Objective: – "To study various types of conventional & non-conventional energy Resources including solid, liq & gaseous fuels." (1)

Module-1 Solar energy

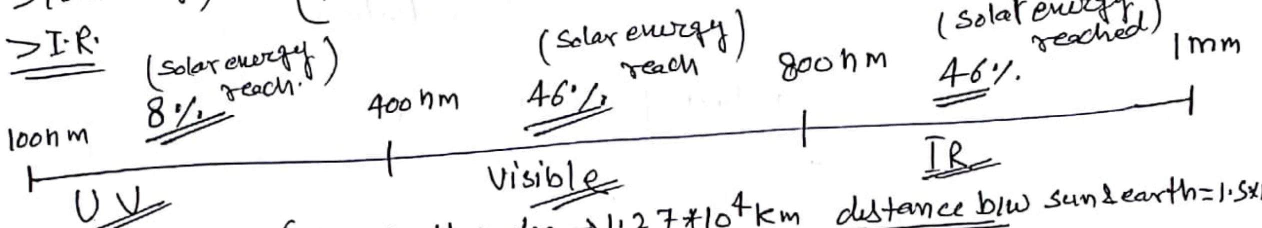
Solar Radiation:— Solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy.

or

It is radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy.

Solar radiation comes in many forms, such as visible light, radio waves, heat (infrared), X-rays & ultraviolets ray.

- radio waves → (10cm – 10m short, >10m long)
- heat (infrared) → (1mm–30mm) (700nm – 1mm) >I.R.
- X-rays → (0.01–10nm)
- ultraviolets → (200–400nm)
- visible light → (400–800 nm)



Sun: – dia → 1.39×10^6 km, Temp → 5762 K; earth: – dia → 1.27×10^4 km; distance b/w sun & earth = 1.5×10^8 km

Solar Constant: — The rate at which solar energy arrives at the top of the atmosphere is called the solar constant (I_{sc}). This is the amount of energy received in unit time on a unit area perpendicular to the sun's direction at the mean distance of the earth from the sun.

The National Aeronautics & Space Administration's (NASA) std value of solar constant.

- * 1353 watt/m^2
- * 116.5 langleys (Cal/cm^2)/hr (1 langleys = 1 Cal/cm^2)
- * 429.2 BTU/ft^2.hr

The earth is closest to the sun in summer & ~~farthest~~ farthest in winter

This can be approximated by the eqn:

$$\frac{I}{I_{sc}} = 1 + 0.033 \cos\left(\frac{360 n}{365}\right)$$

where I = Intensity of solar radiation

I_{sc} = Solar Const

n = number of the days in year

solar radiation intensity at the outer limit of atm = 2074 W/m^2

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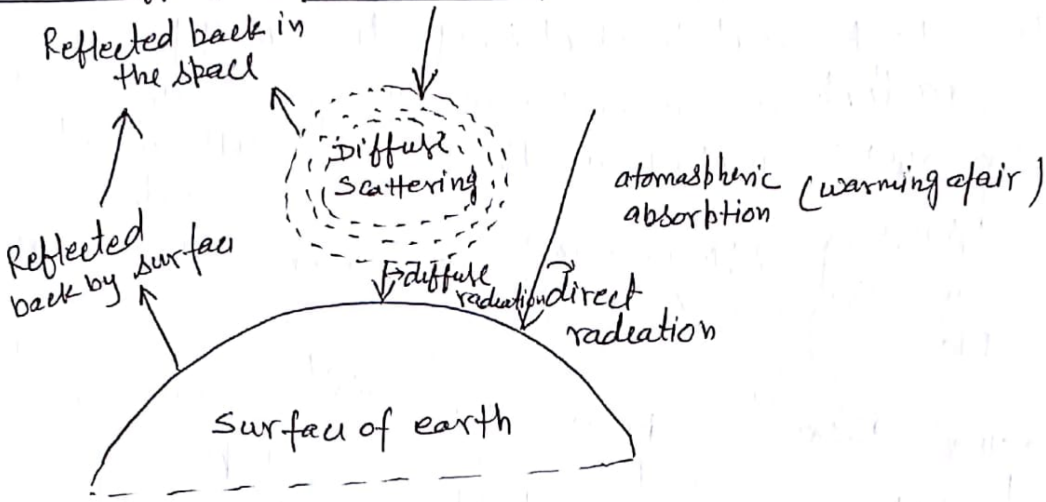
Solar radiation at the Earth surface :- From the point of view of Utilization of solar energy we are more interested in the energy received at the earth's surface than in the extra-terestial energy.

Beam and diffuse solar radiation :-



"Solar radiation that has not been absorbed or scattered and reaches the ground directly from the sun is called direct radiation or Beam radiation"

Diffuse radiation is that solar radiation received from the sun after its direction has been changed by reflection & scattering by the atomasphere.

The Total radiation received at any point on the earth surface is the sum of the direct & diffuse radiation. This is refferred to in a general sense as the isolation at that point.

Isolation is defined as the total solar radiation energy received on a horizontal surface of unit area on the ground in unit time (e.g. 1 day).

* Extra-terrestrial radiation incidents out side the earth atomaspere is called extraterrestrial radeation. on avg it is 1367 W/m^2.

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Solar Radiation measurements :- measurements of solar radiation are important because of the increasing number of solar heating and cooling applications, & need for accurate solar irradiations data to predict performance.
Experimental determination of the energy transferred to a surface by solar radiation required instruments which will measure the heating effect of direct solar radiation and diffuse solar radiation.

Two basic types of instruments are employed for solar radiation measurement.

1) Pyrheliometer, which collimates the radiation to determine the beam intensity as a function of incident angle.

2) Pyranometer, which measures the total hemispherical solar radiation.

1) Pyrheliometer (measures → beam radiation)
   - → Angstrom pyrheliometer
   - → Abbot silver disc pyrheliometer
   - → Eppley pyrheliometer

2) Pyranometers (measures → Total radiation)
   - → Eppley pyranometer
   - → Yellot solarimeter (Photo-voltaic solar cell)
   - → Moll-Gorczyheski solarimeter
   - → Bimetallic Actionographs of the Rabitzsch
   - → Velochme pyranometer
   - → Thermo-electric pyranometer

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Solar Energy Collectors :— It is a device for collecting solar radiation & transfer the energy to a fluid passing in contact with it. Utilization of solar energy requires solar collectors. These are general of two types.

a) Concentrating (focusing) type solar collector.

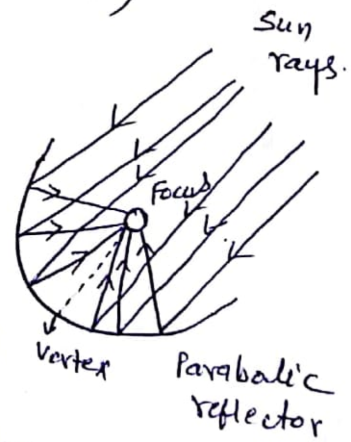
b) Non-concentrating or Flat plate type solar collector.

a) Concentrating Collector — It is device to collect solar energy with high intensity of solar radiation on the energy absorbing surface. Such collectors generally use optical system in the form of reflectors or refractors. A focusing collectors is a special form of flate-plate collector modified by introducing a reflecting (or refracting) surface (concentrator) b/w the solar radiation & the absorber. These type of concentrators can have radiation increase from low value of 1.5–2 to high values of the order of 10^4. As a result of the energy concentration, fluid can be heated to temperatures of 500°C or more.

The main types of concentrating collectors are.

i) Parabalic trough collector
ii) Mirror strip reflector
iii) Fresnel lens collector
iv) Flat plate collector with adustable mirrors.
v) Compound parabolic concentrator (C.P.C.)

i) Parabalic Trough Collector :—

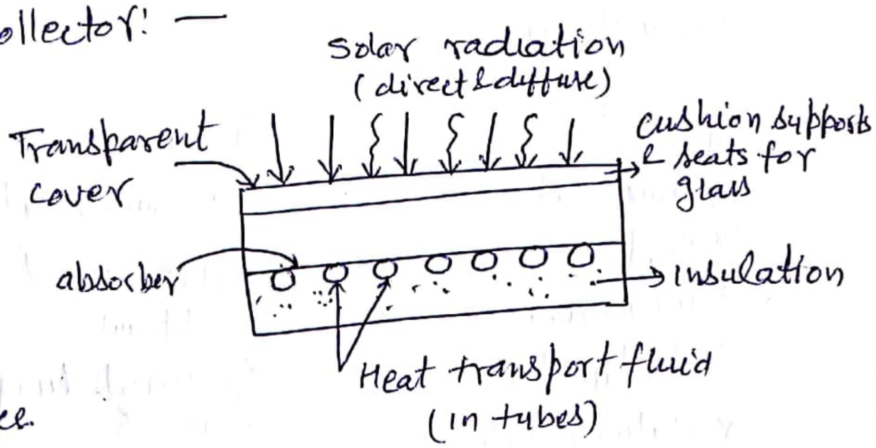


The principle of the parabalic trough, which is often used in concentration collectors, is shown by the cross-section in figure, solar radiation coming from the particular direction is collected over the area of the reflecting surface & its concentrated at the focus of the parabola, if the reflector is in the form of a trough with parabolic C/S, the solar radiation is focused along a line. It have been made of highly polished Aluminium, silvered glass or thin film of aluminium plastic on a firm base.

