MODULE -2

Structure

2.1 MODULE OBJECTIVE:

1. To discuss types of solar collector, their configuration and application.
2. To know about practical solar collectors.
3. Explain the component of solar cell system.
4. Equivalent circuit of a solar cell and it characteristics.
5. Application of solar collectors

SOLAR THERMAL ENERGY COLLECTOR

2.2 INTRODUCTION

Sun's heat is a diffused energy it is always collected and then concentrated. Its temperature level is up to 70-80° C. solar energy collectors are used to harness solar energy and is used in wide

range of application such as water heating system, solar space heating system, solar refrigeration, industrial purpose heat system, solar desalination system, thermal power generation system.

2.3 TYPES OF SOLAR COLLECTOR

Collectors are mainly classified into 2 types flat plate and concentrating type.

2.3.1 FLAT PLATE COLLECTORS

It as a same area of intercepting and for absorbing and also called as non concentrating collector

The main parts of collector are:

- **Dark flat plate absorber of solar energy:** it is a good absorber material of aluminum, steel or copper as they are good conductor of heat. The size of flate plate collector required for 1 gallon of hot water is 0.5 to 1 square foot.
- **Transparent cover:** Allow solar energy to pass through it but reduce heat losses.
- **Heat transport fluid:** to remove heat from the absorber and insulated water tank fluid is transported through it.
- **Heat insulation backing:** often placed at the back of fluid tube.
- **Insulating coating:** it is made up of glass or poly carbonate material

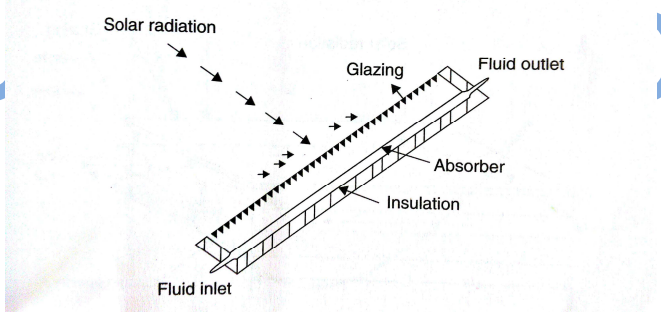

Fig 2.1 Flat plate Collector

Flat Plate Air Collector

- When solar energy is passed through the transparent surface a portion of energy is absorbed by the absorber and transferred to the transport medium in the fluid tube and carried away for use or storage. The transparent cover will reduce the conventional losses.
- The flat plate air collector has a air has a heat transport medium. It is usually used for the purpose of space heating.
- Absorber can be of any material. Air is passed through the absorber by fan or convection method.
- Its efficiency is less then liquid fluid.

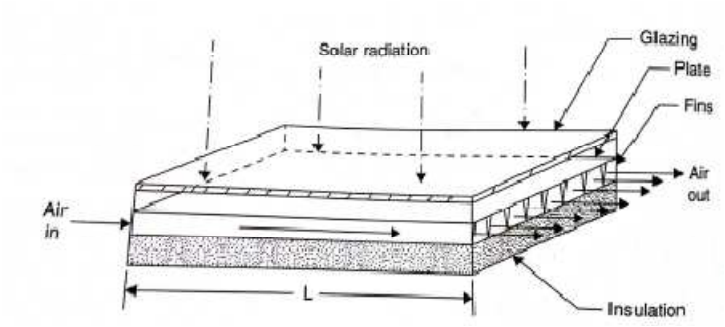

Fig: 2.2 Flat Plate Air Collector

Flat Plate Liquid Collector:

- Liquid is used as a heat transport medium.
- Application: solar pool heating, household water
- Has higher efficiency.

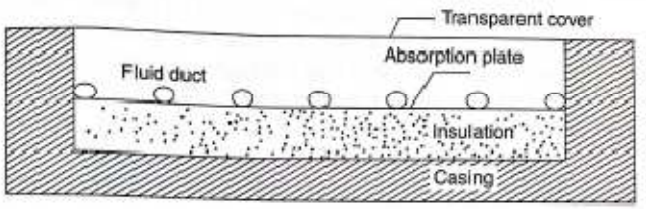

Fig: 2.3 Flat Plate liquid Collector.

2.3.2 CONCENTRATING COLLECTOR

- By use of reflector light is concentrated. Size of the absorber reduces, decrease in heat loss and increase in efficiency.
- Used for the purpose of high temperature application like thermal detoxification, generation etc
- Collector can be of liquid based, air based or oven type.
- Are of two types stationary concentrating collectors and tracking concentrating collectors
- Stationary concentrating collectors application are like AC, solar cookers they have wide angle
- Tracking concentrating collectors application are like electric generation.

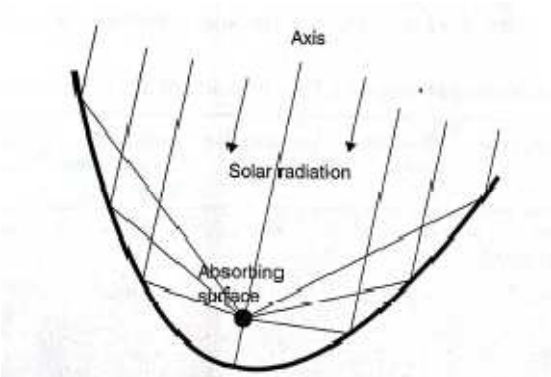

Fig 2.4 Parabolic reflector

2.4 CONFIGURATION OF CERTAIN PRACTICAL SOLAR THERMAL COLLECTOR

1. **Flat Plate Collector:** used for solar water and space heating system. These collector heat liquid or air less than 90°C.it is a insulated metal box with glass or plastic cover with dark colored absorber.
   Liquid Flat plate Collector: the fluid can be oil, water antifreeze, thermal oil etc. it is used for the purpose of water heating and swimming pool heating.
   Air flat Plate Collector: used of solar space heating, ventilation, air heating, crop drying purpose. Absorber can be metal or non metallic material.
2. **Glazed Flat Plate Collectors:** liquid based and air based collector. Moderate temperature application of 30°C to 70°C. used for commercial and domestic heating system.
3. **Unglazed Flat Plate Collectors:** Because they are not insulated it is best suited for low temperature < 30°C. it application are heating of water, fish farming , swimming pool etc. Since they are not glazed large portion of sun energy is absorbed since not insulated energy is lost**.**
4. **Unglazed Perforated plate Collectors**: In this type of collector are perforated with many holes of 2-4 cm. the air flow through the collector to provide preheated fresh air for ventilation. Application are like ventilation crop drying.
5. **Back pass Solar Collectors:** Air based collector use solar energy to heat air for space heating.
6. **Batch Flat Plate Solar thermal Collectors:** reflector plate coated with glazing is placed over a tank surface. Storage surface and the absorber act as a single unit so there is no need of other components.
7. **Fate Plate Collector With Flat reflector:** Addition of reflector on collector will increase thermal efficiency of 44% in winter and 15% in summer. When reflector are placed at the edges aperture angle is larger.

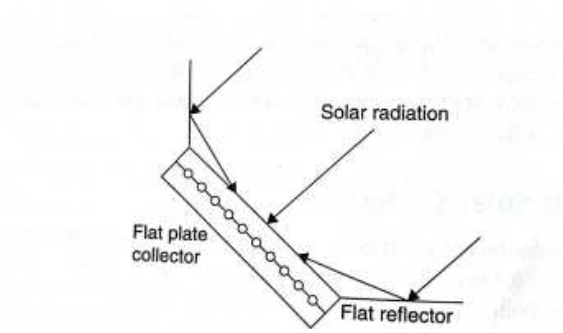

Fig. 2.5 Flat Plate Collector With Reflector

8. **Evacuated Tube Collectors:** These types of collector are used when climate is cold, cloudy and windy days. During such condition performance of other collector are reduced. Evacuated solar collector consists of heat pipe inside a vacuum sealed tube. There are 2 transparent glasses placed parallel. Each tube consists of glass outer tube and absorber tube attached to fin. The fin is covered with coating that absorbs solar energy. air is removed by two glasses placed in parallel to remove air and create vacuum, which reduces losses This can achieve high temperature around 75°C to 180°C. These types of tube are more expensive. Applications are as heating of domestic and commercial hot water, building, swimming pools.

