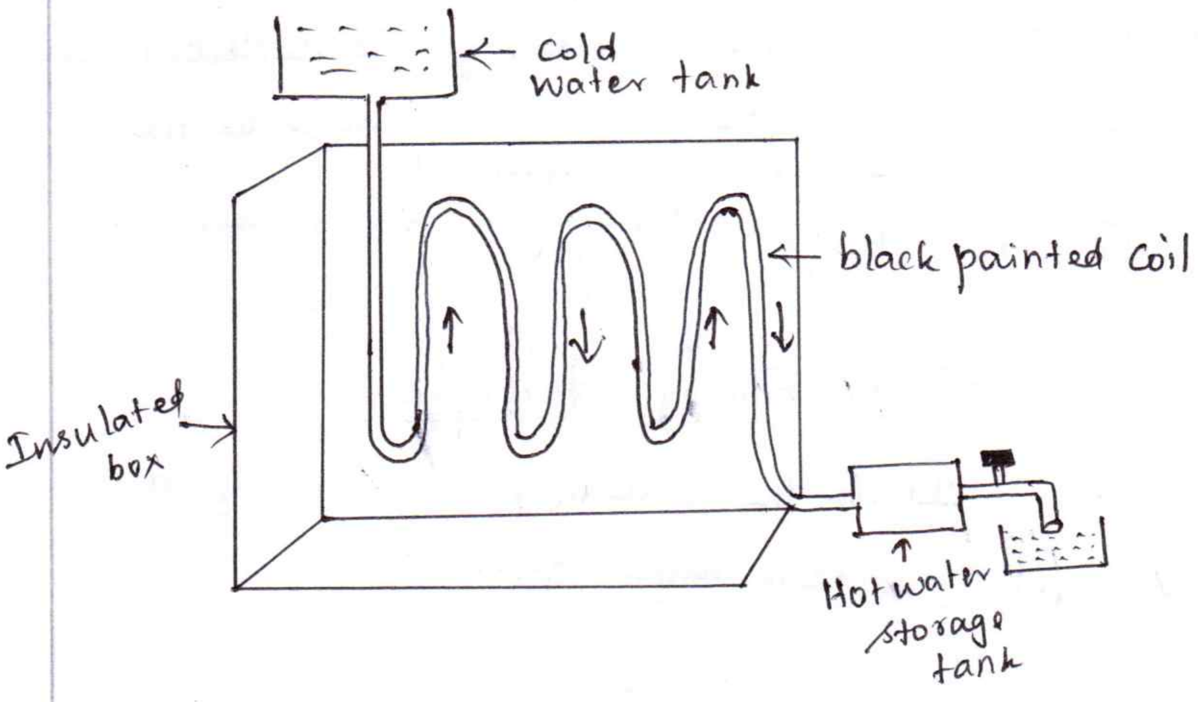


Photo Conversion

Light energy (Sun) ⟹ Electrical energy.

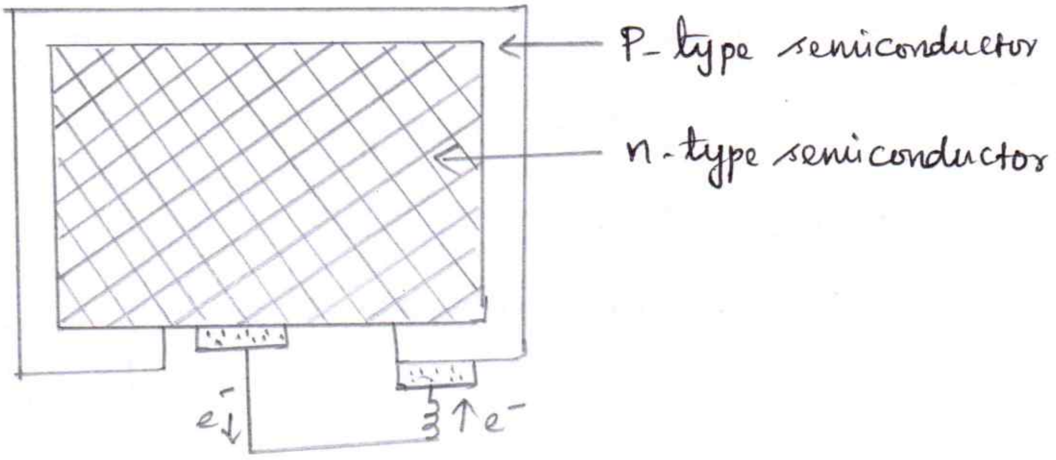
Photogalvanic cell (or) Solar cell

"Photogalvanic cell converts solar energy directly into electrical energy"

Principle

"When the solar rays falls on a two layers of semiconductor devices, a potential difference between two layer is produced. This potential difference causes flow of e⁻ns and produces electricity.