Flat-Plate Collectors: -

A Typical liquid collector: —

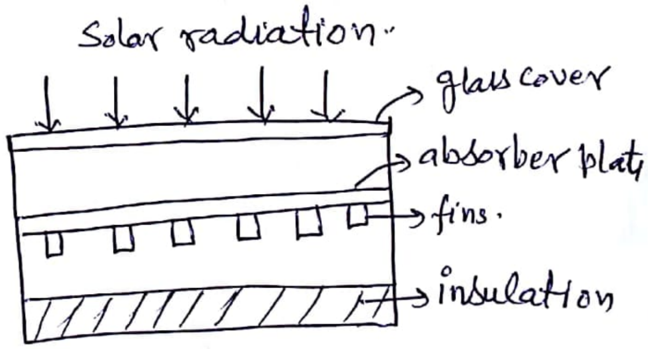
It is the plate and tube type collector. It basically consists of a flat surface with high absorptivity for solar radiation, called the absorbing surface.



Typically a metal plate, usually of copper, steel or Aluminium material with tubing of copper in thermal contact with the plates, are the most commonly used materials. The absorber plate is usually made from a metal sheet 1 to 2 mm in thickness, while tubes, which are also of metal, range in diameter from 1 to 1.5 cm. They are soldered, brazed or clamped to the bottom of the absorber plate with the pitch ranging from 5 to 15 cm.

B - Typical Air Collectors or Solar air heaters: —

Fig shows a schematic flat plate collector where an air stream is heated by the back side of the collector plate. Fins attached to the plate increase the contact surface. The back side of the collector is heavily insulated with mineral wool or some other material. The most favourable orientation of a collector for heating only is facing due south at an inclination angle to the horizontal equal to the latitude plus 15°.



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Sources of energy

- Conventional
  - Commercial
    - ✓ * Coal
    - ✓ * Petroleum
    - ✓ * Electricity
    - ✓ * Natural gas
    - ✓ * water Hydel / Hydropower.
  - non-commercial
    - * Fire wound
    - * Straw
    - * Dried dung
    - * woods.
- Non-Conventional
  - * Bio energy
  - * Solar energy
  - * wind energy
  - * Tidal energy
  - * Energy from urban waste.

Energy → It is power to change things. it is the ability to do work.

* It is defined as the ability / capacity to do work.

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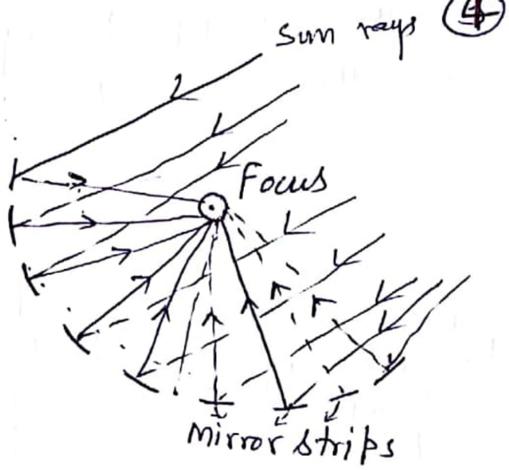
ii) Mirror strip reflector :-

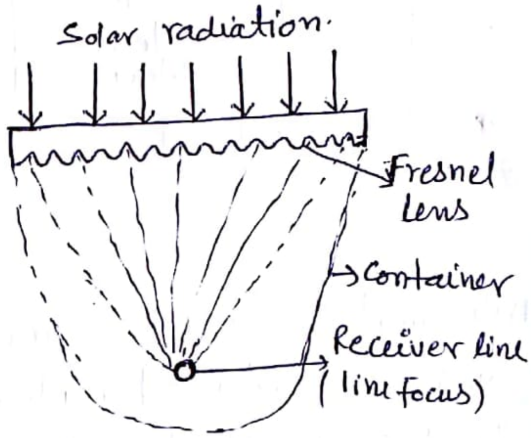
In another type of focusing collector, a number of plane or slightly curved (Concave) mirror strips are mounted on a flat base. The angles of the individual mirrors strips are such that they reflect solar radiation from a specific direction on to the same focal line. The angles of the mirrors must be adjusted to allow for changes in the sun's elevation, while the focal line remains in a fixed position.



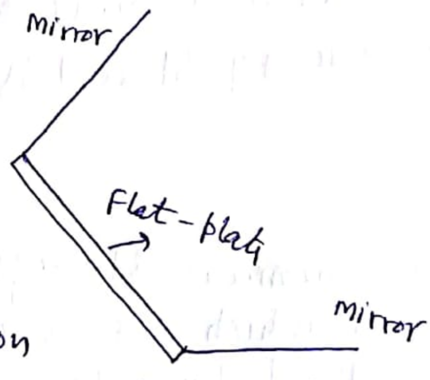
Fresnel lens Collector:—

A refraction type of focusing collectors has been developed. it utilizes the focusing effect of a Fresnel lens. For a trough type collector, the lens is rectangle, about 4.7m length and 0.95 m width. It is made in sections from cost acrylic plastic & can probably be produced in quantity at low cost.

To be fully effective, the fresnel lens must be continuously aligned with the sun in two directions namly, both along & perpendicular to its length. This is achieved by orenting the trough in the south-North direction with rotation about the length wise axis; In addition, the north ends of the troughs are raised to increase the slope as the sun's elevation decreases (and vice-versa)



Non-concentrating Collectors :- The simplest type of concentrating collectors is the mirror boosted, flat-plate collector. It consists of a flat-plate facing south with mirror attached to its north & south edges. If mirrors are set at the proper angle, they reflect solar radiation on to the absorber plate. Thus, the latter receives reflected radiation in addition to that normally falling on it. the mirrors cut off part of the scattered radiation that would otherwise have reached the absorber plate, and only part of scattered radiation falling on the mirrors will be reflected on to absorber. Thus the concentration effect arises mainly from the increase in the direct radiation reaching the absorber plate.



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Solar energy Storage:- Solar energy storage systems may be broadly classified as:

Solar Energy Storage

- Thermal Energy storage
  - Sensible heat
    - Water storage
    - Pebble bed storage
  - Latent heat
- Electrical storage
  - Capacitor storage
  - Inductor storage
  - Battery storage
- Chemical storage
  - Chemical storage
  - Thermo-chemical storage
- Electromagnetic energy storage
- Mechanical Energy storage
  - pumped hydro-elctric storage
  - compressed air
  - Flywheel

1) **Thermal storage:-** Energy can be stored by heating, melting or vaporization of material & the energy becomes available as heat when the process is reversed. Storage by causing a material to raise in temp. is called sensible heat storage. Storage by phase change, the transition from solid to liquid or from liquid to vapour is called latent heat of storage, in which no temp. change is involved.

2) **Electrical storage:-** Theoretically capacitors could store large amount of electrical energy for long periods. The total energy stored is

$$H_{cap} = \frac{1}{2} V \varepsilon E^2$$

V = vol. of dielectric
ε = const.
E = electric field strength

3) **chemical storage:-** It is possible to device a storage battery in which the reactant is generated by a photochemical rxn brought about by solar radiation.

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4) Mechanical Energy storage: —

Pumped by hydroelectric :- electric power in excess of the immediate demand is used to pump water from a supply at a lower level to a reservoir at a higher level.

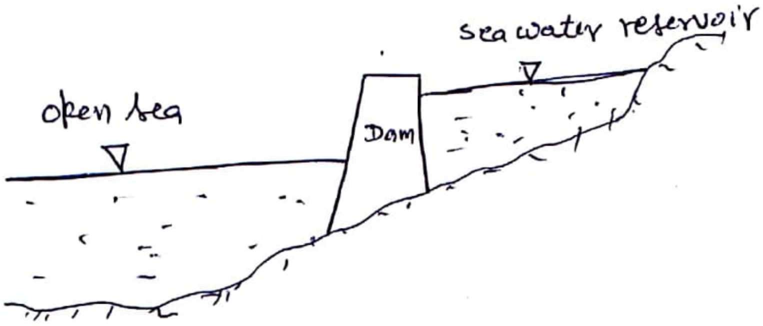

Fig : Storage of solar energy by pumping water behind a dam

5) Electromagnetic energy storage :- electromagnetic energy storage requires the use of super conducting materials, these materials (metals & alloys) suddenly lose essentially all resistance to the flow of electricity when cooled below a certain very low temp. ex :- commercial materials are Niobium (Nb), Titanium (Ti) alloy at temp. below −263°C & compound of Nb & Sn below 255°C.

Solar pond :- working & principal & Neat diagram.

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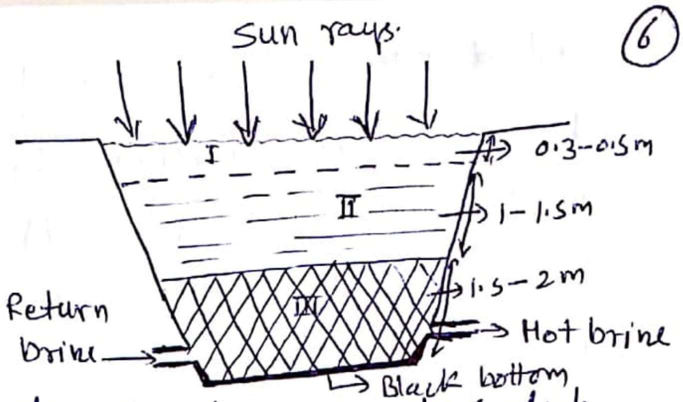
Solar Pond :—

I → Surface convective zone
II → Non-convective zone
III → Storage zone.