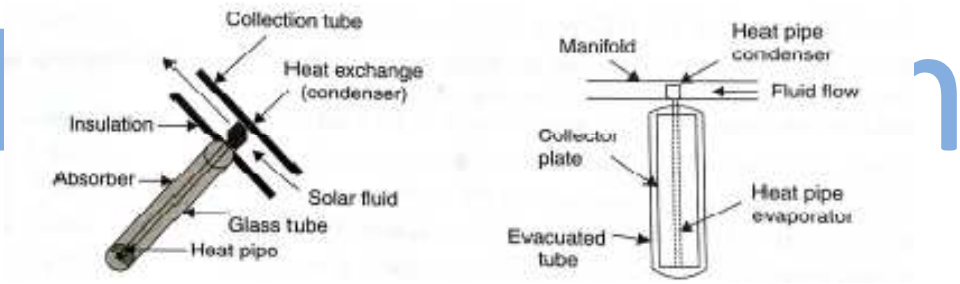

Fig. 2.6 Evacuated Tube Collector

2.5 MATERIAL ASPECTS OF SOLAR COLLECTORS

1. **Absorber**

- flat, grooved, fins, tubes are attached to the absorber
- Cu, Al, Cu with integrated water passage , cu tube, Iron, steel, plastic

Absorptive Coating

- coating is done to increase absorptive
- It must not degrade up to 200 □c, withstand low and high humidity,.
- It should not fade or chip.
- Should not be thick coating

2. **Glazing**

- Glass sheet or radiation transmitting material is used as coating
- It reduces radiative heat losses from the absorber and protects absorber from the UV radiation.

- Material used should have good resistance to UV radiation, thin and tempered glass should not be used, plastic material of low tensile strength should not be used, should be resistant to temperature shock, should have good thermal stress(rain)

Practical application of Glazing

- High Cost
- Longevity
- Black chrome coating
- Absorptive 92%-95% (Visible) 10-20% (IR)

Glazing Materials

- Glass, Fiber, tedlar with fiber glass , fiber glass, optical rating must not change in service period

3. Insulation Shell

- Solar flat plate collector must be insulate on its back side and edges to reduce
- Withstand high temperature (200 □C), should not shrink, it should not melt or evaporate.

2.6 CONCENTRATING COLLECTORS

- It focuses the sun beam radiation into smaller receiving area there by radiation flux increases
- The major drawback is the mirror should have clan and smooth reflecting surface (clean- no foreign particles, smooth surface – should not miss radiation)
- Energy concentrated on a point produce high temperature, on line – moderate temperature, non focusing low temperature.
- Concentrating collectors are classified in many ways
    1. Based on means of connection – mirror or Fresnel lenses
    2. Based on reflecting surface used – parabolic, spherical or flat
    3. Continuous or segmented
    4. Based on formation of image- focusing or non focusing
    5. Focusing- line or point
    6. Based on temperature
    7. Based on types of tracking

2.6.1. Compound Parabolic Solar Collector – these are non focusing type of collector

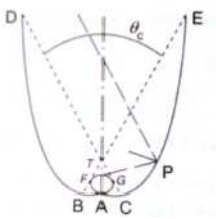

Fig. 2.7 Compound parabolic Solar Collector

2.6.2. Fresnel Solar Thermal Collectors

- High temperature with good efficiency
- Temperature between 50°C -400°C can be obtained.
- Reflectors are bent in the parabolic shape and receiver is placed over a axis, which collect maximum reflected rays by using single tracking system.
- Linear Fresnel reflector (LFR) technology- in this type receiver is mounted over a linear tower and reflectors are placed at the surface of the tower on either side.
- Proper spacing is given between reflectors such that the shadow of a reflector is not seen on the other.
- Has high efficiency compared to parabolic type.

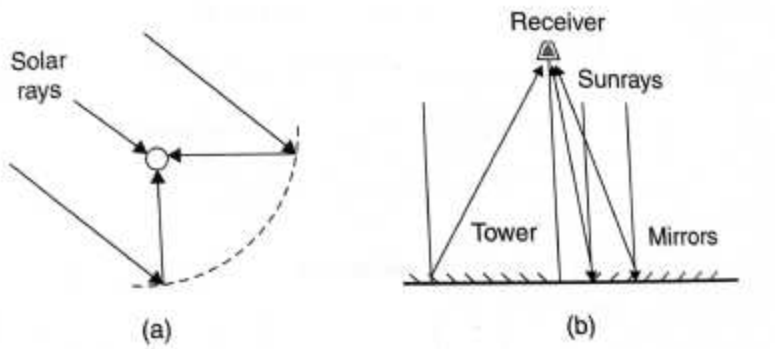

Fig. 2.8 Fresnel trough collector(a) parabolic (b) linear

2.6.3. Parabolic Trough Solar Thermal Collectors

- Parabolic trough is shaped like letter U
- Temperature between 50-400 degree C
- Sheet is bent to parabolic shape
- A metal black tube covered with glass to reduce heat loss and placed long the focal line of the receiver.
- Can be a single or dual axis tracking, some case it may be stationary also.
- Application – combined with gas turbine, to produce steam for generating electricity.

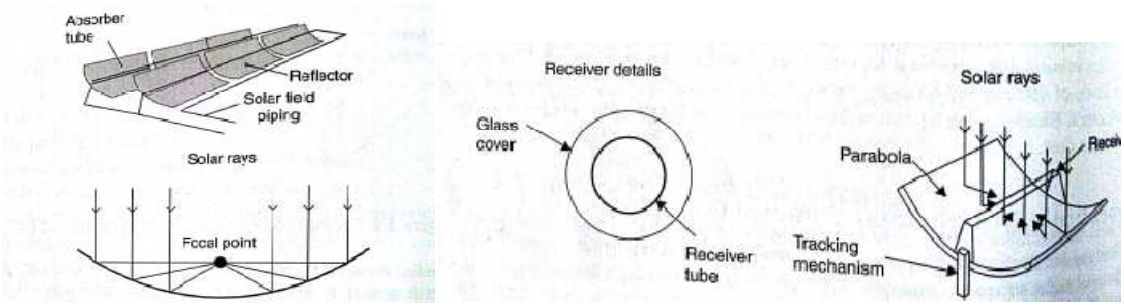

Fig. 2.9 Parabolic Trough Reflector

2.6.4. Cylindrical Trough Solar Collector

- Do not de focus because of deep curve
- It is focusing on a plane not on a line
- Low rim angel it to be designed to get approximate focal line.
- Advantage is that it need not track the sun in any direction as long as there is no interruption

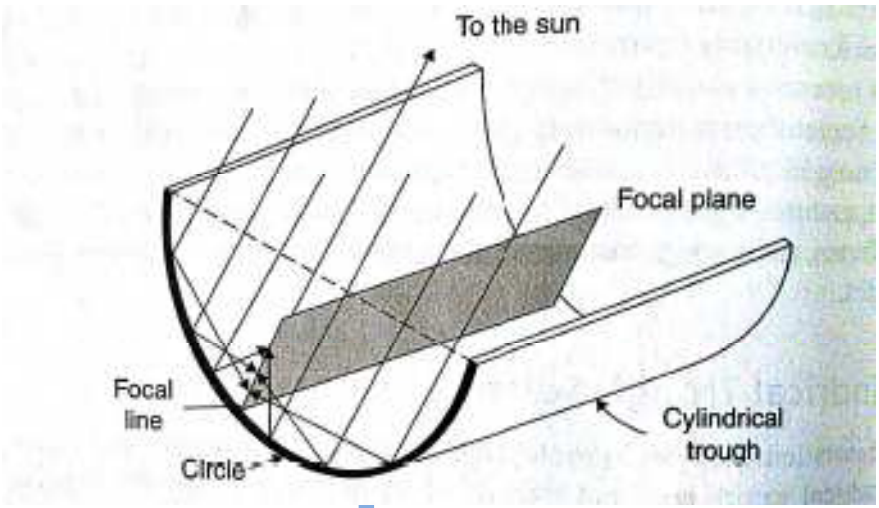

Fig. 2.10 Cylindrical trough Solar Collectors

2.6.5. Parabolic Dish System (Distributed Receiver System)

- The reflector is similar to dish of a satellite
- It as a reflector of mirror type with a focal point
- It uses dual axis sun tracker
- This type of system can achieve temperature upto 1500° C
- Advantages: very high efficiency, high thermal absorption and conversion system, concentration ration of range 500-2000.
- Application : production of electricity

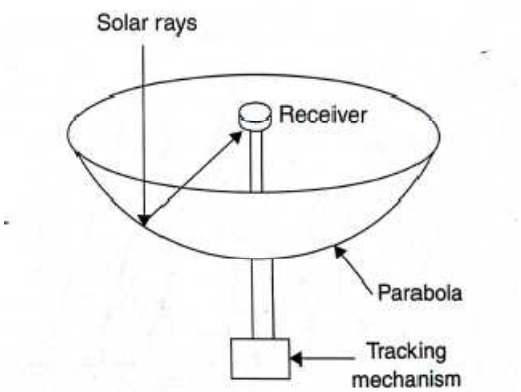

Fig. 2.11 Parabolic dish Solar Collectors

2.6.6 Heliostat Field Solar Collector

- Heliostat is mirror based, point focusing type. It uses two axis solar tracking flat mirror reflector.
- The collected solar energy is converted in electrical energy.
- Application : domestic heating, lighting and electricity
- Flat plate collector has low efficiency but use of glazing has increased the efficiency.
- Heliostat is used for the generation of power ,it has large mirror placed side of a tower and concentrate the energy at the receiver point placed on top of tower

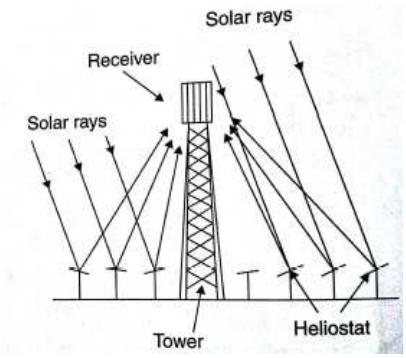

Fig.2.12 Heliostat field Solar Collector

Working of practical solar heliostat

- The movement of mirror up, down left and right reflect sunlight to the fixed point.
- It adjusts itself to the sun to keep receiver point stationary. Angular position of the reflector input is given by computer.
- Since it is focused at a single point it can be used for the purpose of melting steel, heating and cooling of the buildings.
- 1KW of heat is produced per square meter, 100 solar heliometers for 2.2m^2 will produce 220KW of heat. it is sufficient for the building heating purpose
- The main problem is with respect to storage of heat. This is achieved by using a thermal storage if thermal storage used is (hot)water then the storage cost will reduce rapidly.