Construction



It consist of.

p-type semiconductor (Si doped with B)
n-type semiconductor (Si dopes with P)

Working

- Solar rays fall on the top layer of p-type semiconductor
- The e^-ns from the valence band get promoted to the conduction band, cross p-n junction into n-type semiconductor.
- So there is potential difference between two layers.
- Hence, there is a flow of e^-ns, and current is produc

Applications of solar cells

- Solar cells can be used for lighting purpose
- Solar batteries produces more electricity which is enough to run water pump.
- Solar cells are used in calculators, electronic watches, radios and TVs.

Advantages

- Maintenance cost low.
- Solar cells are noise and pollution free
- Their life time is long

Disadvantages

- Capital cost is higher.
- Storage of solar energy is not possible.

Recent developments in Solar Cell materials

Types of highly investigated solar cell materials

1. Crystalline Si
2. Thin films
3. Next generation perovskite Solar cells
4. Solar paints
5. Transparent solar windows
6. Thermoradiative Pv devices
7. Solar distillation.

1. Crystalline Si

- It is the most used semiconducting material in solar panels
- But its efficiency is only 30%.
- Now, high efficiency solar cells are emerging

Ex (i) III-V multijunction materials (efficiency > 30%)

(ii) Six-junction III-V solar cells under concentrated light } (efficiency > 47.1%)

2. Thin films

These solar cells are growing as one of the most promising PV technologies, because of their narrow design (light weight, flexibility and ease of installation)

Eg (i) Cd-telluride (CdTe)
(ii) Copper–Indium–Gallium–Selenide (CIGS)
(efficiency 21%)

3. Perovskite solar cells

These are low price, thinner design, low temperature processing and posses excellent light absorption properties.

Eg Combined perovskite and Si-PV materials shows efficiency up to 28%.

4. Solar paints

It can be coated over the polymer films.

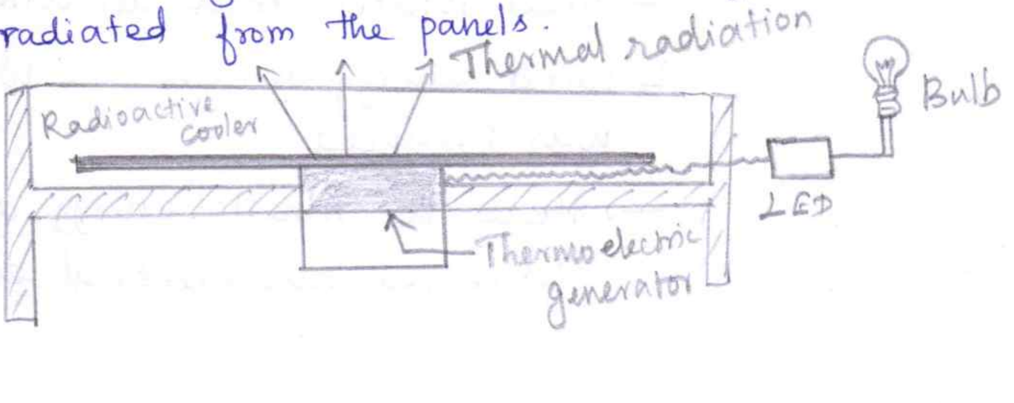
Eg Quantum dots
perovskite-based paints.

5. Transparent solar windows

They posses highly innovative applications. Their solar to electricity conversion efficiency is 10% more.

6. Thermoradiative PV devices (or) Reverse solar panels.

It can generate electricity at night by using the heat irradiated from the panels.