A solar pond is a mass of shallow water about 1 or 2 meters deep with a large collection area, which acts as a heat trap. It contains dissolved salts to generate a stable density gradient. Part of the incident solar radiation entering the pond surface is absorbed throughout the depth and remainder which penetrates the pond is absorbed at the black bottom.

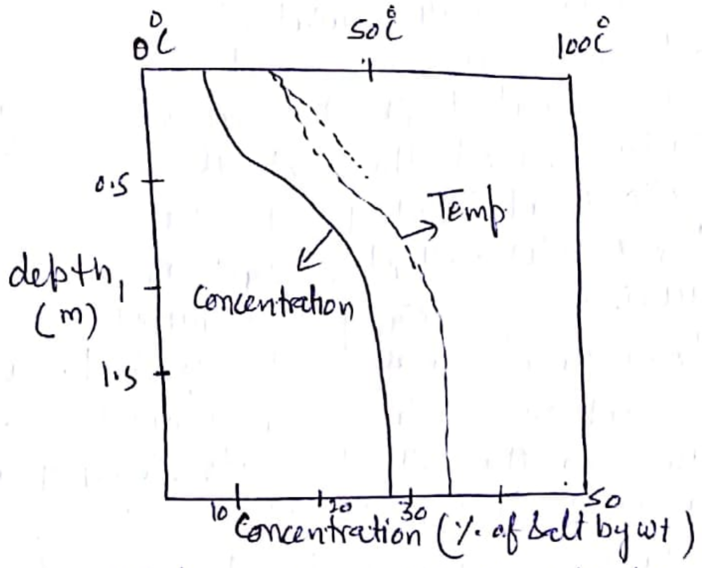
In the salt-gradient solar ponds, dissolved salt is used to create layer of water with different densities – the more salt, the denser water. The concentration of the salt at the surface is low – usually less than 5% by wt & thus the water is relatively light. The salt concentration steadily increases with depth until at the bottom where it is very high, around 20%. Thus the solar pond has three zones with following salinity with depth.

I) Surface convective zone or upper convective zone (0.3 – 0.5 m)
   Salinity < 5%

II) Non-convective zone 1–1.5m, salinity increases with depth.

III) Storage zone or lower convective zone 1.5–2 m & salinity ≃ 20%.

Salt like $MgCl_2$, NaCl or $NaNO_3$ are dissolved in water, the concentration varying from 20 to 30% at the bottom to almost zero at the top.
at bottom layer temp. around 90°C



Temp & Concⁿ profile for typical pond

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Application of solar energy :—

1) Solar water heating
2) Solar Distillation
3) Solar pumping
4) Solar furnace
5) Solar cooking
6) Space heating
7) Space cooling
8) Thermal electric conversion
9) Photo voltaic electric conversion
10) Solar green houses.

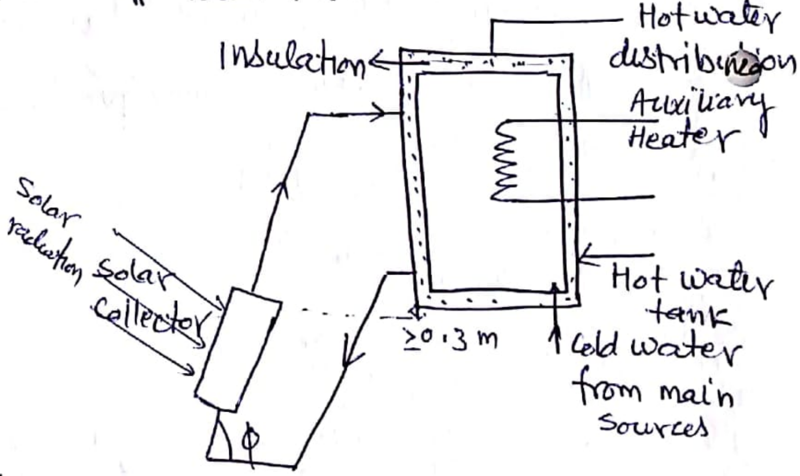
Solar Water Heating :- The basic elements of a solar water heater are :

i) Flat plate Collector ii) Storage tank
iii) Circulation System & Auxiliary heating system
iv) Control of the system

Some typical & commercial designs of solar water heaters are:

a) Natural circulation solar water heater (pressurized)
b) " " " (Non-pressurized)
c) Forced circulation solar water heater

a) Natural circulation solar water heater (~~non~~ pressurized) :—



It consists of tilted collector, with transparent cover glass, a separate highly insulated water storage tank and well insulated pipes connecting the two. The bottom of the tank is at least 1 feet the top of the collector and no auxiliary energy is required to circulate water through it. Circulation occurs through natural Convection or thermosiphoning. As the water is heated in its passage through the collector, its density decreases & hence it rises & flows into the top of the storage tank, colder water from the bottom of the tank has a higher density & so tends to sink & enter the lower heater of the collector for further heating.

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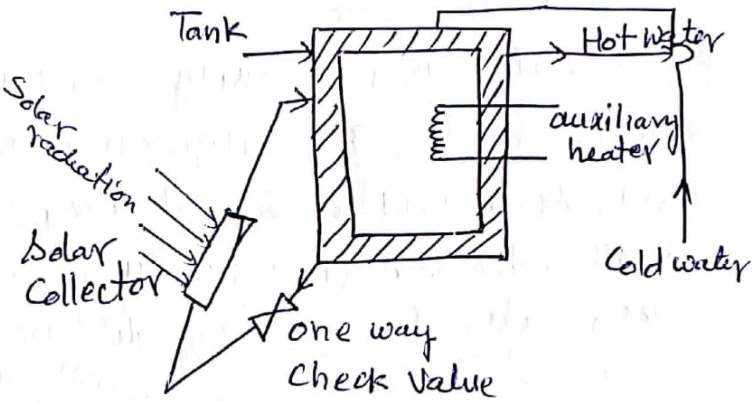
b) Natural circulation solar water heater (Non-pressurized) —

The pressurized system is able to supply hot water at locations of the storage tank. This creates considerable stress on the water channels in the collector which must be designed accordingly. If pressurized hot water is required the difference in height will have will have to be large enough to meet the requirements. If the height of difference can not be accommodated the only solution is to install a separate pump & pressure tank.



c) Forced circulation solar water heater —

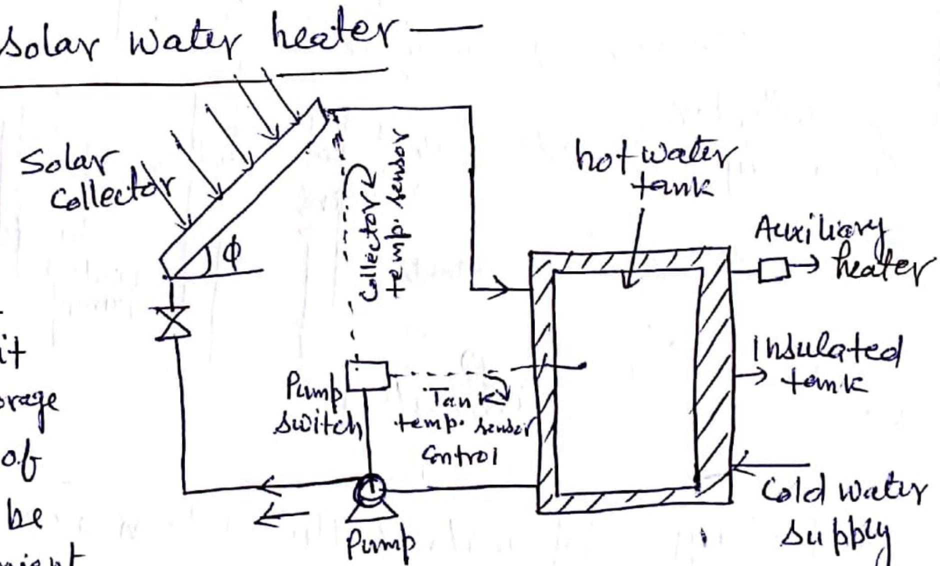


Fig. shows schematically an example of forced circulation system. By including an electric pump in the return circuit b/w the bottom of the storage tank & the lower header of the collector, the tank can be placed at a more convenient level. This is now active system. A control unit permits the pump to operate only when the temp. of the water at the bottom of the tank is below that of the water in the upper header.