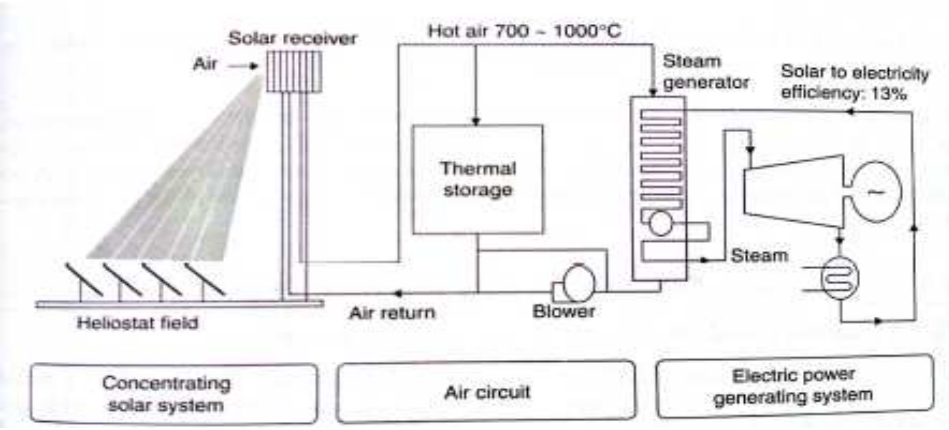

Fig. 2.13 Heliostat Electric Generating Plant

Advantage:

- Since it uses Rankine system cycle it can be hybridized
- Advantages compared to LFS type of collector

Disadvantage:

- Efficiency of conversion is less compared to parabolic dual axis type of collector

2.7 PARABOLIC DISH STRILING ENGINE SYSTEM

It has major three parts

- Solar dish concentrator: collects the heat from the receiver and deliver it to heat transfer fluid to the power conversion system. The need to circulate heat transfer fluid throughout the collector field raises the issue such as pipeing layout, thermals losses and pumping unit.
- Power conversion unit: the main to parts are thermal receiver and heat engine. Thermal receiver will receive heat hydrogen or helium is used as heat transfer medium. The heat is transferred to heat engine and it is intern connected to alternator for the purpose of generation of electricity. The problem is storage of heat. This system can be hybridized with fossil fuel. The string engine is most common type of engine used.
- Tracking system. The parabolic dish system uses computer to track the sun and concentrate sun rays at the receiver. This type of system can reach upto 1000°C at the receiver and has maximum efficiency and used at smaller capacity plants

2.8 WORKING OF PARABOLIC DISH STRILING OR BRAYTON ENGINE SYSTEM

- After heat is concentrated the fluid is heated around 750°C.
- The heated fluid is used in brayton cycle to produce mechanical power rotational kinetic energy and the electricity for utility is generated.
- The light is concentrated at a point and fluid is heats up the compresses working fluid of a cycle (air), as with baryton cycle has a hot compressed air is expended through the turbine to produce rotational kinetic energy. Thw waste heat is preheated to increase the efficiency.

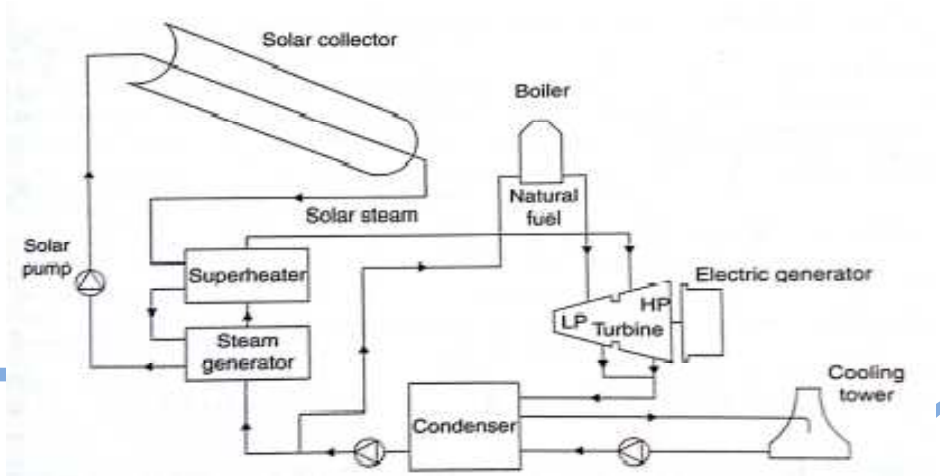

Fig. 2.14 Schematic Solar Electric generation

2.9 SOLAR COLLECTOR SYSTEM INTO BUILDING SERVICES

Speaking interims of economical aspect initial cost of solar conversion system is high and to make it more efficient at all operating condition the solar system is made to meet the demand at full load and change and auxiliary lode is provided by a backup system.

Schematic representation is a shown is figure the main parts of heating system

The main components of the system are

1. Air handling unit
2. Heat storage unit
3. Temperature control system
4. Solar collectors

Based on the position of damper it operates in three different modes

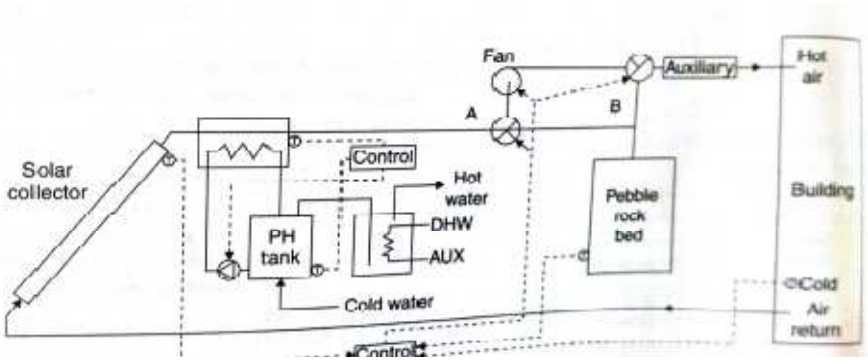

Fig.2.15 Schematic of Solar Air Heating System

- When Damper A and B is close: Day time solar heating mode. The storage unit is bypassed.
- When Damper B is close: when solar heat is collected no space heating required at same time. The fans blows the air inside the storage bed.
- When Damper A is close: this mode is used during cloudy or night period. The return air is pulled through the rock bed when picks of solar heat. The auxiliary furnaces activated automatically if the temperature is insufficient to meet demand.

2.10 SOLAR WATER HEATING SYSTEM

Two main parts of water heating system is solar collector and storage tank. There are two types active system (rely on pump to move liquid from collector and storage tank) passive system (rely on gravity to circulate water)

2.10.1 Active Solar Water Heating System

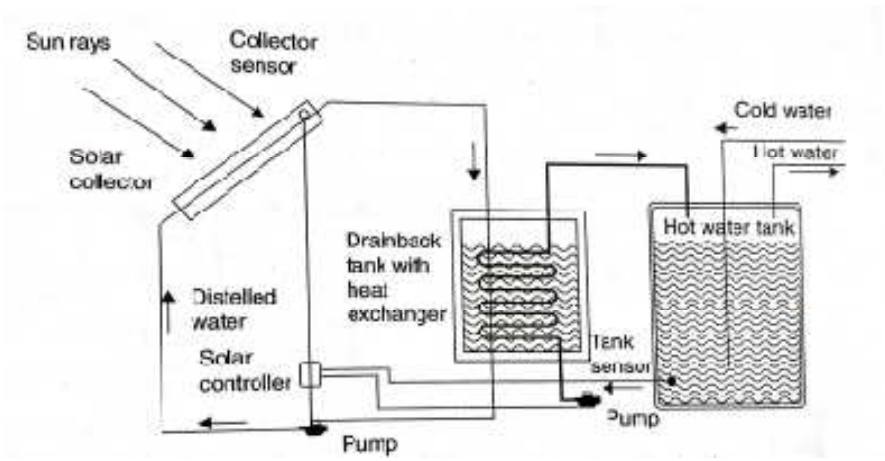

Fig.2.16 Schematic of Active Solar water Heating System

There are 5 major components

1. Collector
2. Circulation system
3. Storage tank
4. Backup heating system
5. Control system

- Water is present in collector only when its pumping
- Distilled water is used as a circulating fluid.
- Proper insulation is given so that tank water is not contaminated.
- In this type collector are placed higher than the heat exchanger vice versa is not possible.
- The heat exchanger is used to exchange heat between the fluid in tube and water in tank used at home.
- Fluids can be water oil antifreeze solution or refrigerant.
- The heat exchanger is separated from storage tank.
- Antifreeze used as fluid then maintenance is required at least once in 2 years. Other type require no maintenance.
- Refrigerant is more costly and handling without leakage is difficult
- Low cost unglazed collectors are available for this purpose.