7. Solar distillation

It can harvest solar energy, if there is an integrated membrane distillation attachment.

x—— x

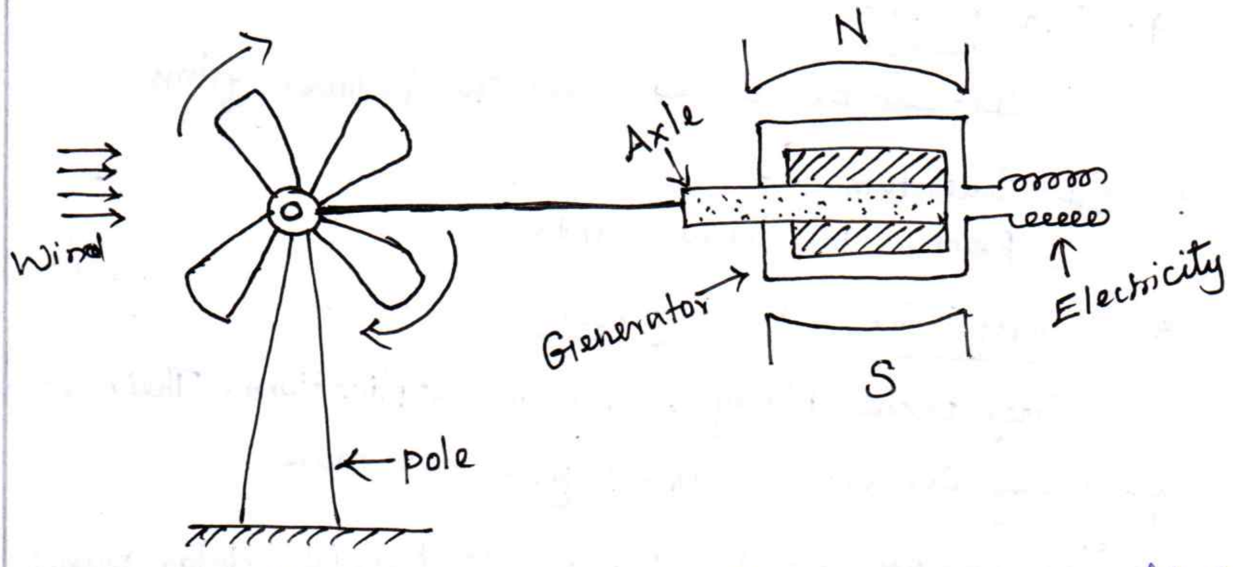
Wind Energy.

"Energy recovered from the force of wind is called Wind energy"

Methods of harnesing Wind energy

1. Wind Mill

Wind energy → Kinetic energy → Mechanical energy → Electrical energy



* Wind mill – It Consist of Wheel contain no.of blades
  - Wheel rotates about an axle on a pole
  - Wind energy rotates the wheel, electricity was produced.
  - Here the kinetic energy of the wind is Converted into electrical energy.

2. Wind farm

- To produce electricity on a large scale, a large no.of wind mills are connected.

3. Other methods

- kite ship (Large free flying sails)
- Sky wind power (flying electric generator)
- Briza technologies (Wind turbine)

Advantages of Wind energy

→ It does not cause any pollution

→ It is very cheap

→ Renewable

Disadvantages

→ Noise pollution

→ Wind turbine interfere with electromagnetic signal.

Uses

→ It is used to operate Water pumps

→ Used to produce electricity.

x— x

Geo-Thermal Energy

Temperature of the earth increases at a rate of 20-75°c per km, when we move down the earth surface. The energy harnessed from the high temperature present inside the earth is called geothermal energy.

1. Natural geysers.

In some places, the hot water (or) steam comes out of the ground through cracks naturally in the form of natural geysers.

2. Artificial geysers

In some places, we can artificially drill a hole up to the hot region and by sending a pipe in it, we can make the hot water or steam to rush out through the pipe with very high pressure.

Thus, the hot water (or) steam coming out from the natural (or) artificial geysers is allowed to rotate the turbine of a generator to produce electricity.

Significance of geothermal energy

* The power generation level is higher

* Geothermal powerplants can be constructed easily.