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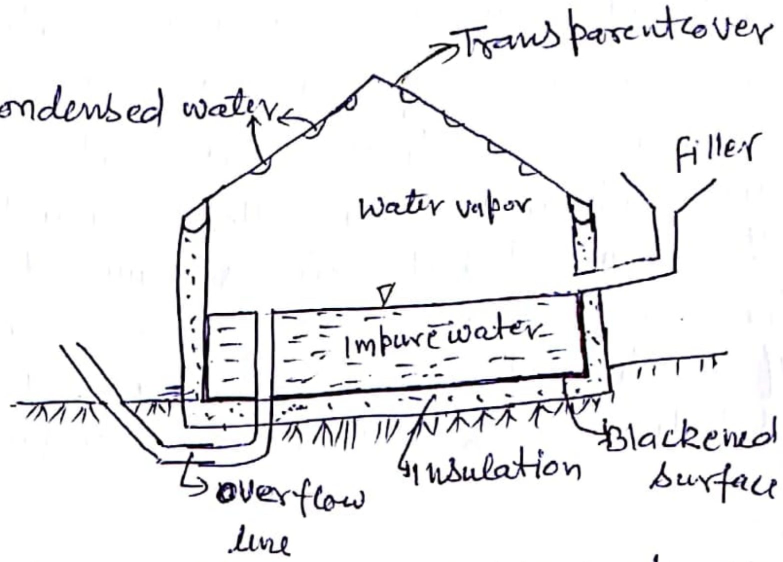
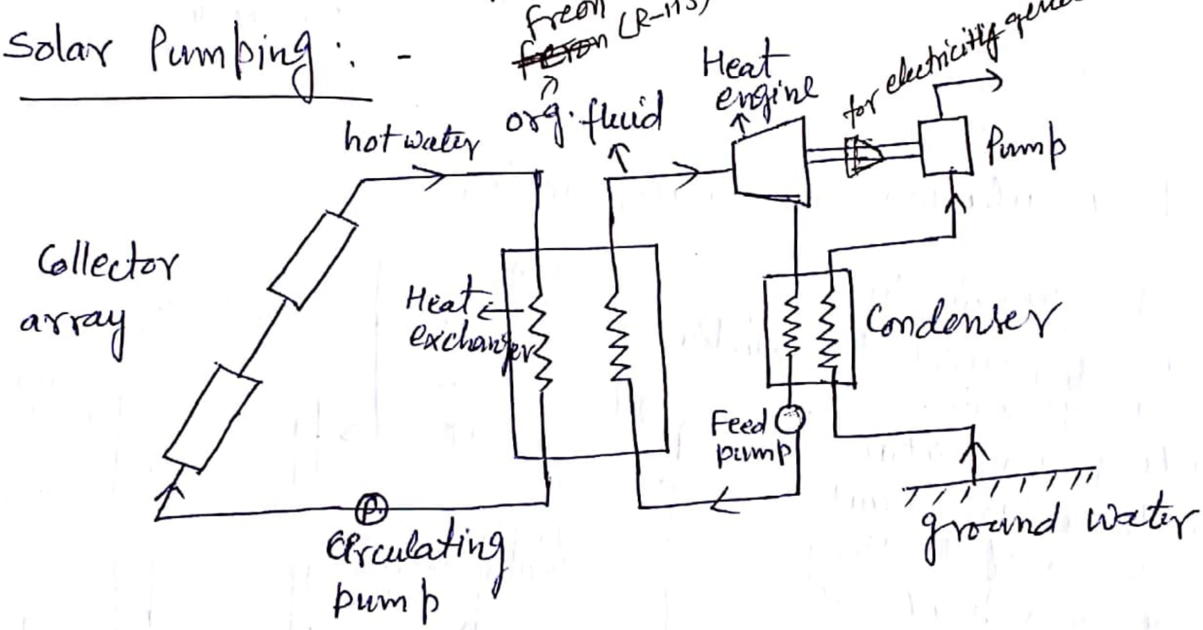
Solar distillation:-



Fresh water is a necessity for the sustenance of life & also the key to man's prosperity. It is generally observed that in some arid, semi arid & coastal area which are thinly populated & scattered, one or two family members always busy in bringing fresh water from a long distance.

Solar Pumping:-



The primary components of the system are an array of flat plate collectors & a Rankine engine with an organic fluid as the working substance. During operation a heat transfer fluid flows through the collector arrays. Depending upon the collector configuration, solar flux & the operating conditions of engine, the fluid will be heated in the collector to a high temp., the solar which is thus converted to the thermal energy. The fluid flow into H.E. due to temp. gradit & come back to the collector. This fluid evaporates & expands in the engine before reaching to condenser, where it condense at low ~~temp~~ pressure. The condenser is cooled by the water to be pumped. The fluid is then reinjected in the boiler to close the cycle. The exp. engine is couple to the pump for electric generation.

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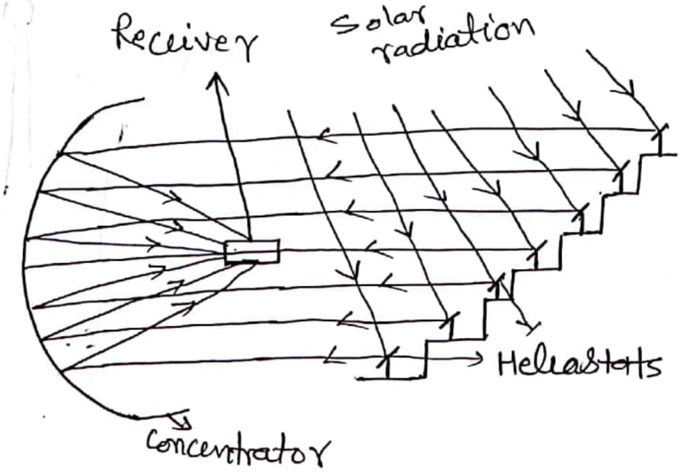
Solar Furnace:—

The heliostats reflect the radiation in a parallel beam toward a paraboloidal mirror 40m high & 54m max. width. The max temp. attained at focal point 3800°C & heat flux 16000 kW/m² (8)

A number of heliostats are rranged in terraces on a slopping surface so that, regardless of the sun's position, they always reflect solar radiation in the same direction onto a large spherical reflecting collector made up of many fixed mirrors attached to the face of structure.

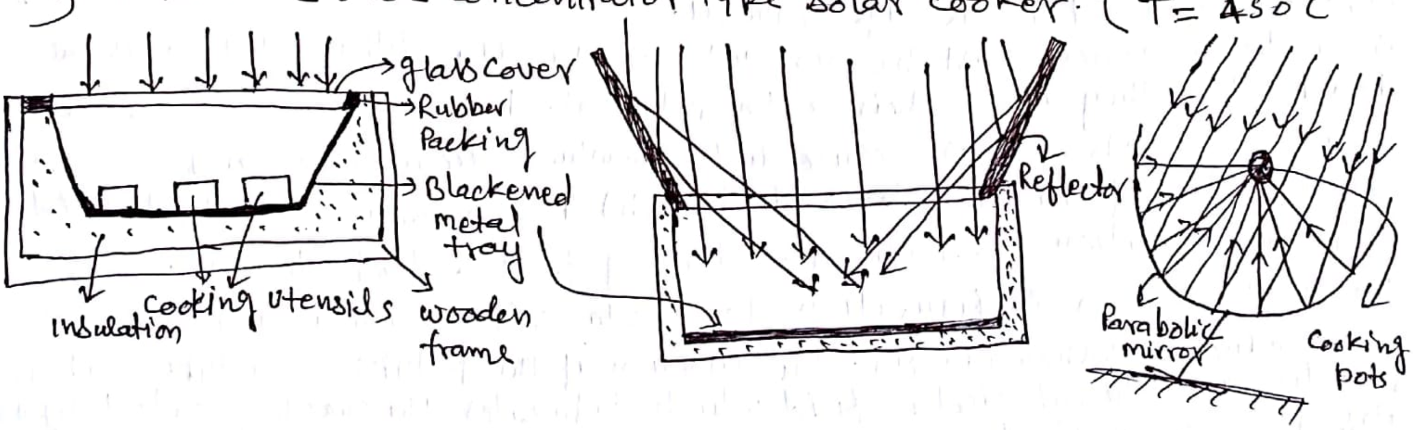


The collector then brings the radiation to a focus within a small volume. The most desirable mirror is that obtained by grinding & polishing a glass plate into an optical flat, aluminizing or silvering by vacuum evaporation & cooling with a suitable film. The change of elevation & that of azimuth can be obtained by the rotation of frame about a horizontal axis & about a vertical axis respectively. In order to rotate the frame, hydraulic or electric driving is used which is coupled with a servo system or time system for sun following.