2.10.2 Active Solar Space Heating System

- It is same has domestic water heating system but connected to heat distribution system. The distribution involves radiator system, forced air system and floor coil system.
- Air distribution system: heated air in storage tank is pumped into air duct when there is a call for heat. This can be done in two ways constant heat at storage tank can be maintained or coil can be placed at a return air duct.
- Hydronic system with radiators: the heated water is circulated in series with the boiler located in the living spaces. Operates effectively at 140°C. Using solar heated water at the boiler source will reduce boiler energy use. If temperature is above requirement it will not offer.
- Hydronic system in slab heat: heated water is pumped through the distribution pipe placed in the floor of home. Temperature not exceeding >80°C.

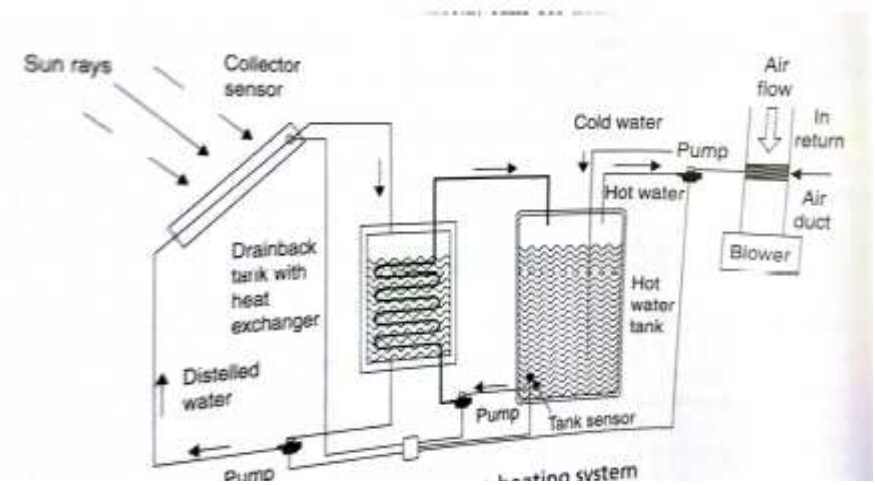

Fig.2.17 Schematic of Active Space Heating System

2.11 PASSIVE SOLAR WATER HEATING SYSTEM

- Passive system is simple and economical.
- There are of 2 types batch and thermosiphon system
- Batch System: water tank coated with black absorbing material and placed in insulated box. A glass or plastic cover is placed over it such that sunlight will directly strike in. It uses house pressure and operates. When taps opened hot water let out and cold water is replaced high insulation, must be used. The pipes used must not freeze during night. Since tank placed outside there is a heat loss from the tank during night. This is avoided by using a insulation sheet.

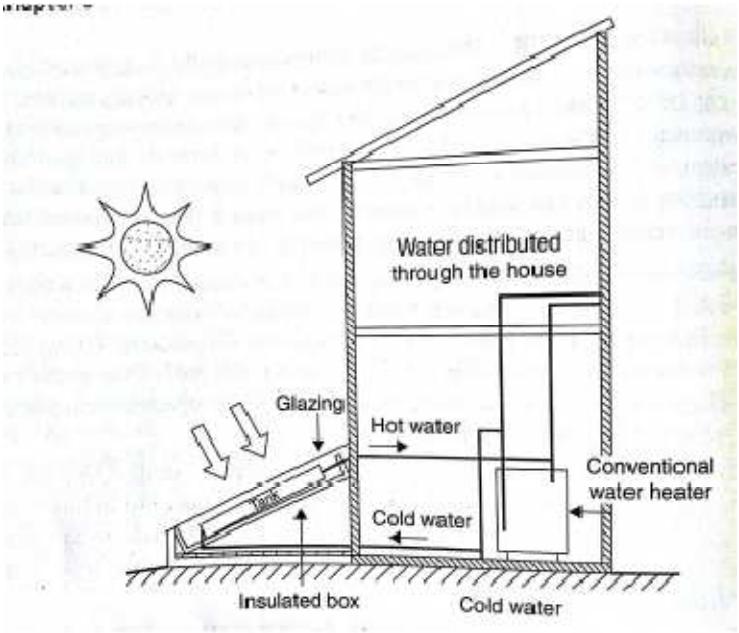

Fig.2.18 Schematic of Batch Domestic Water Heating System

- Thermosiphon system: it uses flat plate collector and storage tank is kept higher than collector. The heated water is stored on the top of tank and cold water from bottom is drawn to heat. The storage tank may or may not use heat exchanger. It is costlier and best suited of indirect system.

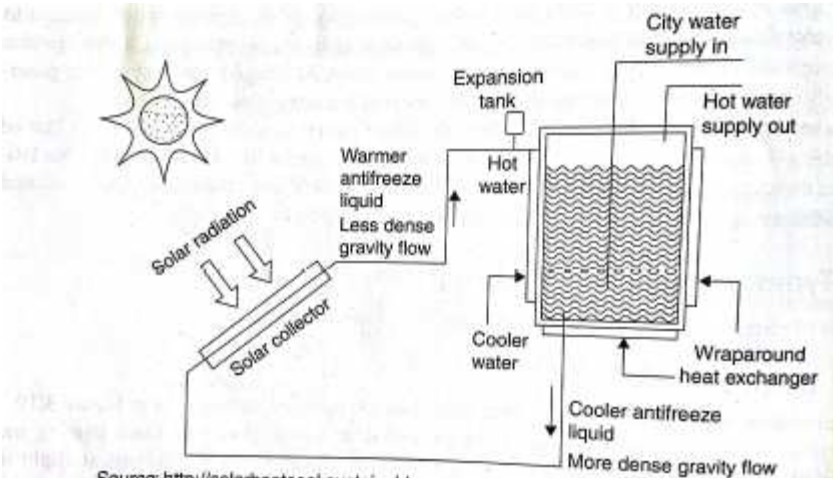

Fig.2.19 Schematic of Thermosiphon Water Heating System

2.12 APPLICATION OF SOLAR WATER HEATING SYSTEM

1. Hotels: batching, kitchen, washing, laundry application

2. Dairies: ghee production, cleaning and sterilizing purpose.

3. Textiles: bleaching, boiling, dye making, curing and ageing

4. Breweries and distillers: bottle washing ,work preparation heating.

5. Chemical \bulk drug unit: boiler fed application and fermentation of mixes.

6. electro plating or galvanizing unit

7. Paper making industries. Boiler application for pulp making

2.13 ACTIVE SOLAR SPACE COOLING

- It is quite costlier; hence system cannot be kept idle.
- Since have same components as that of heating system it can also be used as space heating purpose.
- Heat from solar collectors separate low boiling refrigerant in a generator that receive the pressurized refrigerant from the absorber. Solar heat can also be used in the evaporation of the cycle

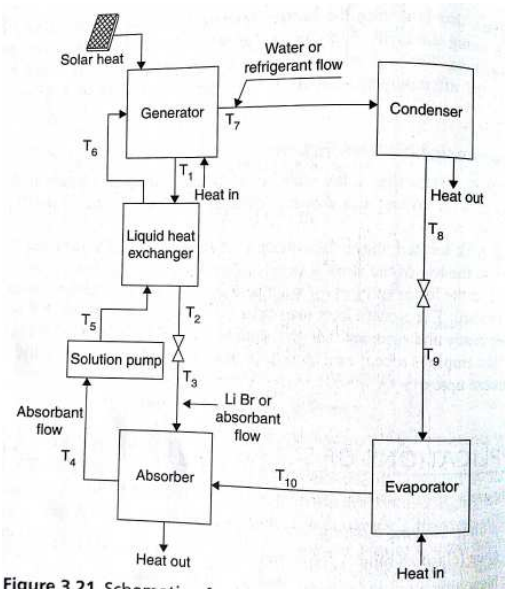

Fig.2.20 Schematic absorption cooling System

2.14 SOLAR AIR HEATING

- It is used for drying of crops and delicate food. There is no pollutants and no fuel costs.
- System removes heat from the surrounding, roof top or wall and passes it to drying chamber through fans and ducts.
- Sensor is used at air flow to have thermostatic control.
- Inside houses coldest air near to floor and warmest air on top of ceiling. As warm air cools down it moves to bottom and the cooler air is warmed up and it is raised.
- It is a thermal technology in which energy from the dun is trapped by absorbing medium and used to heat air.
- It is cost effective, most commercial and industrial application
- The solar collector used are glazed and unglazed type.