* These are efficiency used as hot water bath, resorts, aquaculture etc.

x—x

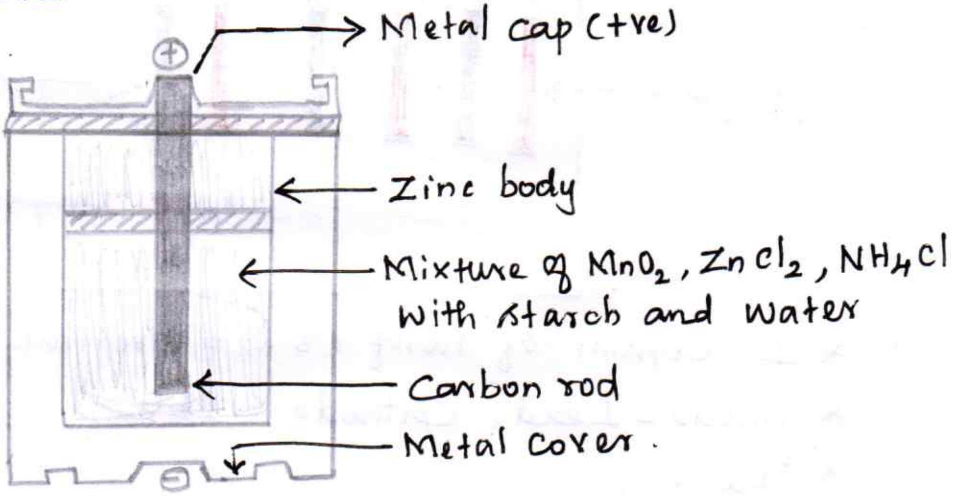
BATTERIES

Dry cell (or) Leclanche's Cell

It is a primary cell

Description :

- * Zinc cylinder - anode
- * Carbon rod - Cathode (it is immersed in the electrolyte)
- * Zinc cylinder filled with an electrolyte consists of NH_4Cl, $ZnCl_2$ and MnO_2 in the form of paste using starch and water.



Cell Reactions

At anode : $Zn \longrightarrow Zn^{2+} + 2e^-$

At cathode : $NH_4^+ + MnO_2 + 2e^- \longrightarrow MnO(OH)^- + NH_3$

overall cell reaction } $Zn + NH_4^+ + MnO_2 \longrightarrow Zn^{2+} + MnO(OH)^- + NH_3$

In cathode reaction, Mn is reduced from +4 oxidation state to +3 oxidation state. The liberated NH_3 gas reacted with $ZnCl_2$ forms, $ZnCl_2 + 2NH_3 \longrightarrow [Zn(NH_3)_2]Cl_2$

The voltage of dry cell is 1.5V.

Disadvantages

- * NH_4Cl being acidic corrodes the zinc body
- * When current is drawn rapidly, voltage drop occurs.

Uses

- * Used in calculators, flashlights, torches etc.

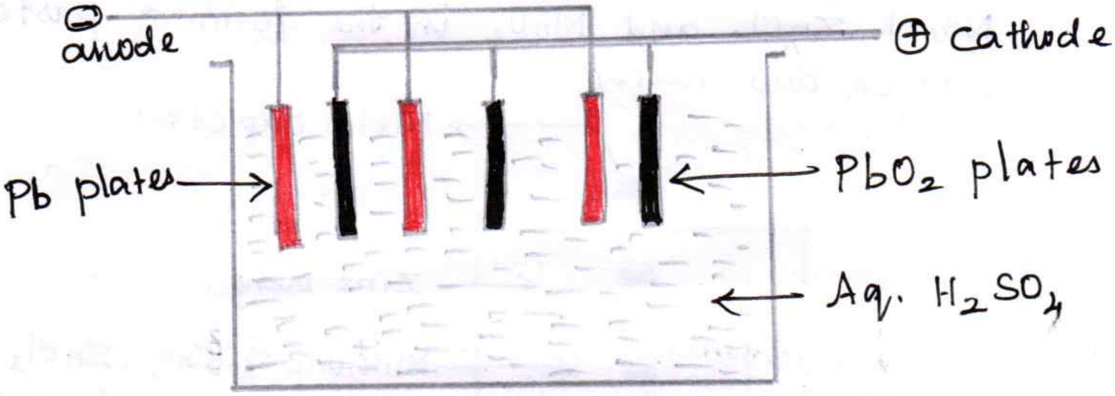
Lead Storage cell (or)

Lead Accumulator (or) Acid Storage cell

- It is a secondary battery (acts as a voltaic cell and as an electrolytic cell)

Voltaic cell - it supplies electrical energy

Electrolytic cell - it recharged.