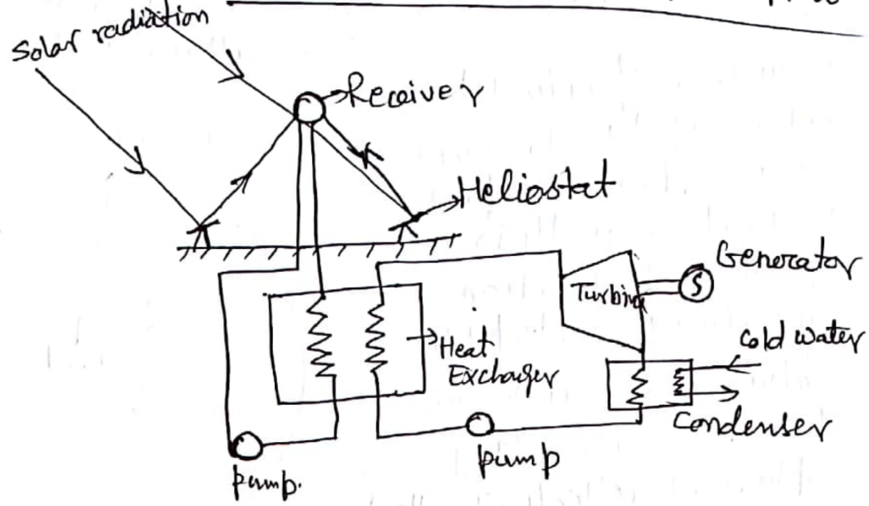
Solar Cooker:—

Basically there are three design of solar cooker

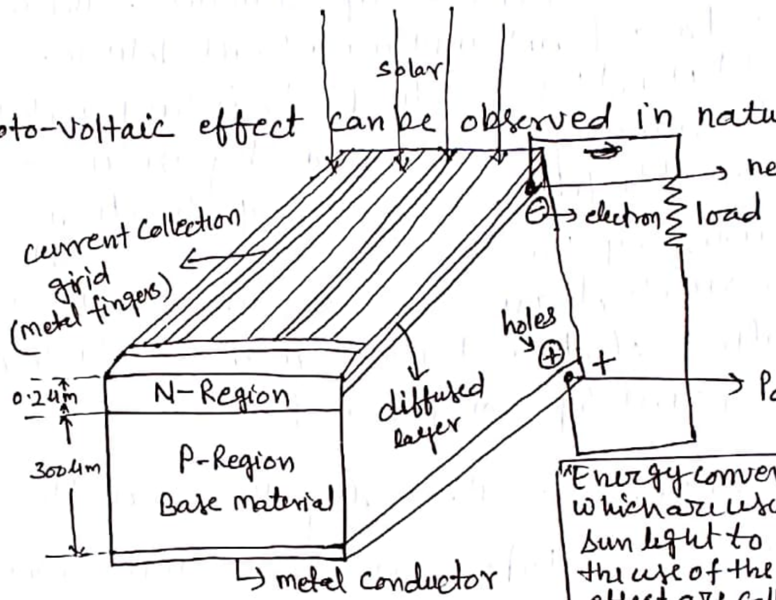
i) Flat plate box type solar cooker with or without reflector (T = 160°C
ii) multi-reflectector type solar cooker/oven (T = 200-250°C
iii) Parabolic disc concentrator type solar cooker. (T = 450°C



Solar Thermal power plants : — Central tower receiver power plant



Solar green house : :



Solar Cell : — The Photo-voltaic effect can be observed in nature in a variety of materials,

"Energy conversion devices which are used to convert sun light to electricity by the use of the Photo-voltaic effect are called Solar cell."

To obtain a useful power o/p from photon interaction in a semi-conductor.

1) The photons have to be absorbed in the active part of the material & result in electrons being excited to a higher energy potential.

2) The electron-hole charge carrier created by the absorption must be physically separated & moved to the edge of the cell.

3) The charge carriers must be removed from the cell & delivered to a usefull load before they loose their extra potential. For completing above processes, solar cell consists of : a) semiconductor in which electron hole pairs are created by absorption of incident solar radiation. b) Region containing a drift field for charge separation & c) charge collecting front & back electrodes.

The most common configuration for a solar cell to make a p-n junction semiconductor is shown in fig. The junction of the 'p-type' & 'n-type' materials provides an inherent electric field which separates the charge created by the absorbtion of sun light. The p-n junction is usually obtained by putting a p-type base material into a diffusion furnace containing a gaseous n-type dopant such as phosphorus & allowing the n-dopant to diffuse into the surface about 0.2 μm. The positive & -ve charges created by absorption of photons are thus encouraged to drift to the front & back of the solar cell. The back is completely covered by metallic contact ... the charges to the electric load.

PANIC

Fuel cell:- A cell or combination of cells capable of generating an electric current by converting the chemical Energy of fuel directly into electrical energy. The fuel cell is similar to other electric cells in the respect that it consists of +ve & -ve electrodes with an electrolyte b/w them.

Fuel in a suitable form is supplied to the -ve electrode & O_2, often from air, to the +ve electrode. When cell operates, the fuel is oxidised & the chemical reaction provides the energy that is converted into electricity.

Fuels :— H_2 & Alternatively impure H_2 obtained from Hydrocarbon fuels, such as Natural gas or substitute of Natural gas, LPG or liquid petroleum products can be used in fuel cells.

Used:- Main uses of fuel cell are in power production, Automobiles vehicles & in special military use

Design & principle of fuel cell:— These are electro-chemical devices in which the chemical energy of fuel is converted directly into electrical energy. This conversion takes place at constant temperature & Pressure. The basic feature of the fuel cell is that the fuel & its oxidant are combined in the form of ions rather than neutral molecules.

The first practical fuel cells are 1) H_2 fuel cell 2) Hydrazine (N_2H_4) fuel cell 3) Hydrocarbon fuel cell & 4) Alcohol (methanol) fuel cell.
fuel cell can be adopted to a variety of fuels by changing the catalysts. Here H_2 fuel cell is describe as example.

The main components of fuel cell are
a) A fuel electrode (anode) (-ve charge)
b) An oxidant or air electrode (Cathode) (+ve charge)
c) electrolyte

* oxidation is a rxn in which electrons are liberated → $X \rightarrow X^{n+} + ne$; $H_2 \rightarrow 2H^+ + 2e$
* Reduction is a rxn in which electrons are consumed → $Y + ne \rightarrow Y^{n-}$; $O_2 + 4e \rightarrow 2O^{2-}$

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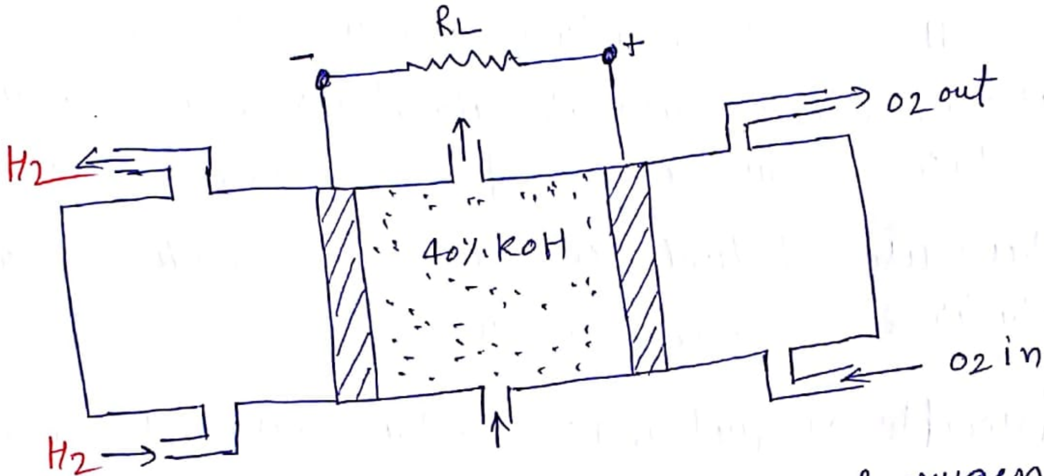
In most fuel cells, H_2 (pure or impure) is the active material at the -ve electrode & O_2 (from the O_2 or air) is active at the +ve electrode. Since H_2 & O_2 are gases, a fuel cell requires a solid electrical conductor to serve as a current collector & to provide a terminal at each electrode. The solid electrodes material is generally porous. Porous Ni & Carbon electrodes are generally used in fuel cells for commercial application. Pt & other precious Metals are being used in certain fuel cell which have potential utility in military & space application.



Hydrogen gas is supplied to one electrode & oxygen gas (or air) to the other. B/w the electrodes is a layer of electrolyte. Most existing fuel cells operate at temperature below about 200 C; the electrolyte is then usually and aqueous solution of an alkali or acid. The liquid electrolyte is generally retained in a porous membrane; but it may be free flowing in some cells. Different electric current is drawn from the cell in the usual manner by connecting a load b/w the electrode terminals.

At the -ve electrode, H_2 gas is converted into Hydrogen ions (H^+) i.e. Hydrogen with a positive electric charge, plus an equivalent number of electrons (i.e. $\bar{e}$), thus

$$H_2 \longrightarrow 2H^+ + 2\bar{e} \quad \text{--- (1)}$$

At this electrode, H_2 diffused through the permeable Ni in which is embedded a catalyst. The catalyst enables the H_2 molecules, H_2 to be absorbed, on the electrode surface as hydrogen atoms, which reacts with the

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(10)

hydroxyl ions (OH^-) in the electrolyte to form water.
When the cell is operating & producing current, the electrons flow through the external load to the +ve electrode; here they interact with oxygen (O_2) & water ~~form~~ from the electrolyte to form -ve charged hydroxyl (OH^-) ions, thus

$$\frac{1}{2}O_2 + H_2O + 2\bar{e} \longrightarrow 2OH^- \quad \text{— (II)}$$

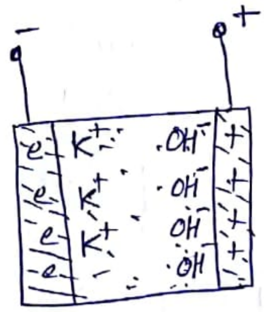
The hydrogen & hydroxyl ions then combine~~d~~ in the electrolyte to produce water

$$H^+ + OH^- \longrightarrow H_2O \quad \text{— (III)}$$

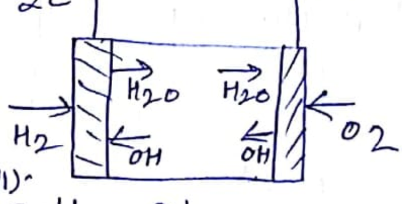
The electrolyte is typically 40% KOH solution because of its high electrical conductivity & it is less corrosive than acids.
Addition of the three forgoing reactions show that when the cell is operating, the overall process is the chemical combination of H_2 & O_2 to form water that is

$$H_2 + \frac{1}{2}O_2 \longrightarrow H_2O \quad \text{(IV)}$$

The O_2 & H_2 are converted to water, which is the waste product of the fuel cell. The reactants are stored outside the cell, and the electrodes & electrolyte are not consumed in the overall processes.