2.15 SOLAR DRYERS

- Used for various domestic and industrial purpose such as textile, wood, fruit, food processing, agro industries etc.
- Advantages: economical, hygienic, eco friendly, low operation and maintenance cost.
- Limitations: can be used only during sunny days, it is slower compared to other types, operated at 40°C-50°C
- A solar rice dryer: Used to remove water in products, air is drawn to the dryer by natural convection, air gets heated up and at dryer when it picks moisture it cools down.
- Warm air collects more moisture than cold air. the amount depends on the temperature in which it need to be heated.

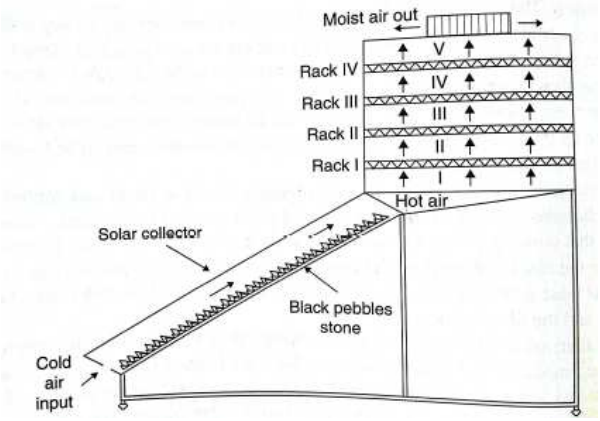

Fig. 2.21 A Rice Solar Dryer

- A rock Bed dryer: air is circulated after collecting a heat from a collector to a lime stone rock which is placed uniformly.
- Rocks are poor thermal conductor temperature disappears when air is not passed.
- Samples placed above the rock can continue drying throughout night.
- Less maintenance, no chance of food getting burnt, non polluting, no fuel cost.
- Heat can be removed from roof tops, plates and passed to drying chamber for heating.
- Crops, timber, distiller grains, textile, tea, coffee, beans, tobacco, dehydration process, sludge, manure, compost etc.

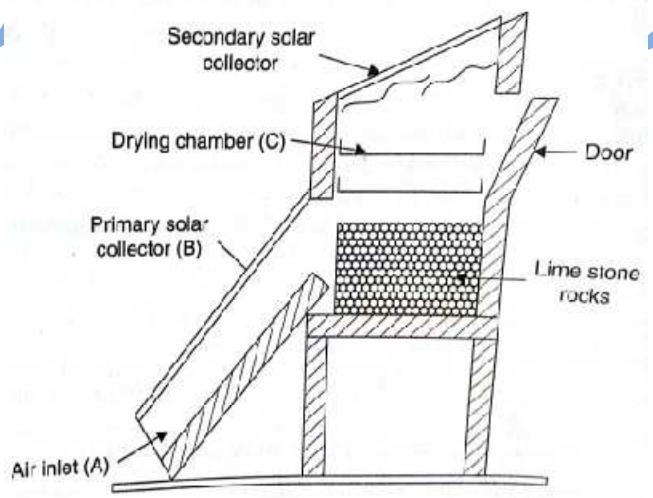

Fig. 2.22 Rock bed Solar Dryer

2.16 CROP DRYER

- While drying crops controlled drying is required.
- It uses stack effect as hot air move upward the dryer dries up and cool air next gets heated up and moves up.
- Size and shape depend on component to be dried.

- Improving and protecting crops are beneficial on health and nutrition.

2.17 SPACE COOLING

- Majority of countries require space cooling system. It is done by passive solar phenomena
- There are many methods of cooling by allowing direct air, using shadows, bamboo houses etc.
- Warm air is taken in and let it warm before living into space.

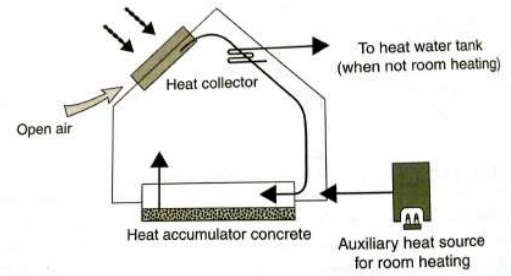

Fig.2.23 Typical Air Heating System

- Type1: very simple construction, ambient air is let into room directly.
- Type 2: circulates room air to the collector, used for apartments building.
- Type 3: used for insulated building heat flows through insulated tube and inner façade. Reduced heat losses
- Type 4: collector flow air though channels in the floor and wall, 4-6h time delays is used.. has large ventilation system with forced fans.
- Type 5: advance type of 4 heat circulated through separate channels of storage. Rarely used because of high cost.
- Type 6: solar air collector and heat exchanger are combined. Hence common radiator and floor heating component are used. Long distance heating possible.

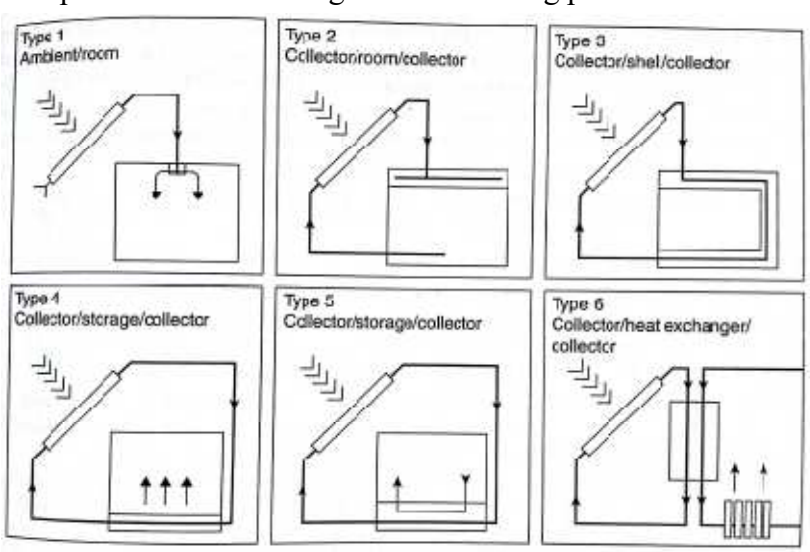

Fig.2.24 Typical Air Heating System

2.18 SOLAR COOKERS

- Used for the purpose of cooking. It consist of box with glass cover, insulated and reflective surface.
- As temperature increases efficiency of the pot also increases.
- There are many types of cookers'
  1. Concentrating sunlight. Reflective mirror of polished glass is used to concentrate light which increases heat energy and heating power
  2. Converting light to heat: light absorption convert light into heat and increases the efficiency of cooker.
  3. Tapping of heat, heat need to be tapped inside, hence a plastic bag tightly sealed to glass cover is used.
  4. Green House effect: glass transmits visible light but block IR radiation that enhances heat trapping effect.
- Types of solar cookers are subdivided into different configuration.
  1. Solar cooking boxes are well insulated boxes with double lid and cover with reflector on the side. Keep food warm in evening and afternoon. Presently widely used.
  2. Reflector cooker concentrate heat at a point where the cooking vessel is fixed. This result in faster cooking.

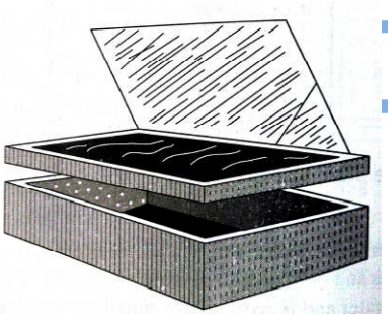

Fig.2.25 Box Type Solar Cooker

3. Parabolic cooker require more precision most complex to build. If sunlight not focused on cooking vesicle then food not cooked efficiently.

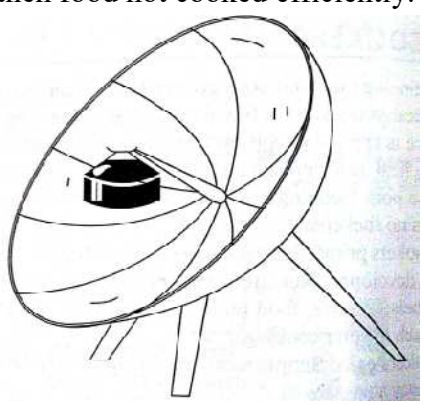

Fig.2.26 Box Type Solar Cooker

4. Solar steam and convection cooker use vapor or hot air as a transfer media. Water evaporated in flat or vacuum collector and fed to cooking vessel.