- It Consist of no. of (3 to 6) Voltaic cell in a series
- Anode - Lead, Cathode - PbO_2
- The entire combination immersed in dil. H_2SO_4 (density = 1.3 gm/ml)

Cell representation

$$\boxed{Pb \mid PbSO_4 \parallel H_2SO_4 \mid PbO_2 \mid Pb}$$

At anode : $Pb + SO_4^{2-} \underset{charging}{\overset{discharging}{\rightleftharpoons}} PbSO_4 + 2e^-$

At cathode : $PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \underset{charging}{\overset{discharging}{\rightleftharpoons}} PbSO_4 + 2H_2O$

The overall cell reaction during use (discharging)

$$Pb + PbO_2 + 2H_2SO_4 \underset{charging}{\overset{discharging}{\rightleftharpoons}} 2PbSO_4 + 2H_2O + Energy$$

When all H_2SO_4 is used up, the battery needs charging

Recharging the battery

$$2PbSO_4 + 2H_2O + Energy \underset{charging}{\overset{discharging}{\rightleftharpoons}} Pb + PbO_2 + 2H_2SO_4$$

Advantages

* It is made easily
* It produces very high current

Disadvantages

* Recycling - environment hazard
* Mechanical strain - reduce battery capacity

Uses

* It is used to supply current mainly in automobiles
* It is also used in telephone exchanges, power stations etc.

x — x

Lithium - ion Batteries (LIB)

Lithium - ion battery is a secondary battery.

It has the following three components.

* A positive electrode (Layers of Lithium - metal oxide) - cathode
* A negative electrode (Layers of porous carbon) - anode
* An electrolyte - polymer gel & separator.

Construction

The positive electrode made of Lithium - Cobalt oxide ($LiCoO_2$) and the negative electrode is made from layers of Porous Carbon (C)

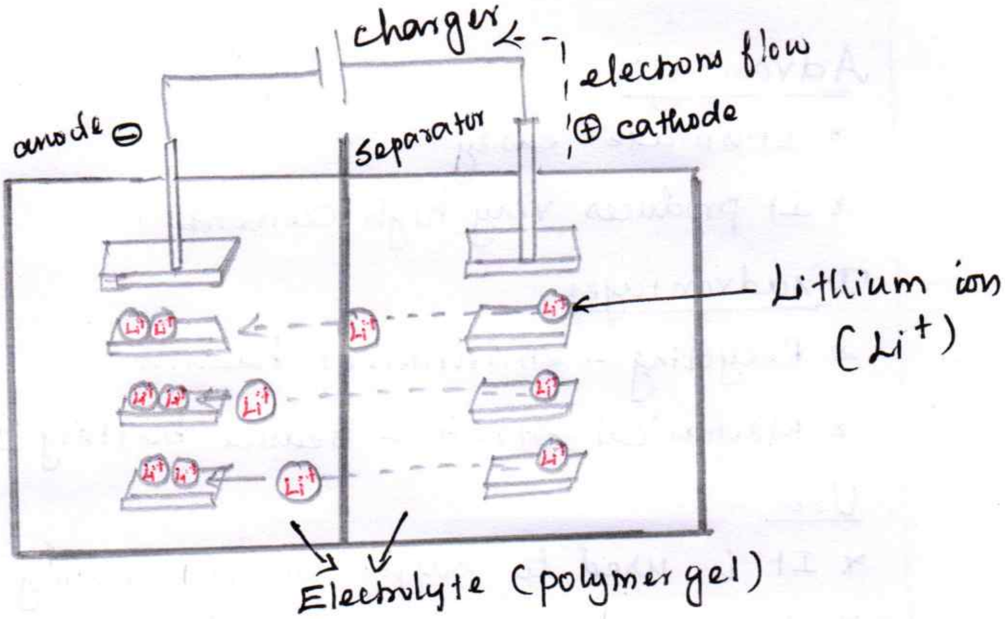
Both electrodes are dipped in polymer gel and separated by a separator which allows Li^+ ions to pass through.