Open circuit electrode :- The H_2 electrode accumulates a surface layer of -ve charge. These attract Pottasium ions (K^+) of the electrolyte, providing an electrical double layer. Similarly, the loss of electrons from the O_2 electrode results in a layer of +ve charges, which turns attracts OH^-, OH^- from the electrolyte.
The magnitude of this emf = 1.23 Vots at 1atm & 25°C



Closed circuit electrode :- The electrons can now leave the electrodes pass through the connecting circuit to the O_2 electrodes & take part in the rxn(II).
This movement of electrons constitutes a current passing through an external load. In this way useful electrical work obtained directly from chemical process

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Hydrogen fuel cell (Hydrox) are two types:

1) low temperature cell: The electrolyte temp. = 90°C & Pressure upto 4 atms.

2) High pressure cell: - Pressure is upto about 45 atms & temp. upto 300°C. A single H_2 fuel cell can be produce an emf. of 1.23 Volts at 1atm & 25°C. By connecting a number of cells, it is possible to create useful potential of 100 to 1000 Volts & power level of 1 kw to 100 MW nearly. The current depends upon the physical size of the cell.

The optimum size of fuel cell at present is about $0.23\ m^3/kw$.

Classification of fuel cell: - It is classified as based on the temperature & physical state of the fuel.

- Low temperature — 25-100°C
- Medium temperature — 100—500°C
- High temperature — 500—1000°C
- Very high temperature — above 1000°C

On the basis of physical state of the fuel.

- Gas → H_2, lower hydrocarbon
- Liquid → alcohols, harazine, higher hydrocarbons.
- Solid → Metals.

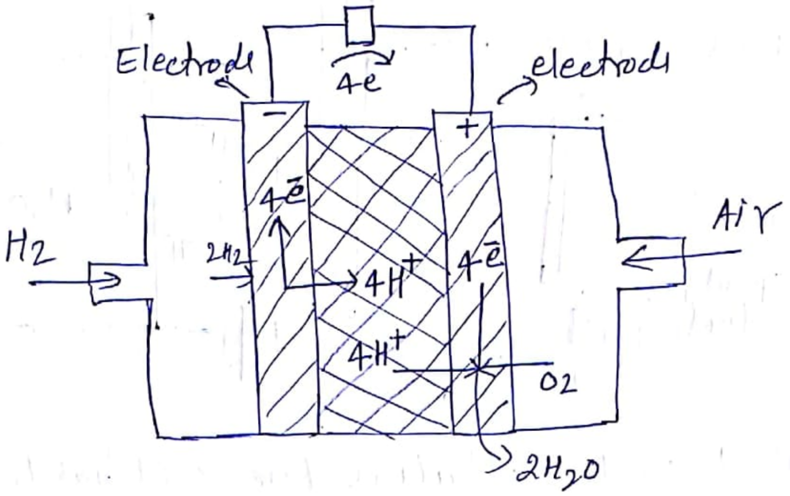
✓ Fuel + oxidants → Products (Total)
✓ Fuel → ions + electrons (Anode)
✓ oxidant + electrons → ions (cathode)

Types of fuel cells: - Following fuels are used in the fuel cells.

a) Hydrogen
b) Fossil fuel
c) Alcohol fuel
d) Hydrazene fuel.

a) Hydrogen, oxygen (H_2, O_2) cell of primary systems is already described using 40% KOH solution as electrolyte. Here now Ion exchange membrane fuel cell will be described which uses membrane electrolyte.

Ion exchange Membrane cell: — The basic design of the cell, which consists of a solid electrolyte Ion exchange membrane, electro-catalysts & gas feed tubes is represented in figures. (11)



The distinctive feature of this cell is that is uses a solid electrolyte in the form of an Ion-exchange membrane. The membrane is non-permeable to the reactant gases, H_2 & O_2, which thus prevents them from coming into contact. The membrane is however, permeable to H_2 ion which are the current carriers in the electrolyte.

The desired properties of in case of Ideal Ion-exchange membrane

I) High Ionic conductivity
II) High resistance to dehydration
III) Zero electronic conductivity
IV) low degree of electro-osmosis
V) Mechanical stability
VI) low permeability of fuel & oxidant

Alkaline Fuel cell: — The Principle of working of alkaline fuel cell is the same as that of a phosphoric acid or H_2-O_2 fuel cell. It uses H_2 or H_2 rich gas as the fuel & O_2 or air as the oxidant. 40% aqueous KOH solution is used as the electrolyte. The hydrogen gas at anode is oxidised, resulting in the liberation of electrons. Electrons are forced through external circuit to cathode. At Cathode, oxygen gas, water & electrons combine to produce OH^- ions. The Rxn is given as follows:

$$\frac{1}{2}O_2 + H_2O + 2e^- \longrightarrow 2OH^- \quad \text{(Cathode)}$$

These OH^- ions move from cathode to anode through the electrolyte, where these combine with H_2 gas to produce water. The rxn is follows.

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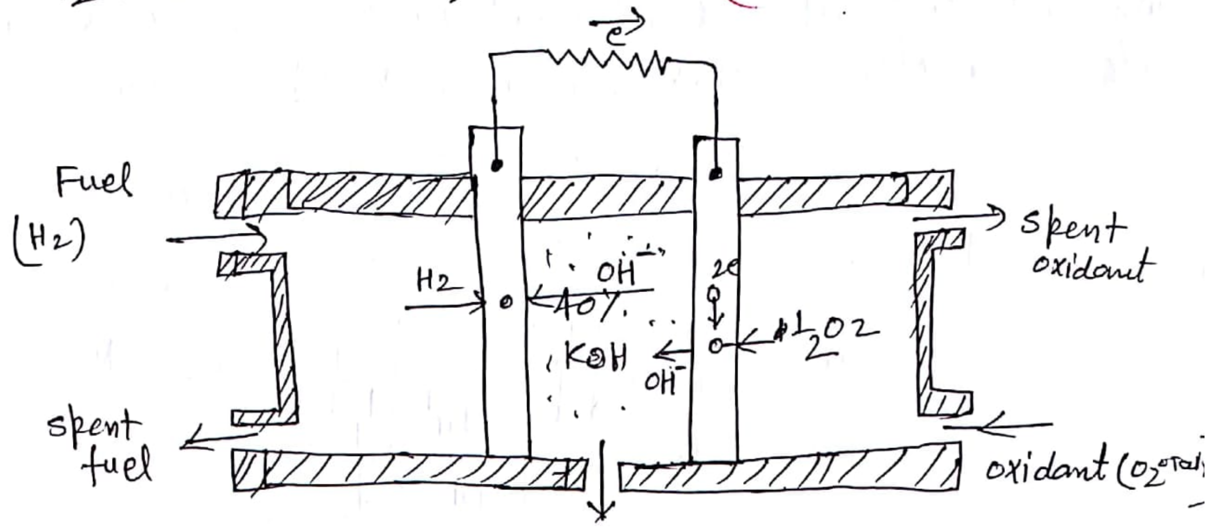
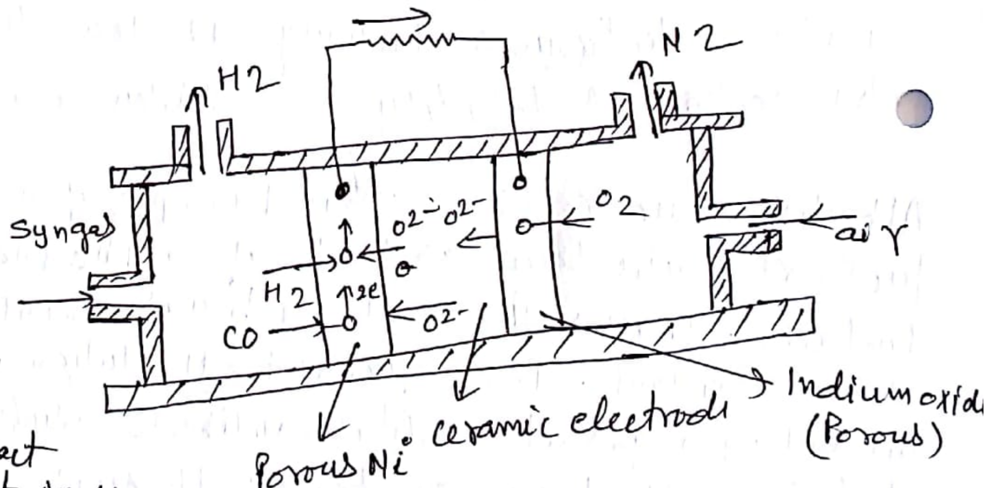
$H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$ (anode)



The fuel used for the alkaline fuel cell has to be free from CO_2 because CO_2 can combine with electrolyte (KOH) to form KCO_3. The KCO_3 increases the resistance to motion of OH^- ions, thereby decreasing the o/p voltage of the cell.

If air is used as the oxidant in place of O_2, the air must be free of CO_2 as the presence of CO_2 lowers the performance of cell.

Solid oxide or ceramics fuel cell:-



The fuel cell has porous 'Ni' as anode electrode & Indium oxide as cathode electrode.

The operating temp. of the cell range from 600-1000°C.

The fuel is a synthesis gas, i.e. mixture of CO & H_2.

At the anode, H_2 & CO react with oxygen ions present in the electrolyte to produce CO_2 & water. H_2 & CO liberate electrons on oxidation. The liberated electrons flow through external circuit to cathode. At the cathode, oxygen is reduced by electrons to oxygen ions. The rxn are as follow

I) $H_2 + O^{2-} \rightarrow H_2O + 2e^-$ (anode) II) $CO + O^{2-} \rightarrow CO_2 + 2e$ (anode)

III) $\frac{1}{2}O_2 + 2e \rightarrow O^{2-}$

The heat of discharge can be utilized as process heat or power generation. The output voltage at full load is about 0.63V.