- Advantages: save fuel, clean, healthy, reduced smoke, economical, save time in collecting fuel, no chances of food getting burned, cooked gently nutrients are not lost.
- Disadvantage: good weather, study sunshine, cannot replace completely conventional system, can't cook night and morning time, , repair replace and maintenance is a problem. High cooking time, food grilled are not possible, cooking person need to be present in sun,

2.19 SOLAR POND

- Solar energy harvested through solar pond.
- A pool of water collects and store energy.
- It as layers of concentrator of salt, of different density at certain depths.
- Low cost and low technology approach
- There are 3 layers of salt
    1. Tap layer, cold, little salt content.
    2. This acts as a insulating layer that as slat gradient , it acts as heat exchange convection of water.
    3. Bottom layer is hot to 100°C and has high salt conversion
- Because of different layer of water has different density.
- Heat is captured in salty layer of solar pond. Which is used for heating, industrial purpose,
- In his system salty layer acts as a plate collector, hence solar energy is extracted.
- Can get temperature around 90°C.
- There are 3 different layers in solar pond. Top layer has less concentration of salt, intermediate as insulator; last layer has high concentration of salt.
- Efficiency <15%
- Since heat is stored energy can be used any time.
- Advantages: low cost, easy construction, generation of electricity, no fuel requires, no pollutant, conventional energy resource is conserved pond acts as purifier.

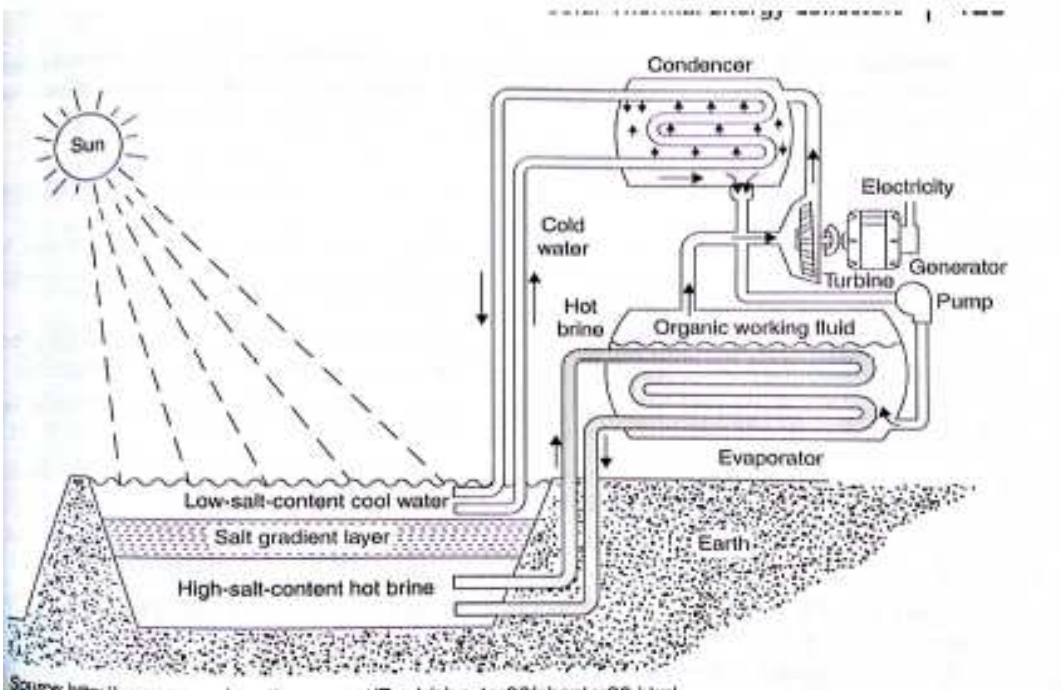

Fig.2.27 Solar Pond

SOLAR CELLS

2.20 INTRODUCTION

A solar cell is and electric device which convert the solar light directly into electricity. This takes place on the principal of Photo voltaic effect. Some material will exhibit the property known as Photovoltaic effect that convert the light energy by absorbing photon and releasing electron. These free electrons are used to produce electricity on a smaller base. The efficiency is 5-11 times less compared to fossil fuel but is eco friendly

Need For Solar Cell:

- For low maintenance
- Cost effective power supplies
- Eco friendly
- No n polluting
- Flexible source
- Reduced global warming

Components of Solar cell system:

Solar panel, batteries, charge controller unit, inverter o utility grid, wiring, mounting hardware or a framework

Key Elements of silicon solar cell:

Substrate: it is a wafer of silicon P region as a base material. While selecting a base should consider parameters such as orientation, resistivity, thickness and doping. Typical thickness is 180-300µm. resistivity 1-2 Ω cm. and doping $5*10^{15}/cm^2$ to $1*10^{16}/cm^2$

Emitter: This formation involves doping of impurities such as phosphorus; arsenic etc. doping is done by the process of diffusion. Commonly phosphorus is used as impurity it is diffused at 850ºC to 1000ºC. The junction depth is in the range o 0.2 -1 µm. this is commonly known as n region diffused layer

Electrical Contacts: This establishes the bridge between semiconductor and eternal load.

(a) Back contact: a metal contact completely covering the back and is placed side away from the incoming sunlight. It is made up of aluminum.

(b) Front Contact: it is a current collections grid of metallic figure arranged on the surface of the light receiving side. This can be placed on the side also but the resistivity increases hence it is placed over a surface but it covers the region of light receiving at n junction which reduces the

efficiency of solar cell. To improve the conversion efficiency shading effect need to be minimized.

(c) Anti reflection coatings: it is a coating applied to reduce he surface reflection and maximum cell efficiency. A thin layer of silicon dioxide and titanium dioxide is applied to reduce the sunlight reflecting back an allow maxim light to reach the semiconductor . it increases cell efficiency at 3-4%.

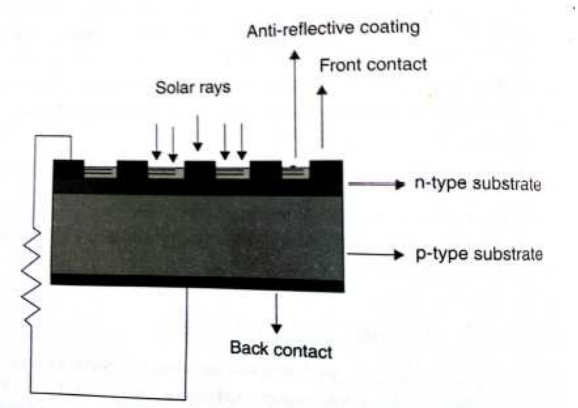

Fig. 2.28 Basic Elements of Photovoltaic cell

Important requirement of Solar Cell(PV cell Design)

1. **Photon energy of Solar light:** photon having certain level of energy can only free the electron from the semiconductor material from the atomic bond to produce electric current. If the photon energy is larger than bandgap it extract extra hat while freeing electron.
2. **Bandgap energy of semiconductors:** the energy required to free the electrons is known as bandgap energy.
3. **Photon Energy Absorption:** Photons are absorbed in the p layer. It absorbs photons and release electron to the maximum.
4. **Electron conduction:** the material which allows the electron through conductor to the electric circuit. The design of this has an impact on efficiency.
5. **Electric contact resistance:** the important aspect is to minimize the resistance losses. If the material opposes the flow o current will result in heating and shading effect must be balanced reduce resistance losses. Therefore figure type projection is spread over a surface and it should be thick enough to conduct and thin enough to conduct light.
6. **Anti Reflecting Coating:** silicon is highly reflecting materials it will reflect1/3rd o light therefore coating is done o reduce reflection and increase efficiency.

Creating P type and N type Semiconductor

The crystalline silicones electrical field is established by adding p type to n type and vice versa. This is done by adding impurities the process of adding impurities is known as doping. Dopants will have 5 or 3 valence electron.

N type semiconductor

Phosphorous atom (5 valence electron) will be doped with n type of semiconductor. The free electron having no bonding is responsible for the conduction of electron. The common method of doping is coating silicon with phosphorous layer and is heated up as temperature cools down the atom electrical property is altered forming a n type. The other method is spraying a high just of phosphorous over a silicon layer. N type of silicon is added to form a electric field.

P type of semiconductor

Pure silicon is place in an induction furnace where it melts

Boron is then added to the melt from which p type crystals are withdrawn

The p type base material is then places in a diffusion furnace contacting a gaseous n type dopants like phosphorous

N type dopant I allowed to diffuse on the surface thus forming p-n junction

Metal conductor girds are added as back and front contact for current collection

SOLAR CELL MATERIALS

Many combination of solar cell material is available. More than 80% of solar cell used are of crystalline silicon because of its greater efficiency than other types.