Working

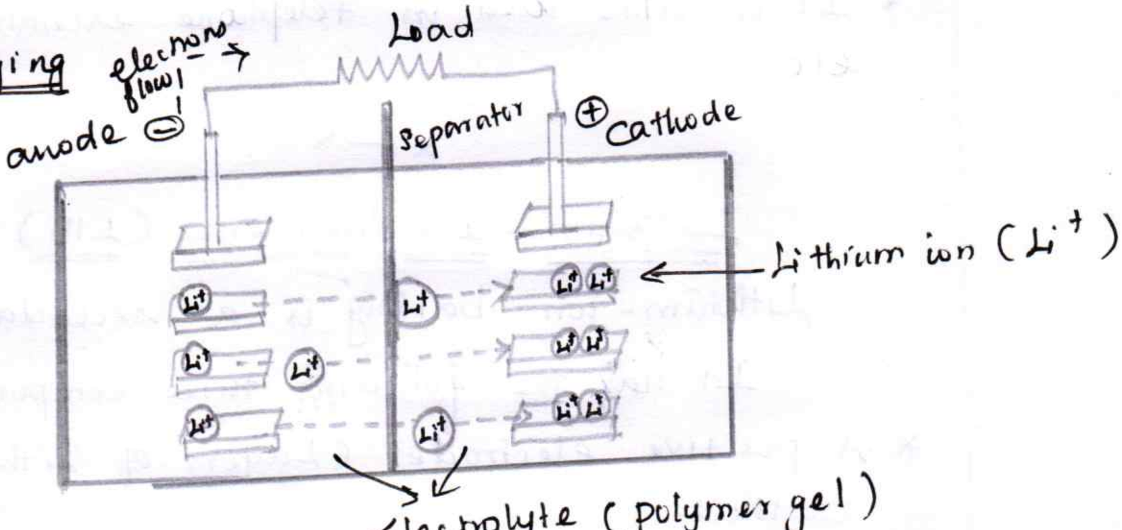
Charging

$$LiCoO_2 + C \longrightarrow Li_{1-x}CoO_2 + CLi_x$$

Charging



Discharging



$$Li_{1-x}CoO_2 + C\,Li_x \longrightarrow LiCoO_2 + C$$

Advantages

- High voltage and light weight batteries
- Smaller in size.
- It produces three time voltage of Ni-Cd batteries

Uses

Used in cell phone, portable LCD TV, semiconductor driven audio etc.

x — x

Electric Vehicles

Electric vehicles are the vehicles that are powered on electric power. They have an electric motor ~~ind~~ instead of an internal Combustion (IC) engine. As it runs on electricity, the vehicle emits no exhaust gases.

Components of EV

1. Battery : It provides electricity
2. Charge port : It is used to connect the vehicle to external power supply.
3. DC/DC Converter : It Converts higher voltage DC power to lower voltage DC power.
4. Electric motor : It drives the vehicle's wheels.
5. Onboard charger : It Converts AC electricity to DC power for charging the battery.
6. Power electronics controller : It Controls the speed
7. Thermal system : Maintains proper operating temperature of the engine.
8. Transmission : Transfer mechanical power to the wheels.

Working Principle

Electric vehicle take electricity during charging, then store electricity in battery which rotates the wheel. Electric vehicles accelerate faster than the traditional fuel engines.

Various steps

Step I → Controller regulates electrical energy from battery to inverter.

Step II → Then inverter sends electrical energy to the motor.

Step III → The motor converts electrical energy to mechanical energy.

Step IV → The wheels turn and then the vehicle moves.

Step V → When brakes are pressed, the motor produces power which is sent back to the battery.

Advantages

- It reduces emission
- performance is high and maintanence is low.