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Efficiency of fuel cell: — Electrochemical rxn take place in fuel cell in which reactant (fuel & oxidant) are converted into work (electric output) by a steady flow process. The energy equation in steady flow condition by first law of thermodynamics is as follow

$$\Delta Q = \Delta W + \Delta KE + \Delta PE + \Delta H \quad \text{— (I)}$$

ΔQ ↓ Heat Transfer; ΔW ↓ work done; ΔKE ↓ change in K. Energy; ΔPE change in P. energy; ΔH change in enthalpy.

If $\Delta KE = \Delta PE = 0$, then steady flow equation is as follow

$$\Delta Q = \Delta H + \Delta W$$

for max work output, the process has to be reversible. For reversible process $\Delta Q = T\Delta S$ hence $\Delta W = \Delta W_{max}$, when $\Delta Q = \Delta S\, T$

$$\Delta W = -(\Delta H - T\Delta S) \quad \text{(II)}$$

But gibbs free energy is given as following eqn $G = H - TS$ — (III)

on differentiation, we get $\Delta G = \Delta H - (T\cdot\Delta S - S\cdot\Delta T)$ — (IV)

As temp. remains constt in the fuel cell, $\Delta T = 0$ then eqn (IV) will be $\Delta G = \Delta H - T\cdot\Delta S$ — (V)

from equation (II) & (V), we have $\Delta W_{max} = -\Delta G$ — (VI)

The efficiency of fuel cell in steady flow condition is given by

$$\frac{-\Delta G}{-\Delta H} = \eta = \text{Work output / change in enthalpy} = \frac{\Delta W_{max}}{-\Delta H}$$

The Gibbs free energy is related to electromotive force (E) that drives the electron through circuit, which is given by following eqn.

$$E = \frac{-\Delta G}{n\cdot F}$$

n = no. of electron transferred per molecule of the reactant.

F → Faraday constt = 96500 coulomb/gm mole

then,

$$\eta = \frac{nFE}{\Delta H}$$

Q Find electromotive force generated in a $H_2 - O_2$ fuel cell. Assume change in Gibbs free energy for the chemical rxn at 25 °C as 237.3×10^3 J/gm.mole of H_2.

Soln:- Rxn in fuel cell is as follows.

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

Hence $n = 2$ & $\Delta G = 237.3 \times 10^3$ J/gm.mol

Now electromotive force of fuel cell is

$$E = \frac{\Delta G}{n\cdot F} = \frac{237.3 \times 10^3}{2 \times 96500} = 1.23\,V \quad \text{Ans}$$

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Q. For a hydrogen – O_2 fuel cell, find the following:

a) Cell efficiency

b) Electrical work output per mole of hydrogen consumed & per mole of water produced.

c) Heat transfer to the followings. The cell operates at 25°C. Assume $\Delta H_{25°C} = -286 * 10^3$ KJ/gm mole.

$\Delta G_{25°C} = -237.3 * 10^3$ KJ/gm mole.

Sol^n

The reaction is as follows.

$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$$

Hence n = 2, & efficiency is given by

$$\eta = \frac{\Delta G}{\Delta H} = \frac{237.3 * 10^3}{286 * 10^3} = 83\%$$

Electrical work output per mole is given by $\Delta W = nFE$

But $E = \frac{\Delta G}{nF}$ or, $\Delta W = \Delta G$.

$$\Delta W = 237.4 * 10^3 \text{ KJ/Kg mole of } H_2.$$

As 1 mole of H_2O is generated for each mole of H_2.

ΔW per mole of water = ΔW per mole of H_2

$= 237.4 * 10^3$ KJ/Kg mol of H_2O

Heat Transfer to surrounding is given by

$$\Delta Q = \Delta H - \Delta W = \Delta H - \Delta G.$$

$$= -286 * 10^3 + 273.3 * 10^3$$

$$= -48.7 * 10^3 \text{ KJ/Kg mole}$$

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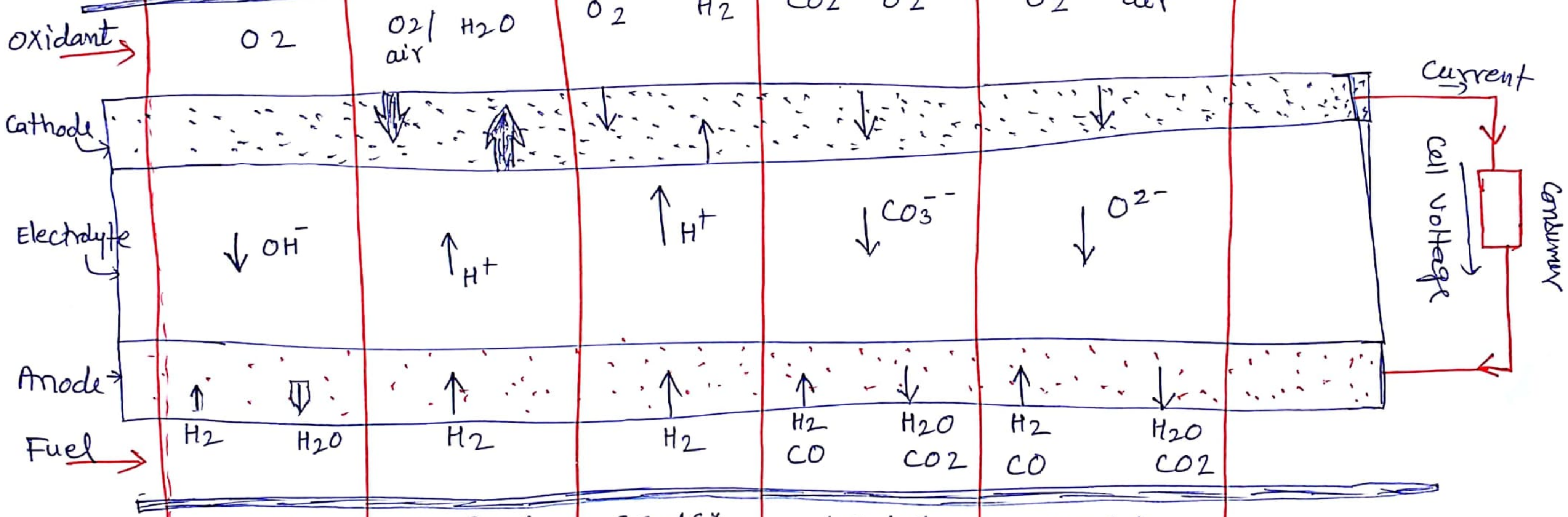
Fuel cell Types:—

	AFC 80°C → Alkaline fuel cell	PEM 80°C → Polymer electrolyte membrane fuel cell	PAFC → Phosphoric acid fuel cell	MCFC → Molten Carbonate Fuel cell	SOFC → Solid oxide fuel cell.
Oxidant	O_2	O_2/air, H_2O	O_2, H_2	CO_2, O_2	O_2, air
Electrolyte	OH^-	H^+	H^+	CO_3^{--}	O^{2-}
Fuel	H_2, H_2O	H_2	H_2	H_2, CO, H_2O, CO_2	H_2, CO, H_2O, CO_2
η (%)	50-65%.	50-80%.	35-45%.	45-60%.	50-60%.
Application:	Transport, space ships	Transport, space, house, ship Mobile.	100 MW Plants, 50-500 kW block heating plants.	100 MW Plants, 50-500 kW block heating plant	Same.
Status:	50-100 kW, can be bought, expensive	20 kW, high efficiency	—	100 kW Prototype	20 kW prototype.



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Hydrogen energy

Hydrogen as an energy carrier can play an important role as an alternative to conventional fuels, provided its technical problems of production, storage & transportation can be resolved satisfactorily & the cost could be brought down to acceptable limits. one of the most attractive features of H_2 as an energy carrier is that it can be produced from water which is abundantly available in nature. its burning process is non-polluting & it can be used in the fuel cells to produce both electricity & usefull heat: Use of H_2 as energy source involves five basic issues.

a) Production.
b) storage & Transportation
c) Utilization
d) Safety & Managment
e) Economy.

The H_2 can be used as a fuel directly or it might be used as a raw material to produce Methanol, Ammonia, or hydrocarbons by using either CO_2 or N_2 from the atmosphere.

The combination of H_2 with O_2 (e.g. from air) results in the liberation of energy with water as the sole material product;

$$H_2 + \frac{1}{2} O_2 \longrightarrow H_2O + Energy.$$

The current & projected needs of H_2 are growing rapidly, application include nitrogeneous fertilizers, Coal liquifaction basic chemicals etc. larger term used are electric power producing fuel cells, fuel for gas turbine or for a spark-ignition engine.
Its heating value of 28000 Kcal/kg is almost three times that of hydrocarbons fuels.

Properties of H_2: —— Hydrogen at ordinary T & P is a light gas with a density only $\frac{1}{14}$th that of air & 1/9th of natural gas under the same conditions. By cooling to the extremely Low temp. $-253^\circ C$ at atm. pressure, the is Condensed to a liquid with specific gravity of 0.07, roughly 1/10th of that of gasoline.