The absorption coefficient of material: indicates how far the light of specific wavelength can penetrate the material before being absorbed. It depends on two factor wavelength and material

Bandgap of a semiconductor material: it is the minimum energy required to move the atom from bond state to Free State atom. Valence band has higher energy level conduction band lower energy level. Bandgap is the difference between these two bands.

Silicon types:

1. Mono crystalline or single crystal silicon
2. Multi crystalline silicon
3. Polycrystalline silicon: molten silicon is melted and molded and casted to form wafers. Its efficiency is low because of casting
4. Amorphous silicon-it is a thin film technology

Thin film:

it uses layers of silicon of thin film of few micrometer thick. This films technology has made possible for many types of solar cell based on application rooftop, roof tiles, building facades, glazing for skylights.

These thin films are made up of CuInSe or CdTe are increasing because of good efficiency.

PRACTICAL SOLAR CELLS

Cell material	**Theoretical efficiency**	**Practical efficiency**	**Technology**
Mono	20-26	12-18	Wafer
Amorphous	12-14	5-10	Thin film
Copper	16-18	8-10	Thin film
Cadmium telluride	15-16	5-8	Thin film
Gallium arsenide	26-32	18-25	Wafer
Ribbon grown silicon	10-16	10-12	Wafer
Ovshinsky	8-10	< 10	Thin film

SL.No	Silicon Type	Description
1	Crystalline silicon	• Reduced cost • Multi crystalline material, mono crystalline, poly crystalline. • Module have long time • Production efficiency is 18%
2	Amorphous Silicon	• Cheaper • Less efficient type • thin films
3	Cadmium telluride and copper indium diselenide	• thin module • costlier • high efficient
4	High efficient solar cells	• Gallium arsenide, indium phosphide used under high intensity concentrated light. • Application is specialized to satellite.

MAIN COMPONENT AND FUNCTION OF SOLAR CELL

The important function is carrier generation, carrier separation an carrier collection

1. Photovoltaic cell: thin square ,disc an films of semiconductor material that generate voltage an current

2. Module: PV cells wired together and laminate between a clear glazing and covering substrate.
3. Array: one or more module connected together for specific voltage and current
4. Charge controller: to regulate the battery voltage
5. Battery storage: medium which stores DC energy
6. Inverter: used to convert DC to AC for AC Loads
7. DC loads: Equipments powered by DC
8. AC Loads: Equipments powered by AC

THEORY OF SOLAR CELL

The basic effect of solar cell is based on photo electric effect. The photon energy is greater than band gap energy can excite electron from valence band to conduction band. The photovoltaic device is technically very easy to convert light electricity by purely electronic process. The principle of operation depends on the fact that a semiconductor will absorb radiation of high frequency to excite an electron across the energy bandgap and the electron excited in this way returns to the valence band and combine only after comparatively long time.

Process of photovoltaic potential development

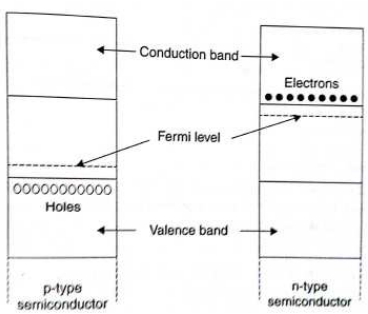

Fig.2.29 Energy Band Diagrams of The P Type And N Type Crystals Before The Contact.

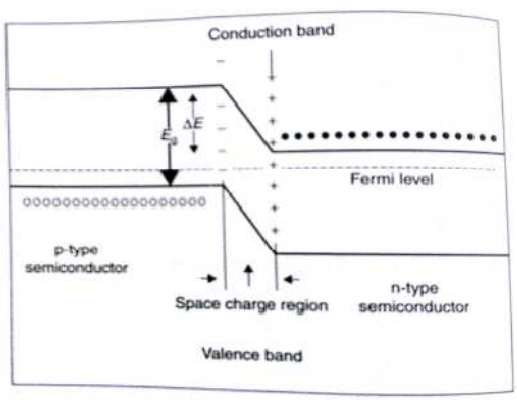

Fig. 2.30 Energy Band Diagram of the P-N Semiconductor Junction at The Final Equilibrium Condition

When two crystal are pushed too gather n type diffuse to p side and p type diffuse to n side where they recombine. When diffused n side becomes positive charge and p side becomes negative charged. The charge distribution will give the potential difference across the junction. Due to this at the contact energy ΔE is developed. The contact potential cause p side to be displaced upward and n side downwards. Therefore Fermi level of two side will line up and system achieve equilibrium.

For a current to flow suitable potential difference is required eV. this is created by difference in Fermi level at the junction. Potential hill equal to (ΔE-eV) in SC case. The charge carrier can move in wrong direction causing a leakage current I_0 with reduces the load current I. This is possible only when hγ > Eg. Equilibrium condition causes a potential difference across a junction called as open circuit voltage (Voc) if resistance is connected then it reviles the short circuit current Isc.

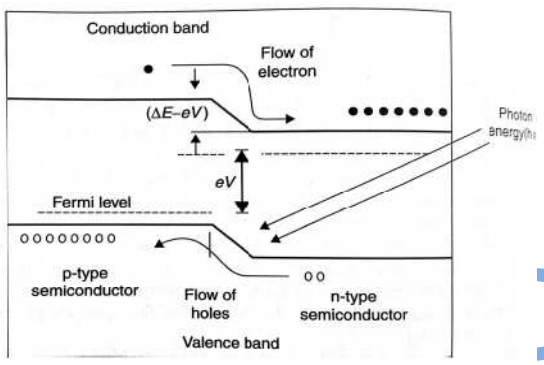

Fig.2.31 Energy Band Diagram of the P-N Semiconductor Junction under Solar excitation

Junction current (Ij)

The majority charge carriers(hole in p side and electron in n side)can't cross the junction unless the energy is greater than the barrier voltage (ΔE-eV)

based on Maxwellian distribution majority charger succeed by making

$$\text{Exp}[-(\Delta E - eV)/kT]$$

K Boltzmanns constant and absolute temperature

n 1- density of electron in n side , n2 - density of holes in p side, n3 - density of holes in p side, n4 - density of holes in n side, I_1 electron current from p to n side, I_2 electron current from n to p side. I_3 –hole current from p-n side, I_4 – hole current from, n-p side.net current

$$I_j = I_1 + I_2 + I_3 - I_4$$

$I_1 = K_1 * n_1$; $I_2 = K_2 * n_2 * \text{Exp}[-(\Delta E - eV)/kT]$; $I_3 = K_3 * n_3 * \text{Exp}[-(\Delta E - eV)/kT]$; $I_4 = K_4 * n_4$;

By substituting in the Ij and simplifying we get equation

$$Ij = I_0[Exp(eV/KT)-1]$$

Solar cell performance (equivalent circuit)

The source current produced by the light current depends on

Junction resistance Rj

Internal shunt resistance Rsh

Internal series resistance Rs

Internal shunt capacitance Csh

External load resistance R

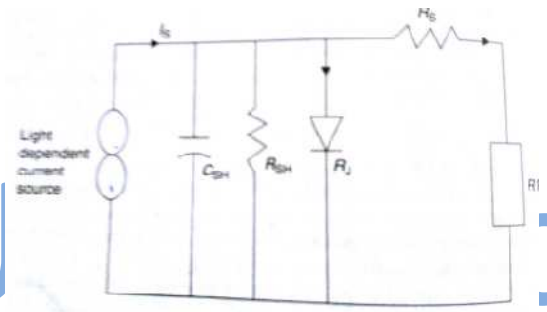

Fig. 2.32 Equivalent Circuit of PV Cell

The shunt resistant connected internally will be very larger compared to load resistance hence the current will flow through the load. Since series resistance is less, less power is dissipated internally.

Load current(ideal condition)

$$I=Is -Ij$$

Junction current,

$$Ij = I_0[Exp(eV/KT)-1]$$

I_0 reverse saturation current, V Voltage eveloped across the junction , K Boltzmanns constant, e electron charge, T absolute temperature.

The short circuit current is always less than the ideal value,

Under SC condition V=0, I=Is

Under OC condition V=Voc, I=0

Sub in ideal equation we get

$$I= Is - I_0[Exp(eV/KT)-1]$$

Under OC condition I=0

$$Exp(eV/KT)-1= Is/Io$$

$$Voc=(kT/e)[In\{(Is/Io)+1\}]$$

2.21 I-V CHARACTERISTICS OF SOLAR CELL

Short circuit current on Y axis and open circuit voltage on x axis

When positive and negative terminal is short the current Isc is produced and voltage is zero at this condition load resistance is zero.