Disadvantages

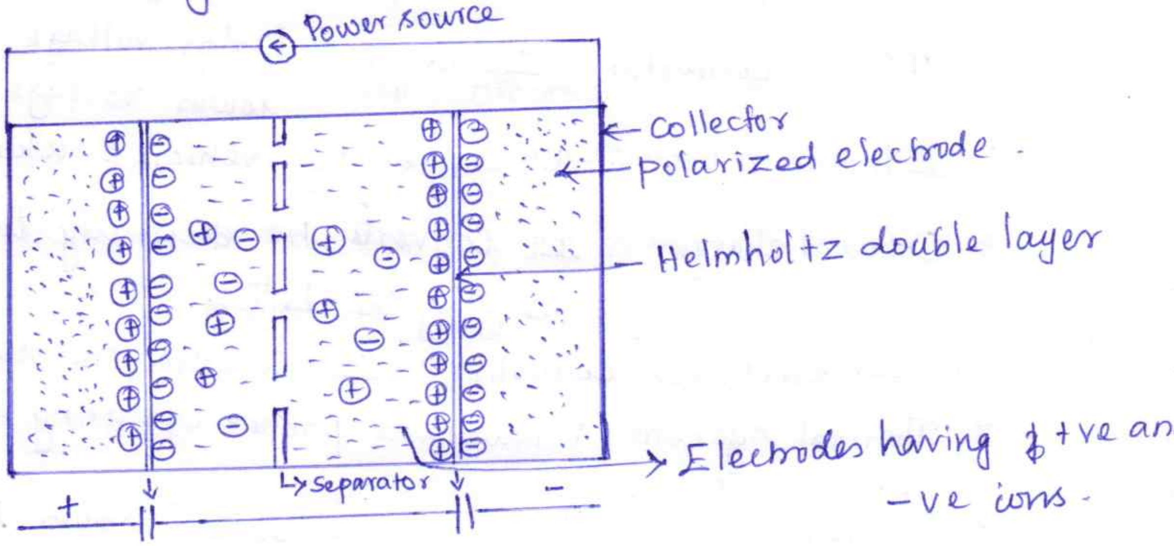
- It can travel less distance
- Takes longer time to recharge
- Expensive.

Super-Capacitor

- It is a high capacity capacitor (more capacitance value)
- Supercapacitors use electrostatic double-layer capacitanc

Design

It has two electrodes - made from metal coated with a porous substance like powdery activated carbon, separated by an ion-permeable membrane (separator) dipped in an electrolyte, containing positive and negative ions, connecting both the electrodes.



Working

- When the electrodes are connected to the power source, ions in the electrolyte forms electrical double layer
- Electrode / Electrolyte interface. (i) +vely polarized electrode will have a layer of -ve ions
  (ii) -vely polarized electrode will have a layer of +ve ions.
- This electric field polarizes the dielectric, so its molecules lineup in the opposite direction to the field and reduce its strength.

Advantages	Disadvantages	Applications
* Highly safe	* Cost per watt is high	* Energy harvesting
* Life time is high	* Cannot be a source for continuous power supply	* Consumer electronics
* Can be charged in seconds	* High self-discharge	* Kitchen appliances
* Performance is excellent even at low temp^e^ (-40°c)		* Switches, LEDS

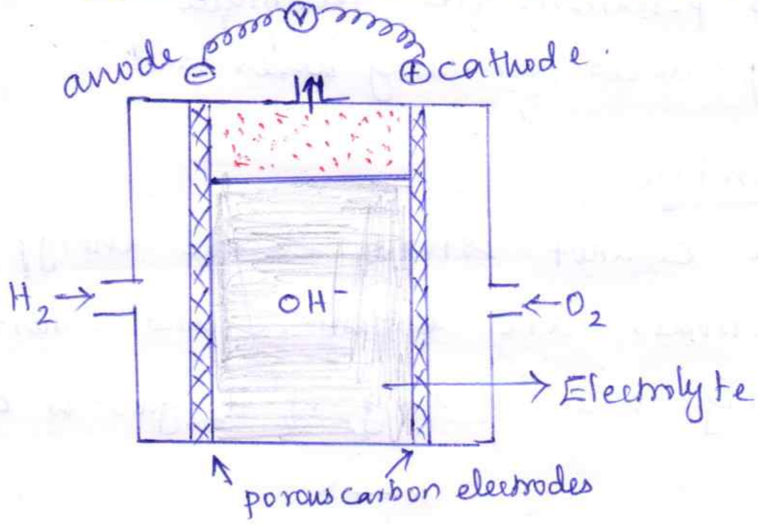
Fuel Cells

Definition

Fuel cell is a voltaic cell, which converts the chemical energy of the fuels directly into electricity without combustion.

$$\text{Fuel} + O_2 \longrightarrow \text{Oxidation pdt}$$

Hydrogen - Oxygen Fuel Cell



Description

- It has two porous electrodes (anode and cathode)
- porous electrodes - Compressed Carbon with small amount of catalyst (Pt, Pd, Ag)
- Electrolytic solution - 25 % KOH (or) 25 % NaOH
- Two electrodes are connected through the volt meter.