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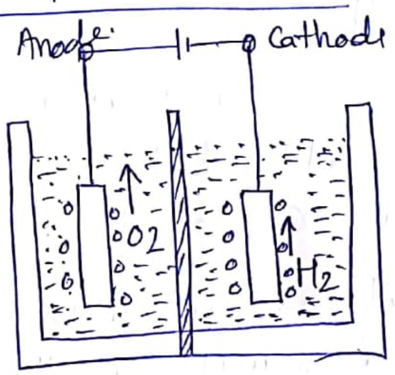
The standard heating value of H_2 gas is 12.1 MJ/m3 compaired with an average of 38.3 MJ/m3 for natural gas. The heating value liquid H_2 is 120 MJ/kg or 8400 MJ/m^3; the corresponding value of gasoline is 44 MJ/kg or 32,000 MJ/m^3. Hence for producing a specific amount of energy, liquid hydrogen is superior to gasoline on a weight basis but inferior on a volume basis.

Hydrogen production: — The methods of producing H_2 may be classified according to the source of addition of energy to decompose, thus electrical energy (in electrolysis), heat energy (in thermochemical) fossil fuels & solar energy.

a) Electrolysis or the electrolytic production of H_2: —



Electrolysis of H_2O

It is the simplest method of H_2 production. The method uses an electrolytic which consists of two electrodes immersed in an aqueous conducting solution called electrolyte as shown in fig. When a direct current is passed through the cell, it decomposes water in to H_2 & O_2. O_2 is formed at anode while H_2 is formed at cathode. Metal or carbon plates are used as electrodes. The aqueous KOH soln is used as the electrolyte. A decomposition voltage of 2V is applied. the chemical rxn decomposition of water are as follows.

$$4H_2O + 4e^- \rightarrow 2H_2\uparrow + 4OH \quad \text{(Cathode)}$$

$$4OH^- \rightarrow O_2\uparrow + 2H_2O + 4e^- \quad \text{(anode)}$$

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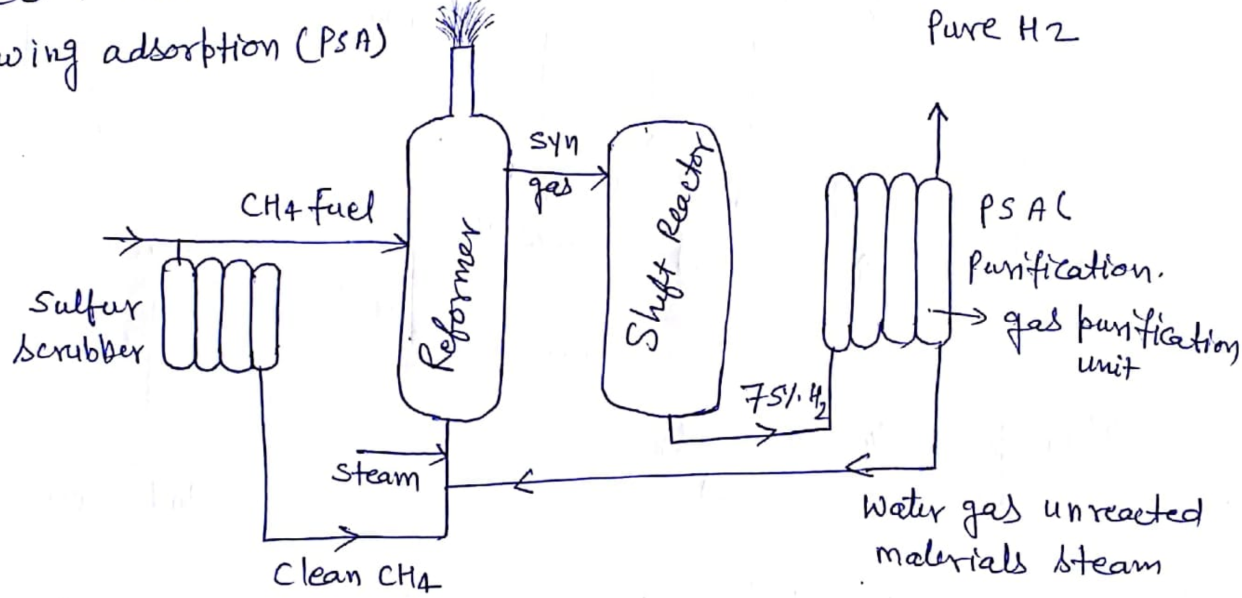
Thermochemical Method: — This method consists of steam reforming of Natural gas to produce H_2. It is the most efficient, cost effective & commercialized technology available. The natural gas consisting the CH_4 & CO is reformed with the help of steam at 900°C to produce a mixture of H_2 & CO_2. CO_2 is removed at the latter stage by scrubbing process to get H_2. The cost of production of H_2 by this is very much same to what it costs to produce electricity using natural gas. The rxn of reforming natural gas with steam are as follows.

1) $CH_4 + H_2O \xrightarrow[Ni]{600-700°C} CO + 3H_2$ endothermic rxn

2) $CO + H_2O \xrightarrow[Cu-Zn\ Low\ T]{Fe-Cr\ high\ T} CO_2 + H_2$ exothermic rxn.

Pressure swing adsorption (PSA)



3) Gas purification → CO_2 absorption in amine unit

4) Methanation → To remove residual CO & CO_2

$CO + 3H_2 \rightarrow CH_4 + H_2O$

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

] exothermic rxn, Ni/Al_2O_3 at 370-427°C

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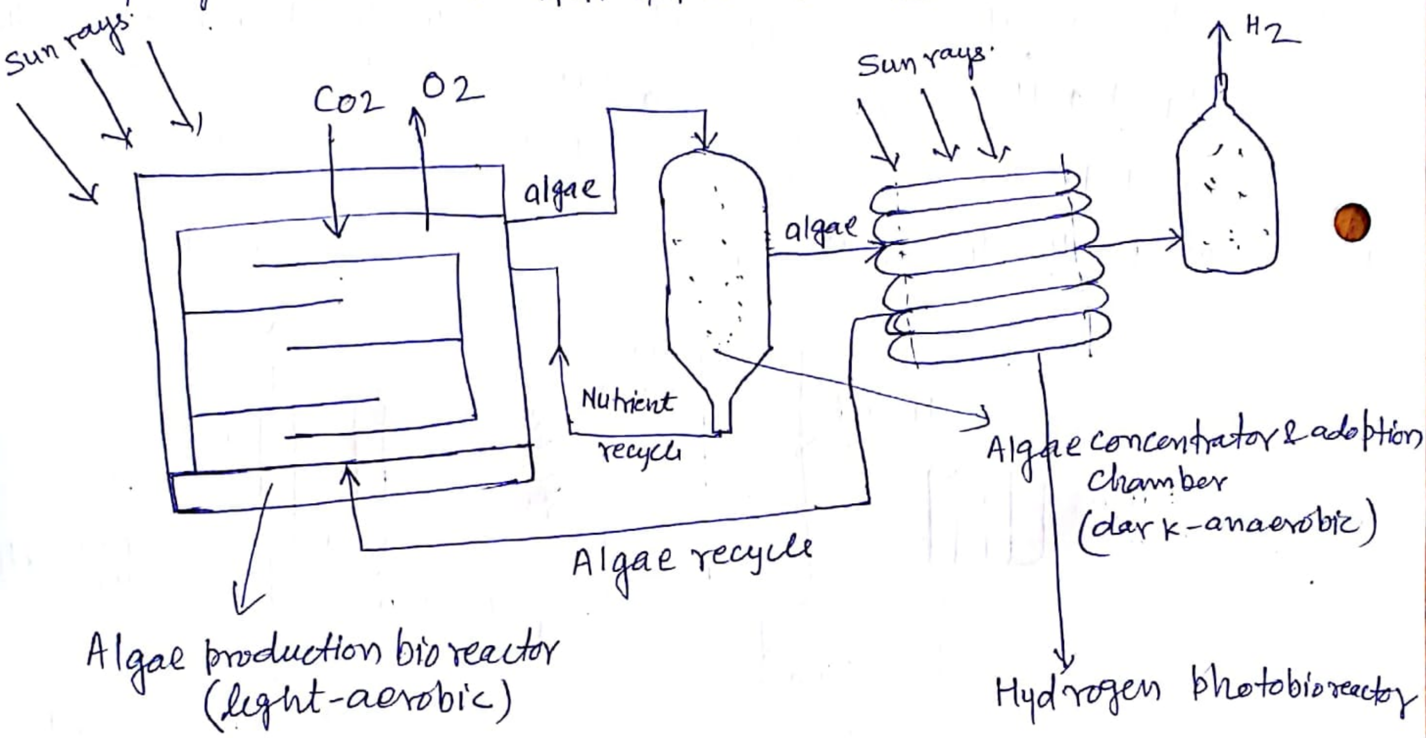
Biological Method of H_2 Production: — Photo-biological production of H_2 is based on two steps: Photosynthesis & H_2 Production catalysed by hydrogenases. for example, green algae & cynobacteria.

Photo-synthesis → $2H_2O \rightarrow 4H^+ + O_2 + 4e^-$

Hydrogen Production → $4H^+ + 4e^- \rightarrow 2H_2$



Aerobic → It is take place in the mitochontria & requires oxygen and glucase & Produces CO_2, H_2O & energy.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Anaerobic → It is also produces energy & use glucase, but it produce less energy & does not require oxygen.

$$C_6H_{12}O_6 \rightarrow 2C_3H_6O_3 \text{ (lactic acid)}$$

The lactic acid then needs to be oxidised later to CO_2 & H_2O after word to prevent it buildup.

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