When positive and negative terminal is open the current Voc is established and current is zero at this condition load resistance is infinity

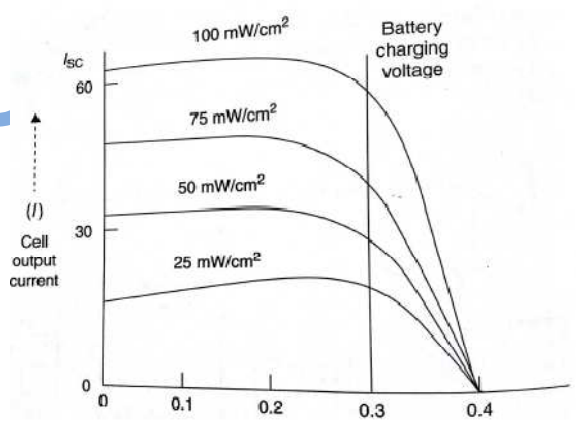

Fig. 2.33 I-V Characteristics of a Typical Solar Cell Under Different Illumination

Output power

$$\text{Output power } P = \{ Is - I_0[Exp(eV/KT)-1]\} * V$$

P=V*I maximum power when IV is Maximum

Maximum power output of the cell

On differencing the equation with respect to v and sup $V=V_{MP}$ we get dP/dV=0

$$[Exp(eV_{MP}/KT)][1+ eV_{MP}/KT] =(1+Is/Io)$$

At absolute temperature T, taking Isc on y axis and V on X axis , by considering V max, I max and P max can be found

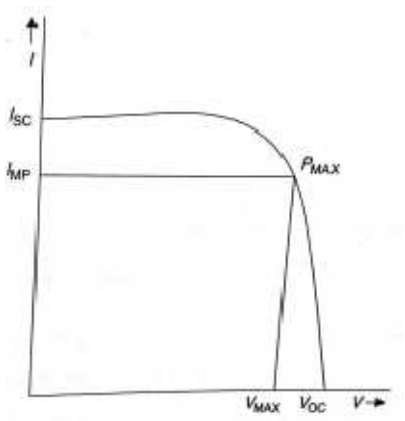

Fig. 2.34 I-V Characteristics of an Ideal Solar Cell

$$I \text{ max} = (eV_{MP}/KT)] / [1+ eV_{MP}/KT](Is-Io)$$

2.22 EFFICIENCY OF SOLAR CELLS

η = maximum output power in W /(irradiance in W/m2* area of a cell in m2)

$$\eta = Pmax /(E*S)$$

The I-V characteristic is obtained by considering isolation as a constant or a temperature as a constant. By varying load resistance from zero to infinity maximum power can be reached having greater efficiency. The maximum voltage having a maximum current will give a maximum power point. Maximum power can be generated at only one point on the curve, it is seen about the knee of the curve. This represents the maximum efficiency of a solar device where maximum sunlight is converted to electricity.

Fill factor

The overall circuit behavior is defined by a fill factor

FF = maximum power output / (open circuit voltage* short circuit current)

$$FF = Pmax/(Voc*Isc)$$

$$= (V_{MP}*I_{MP})/ /(Voc*Isc)$$

$$FF= (\eta*S*E)/(Voc*Isc)$$

The series and shunt resistance will affect the FF, by increasing Rsh and decreasing Rse maximum efficiency can be obtained.

Factor limiting the efficiency of the cell

1. **Wavelength of the solar Spectrum:** solar cell will response to only a portion of sunlight. Wavelength > 1.1 μ m. does not have sufficient energy to create a electron hole pair.
2. **Temperature:** normal operating temperature of a cell is 60° and these temperature decreases cell efficiency. To operate at higher temperature heat sink must be provided
3. **Mounting of the cell:** this is a heat sink either heat conductive but electrically insulated. Water may act as heat sink.
4. **Arrangement and maintenance:** -ve side of the cell faces sun and has antireflection coating. This surface to be protected from foreign practical. The accumulation of dust will decrease efficiency by 10%.
5. **Position of the cell:** placed towards south in north of equator and vice versa. The angle depends on the latitude of place and placed in such a way that maximum efficiency can be obtained.

2.23 PHOTOVOLTAIC PANELS (SERIES AND PARALLEL ARRAYS)

A single cell voltage is 0.5V and current is 50mA. Connected in series(+ve to -ve) to get maximum voltage. If maximum current is required then to be connected in parallel.

Panels are divided into 3 basic categories

Low Voltage/power panel: few cell connected of about 1.5 to 6V having few mill watts output. Used in clocks, watches, calculator etc. amorphous type of silicon is used

Small panel: 3 to 12V, output power 1 to 10W, of area 100cm^2 to 1000cm^2, poly crystalline amorphous silicon is used. Main uses are radio, toys, small pumps, electric fence.

Large panels: 6-12V, output power 10 to 60W, of area 1000cm^2 to 5000cm^2 by joining around 10-36 full sized cell. Used for the purpose of communication, remote area power supply.

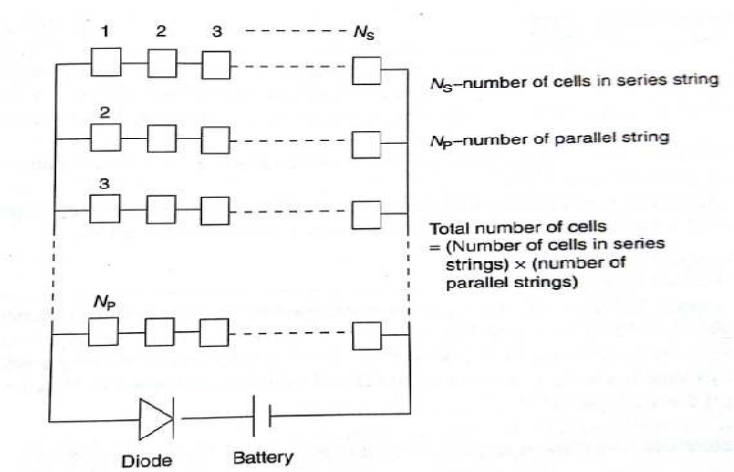

Fig.2.35 Series-Parallel Array with Diode and Battery

Number of solar cell required in series.

$$\mathbf{Ns = (V_B+V_D+V_w)/V_{MP}}$$

V_B – bus voltage, V_D – Diode voltage, V_W – wiring drop, V_{MP} – maximum cell voltage

Number of solar cell required in parallel

$$\mathbf{Np = I_L/I_{MP}}$$

IL- load current, IMP- maximum Current

2.24 APPLICATION OF SOLAR CELL SYSTEM

1. **Solar Water pumps:**
   - Used in farms to supply water to livestock.
   - In developing countries used extensively to pump water from rives, wells for domestic and irrigation purpose.
   - Here solar photovoltaic cell is powered to motor to run and lift water.
2. **Solar Vehicle**
   - Solar energy is converted to electrical energy and all parts of a vehicle propulsion is powered solar energy.
   - Is used for the purpose of communication and other auxiliary.
3. **Solar lanterns**
   - Petromax-type lantern are plugged into solar PV cell to store charges in the battery and electricity is produced to light up house and play radio.
   - 4 to 5 hours a lantern can light up the house.
4. **Grid Connected photovoltaic power system.**
   - The power generated and given to utility Grid.
   - Grid connected PV system supply power to the connected load. It consists of PV panel, battery, controller unit, solar inverter and grid connecting unit.
   - At residential less than 10Kw is sufficient for the consumer extra power can be pumped to grid.
5. **Cathodic protection System**
   - It is a method of protecting a metallic structure from corrosion.
   - Applicable to bridges, tanks, wells, rail lines ..
   - A small negative voltage is applied to a metal structure and it prevents from oxidation or rusting. Positive terminal is connected to a scrap metal which corrodes instead of structure. PV cell are used in remote place to provide voltage
6. **Remote lighting Systems**

- Lighting used at remote power where in the cost of utility grid power is high.
- Application such as security, navigation, railway crossing, lighting.
- It consists of PV cell, battery charging unit, storage battery, power conditioner, DC florescent lamp.

7. **Telecommunications and remote monitoring systems.**
   - Cost effective telecommunication repeater station are developed to overcome the disadvantage of the aged method.
   - This consist of receiver, transmitter and solar cell based power system.
   - >1000 units have been installed which is working efficiently and reliably
   - Application can be seen at Radio, television, emergency telephone, weather data from remote place
8. **Rural Electrification**
   - Low voltage batteries are used in remote places to provide electric power for lighting and vehicles.
   - Consist of small solar cell, charge controller unit and a battery.
9. **Water treatment System**
   - Used for purifying of drinking water at remote areas.
   - Strong UV radiation is used to kill bacteria in drinking water solar energy is used to power for this purpose.
   - Desalination of brackish water can be achieved via PV powered reverse osmosis system.

2.25 Module Outcome:

At the end of Module are capable enough to know,

- Types of solar collector and it practical application
- Characteristic of Solar cell
- Application of solar collectors
- Application of solar cell system