Working

Anode - Hydrogen is ~~p~~ bubbled (oxidation)

cathode - oxygen is bubbled (Reduction)

Various reactions

At anode : $2H_2 + 4OH^- \longrightarrow 4H_2O + 4e^-$

At cathode : $O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$

$$2H_2 + O_2 \longrightarrow 2H_2O$$

Emf of the cell = 0.8 to 1.0 V

Applications

* Used in space vehicle, military vehicle
* The product (water) - used by astronauts.

Advantages

* These are efficient
* It is pollution free technique
* It produces drinking water.

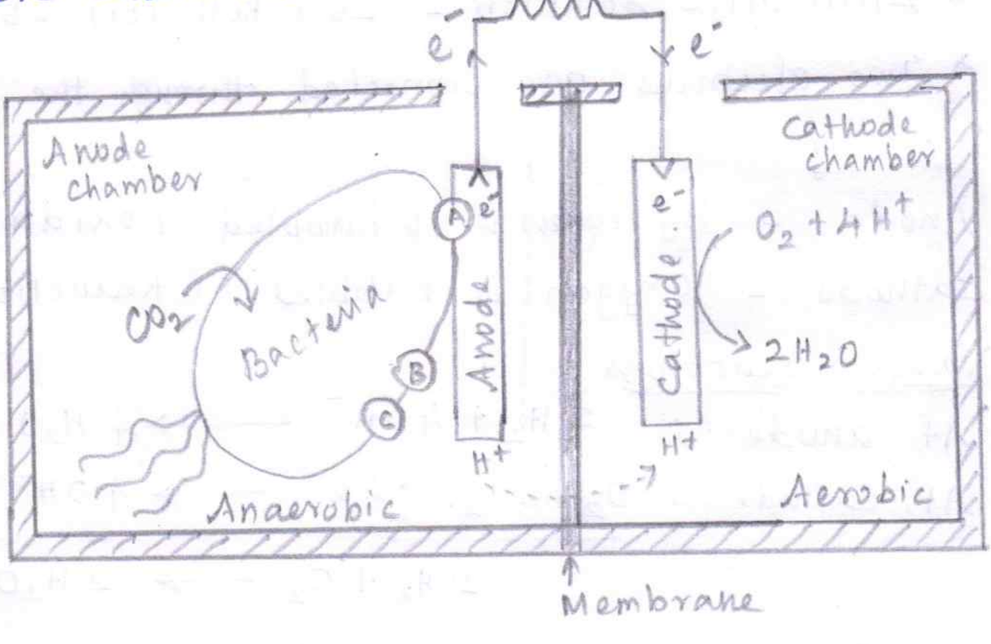
Disadvantages

* These cannot store electric energy
* Electrodes are expensive and short lived
* Storage and handling of H_2 gas is dangerous.

x — x

Microbial Fuel Cells (MFCs)

MFCs converts chemical energy to electrical energy by the action of micro-organisms under anaerobic conditions.



Principle

- MFCs are electrochemical cell - has bioanode and biocathod
- A membrane separates anode and cathode
- The electrons produced during oxidation (at anode) transfer to cathode.
- Organic electron donors, oxidized to produce CO_2, protons and electrons are used in most MFCs.

Components

(i) Anodic compartment - It consists of microbes suspended under anaerobic conditions.

(ii) Cathodic compartment - It consist of electron acceptor (O_2

(iii) Permeable membrane - Cationic and anionic compartm separated by permeable cation-specific membrane.

Working

- At anode oxidation occurs on organic waste and e's were released
- The electrons transferred directly to cathode across external circuit
- For every electron conducted, a proton is transported across the membrane to the cathode.
- Finally, O_2 present at cathode combines with hydrogen and electron to produce water.

Applications

- Used in wastewater treatment
- Used in deep-water environments
- Used to convert carbon rich wastewater into methane
- Used in space
- MFCs plays an important role in the field of microbiolog and soil chemistry