LECTURE NOTES

ON

RENEWABLE ENERGY SYSTEMS

(UNIT 1 & UNIT 2)

2023 - 2024

IV B. Tech I Semester (JNTUA-R20)

Unit-1 PRINCIPLES OF SOLAR RADIATION

Introduction

The word ‗*energy*' itself is derived from the **Greek** word ‚*en-ergon*, which means ‗*in-work'* or *work content*. The work output depends on the energy input. Energy is the most basic infra-structure input required for economic growth & development of a country. Thus, with an increase in the living standard of human beings, the energy consumption also accelerated.

A systemic study of various forms of energy & energy transformations is called energy science. While fossil fuels will be the main fuel for thermal power, there is a fear that they will get exhausted eventually in the next century. Therefore other systems based on non- conventional & renewable sources are being tried by many countries. These are solid, wind, sea, geothermal & bio-mass.

The need for alternatives:

1. The average rate of increase of oil production in the world is declining & a peak in production may be reached around 2015. There after the production will decline gradually & most of the oil reserves of the world are likely to be consumed by the end of the present century. The serious nature of this observation is apparent when one notes that oil provides about 30% of the world‗s need for energy from commercial sources & that oil is the fuel used in most of the world‗s transportation systems.
2. The production of natural gas is continuing to increase at a rate of about 4% every year. Unlike oil, there has been no significant slowdown in the rate of increase of production. Present indications are that a peak in gas production will come around 2025, about 10years after the peak in oil production.
3. As oil & natural gas becomes scarcer, a great burden will fall on coal. It is likely that the production of coal will touch a maximum somewhere around 2050.
4. Finally, it should be noted that in addition to supplying energy, fossil fuels are used extensively as feed stock material for the manufacture of organic chemicals. As resources deplete, the need for using fossil fuels exclusively for such purposes may become greater.

India's production & reserves of commercial sources:

***Coal*:** Coal is the end product of a natural process of decomposition ofvegetable matter buried in swamps & out of contact with oxygen for thousands of years. The word ‗coal' denotes a wide variety of solid fuels. The varieties in approximate order of their formation are peat, lignite, bituminous & anthracite coal.

The rate of production of coal in India over the last 50 years is shown in fig (a). It can be seen that there has been an eleven-fold increase in production from 1951 to 2004 & that the average annual growth rate has been about 4.5%. In 2000, India's production was 300mt, which was about 6.7% of the world's production. India has fairly large reserves of coal.

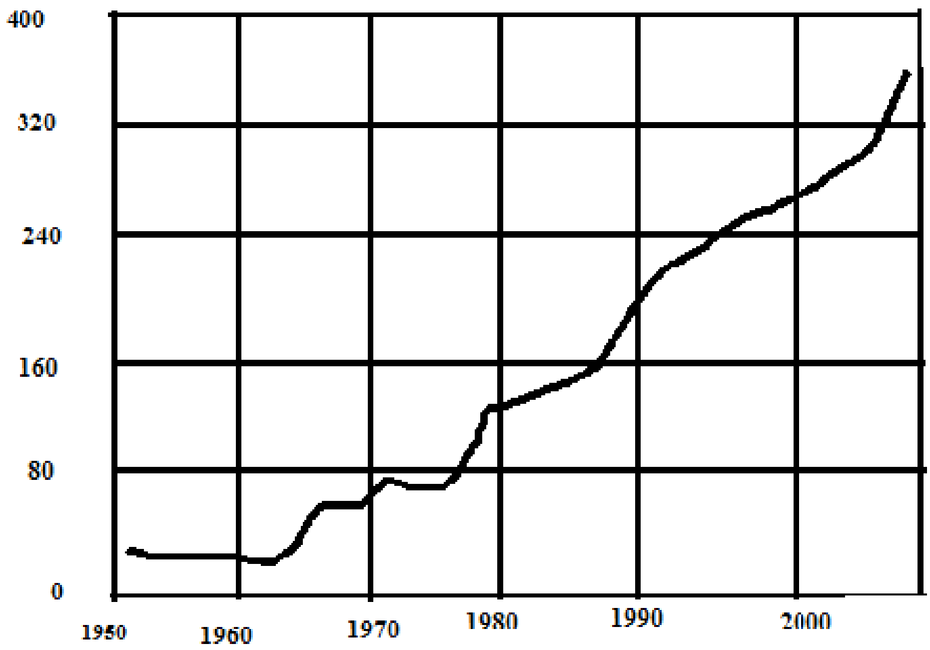


Fig.1. Annual production of coal in India [production rate (Mt/Year] v/s Year

Table 1: Coal reserves in India (in Mt)

Year	Proved reserves	Indicated & inferred reserves	Total reserves (Resources)
1972	21360	59590	80950
1981	27912	87490	115402
1985	35030	120870	155900
1992	64800	129000	193800
2006	95866	157435	253301

Oil: The below fig.2. Represents presents data on the annual consumption of petroleum products in India (curve 3) from 1951 onwards. It also shows the variation in the domestic production of crude oil (curve 1) & the import of crude (curve 2) over the years.

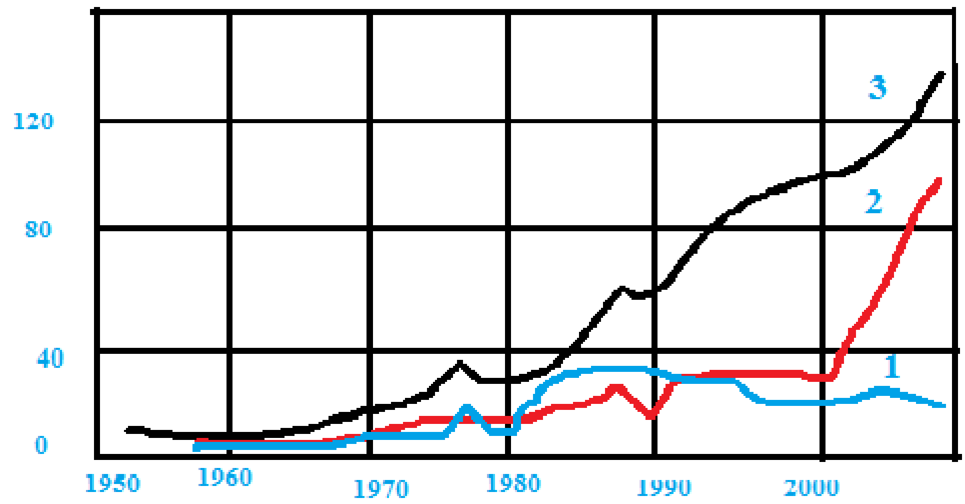


Fig.2. Annual production, import & consumption of oil in India [Production Rate (Mt/Year) v/s Year]

*Curve 1.*Domestic production of crude, *Curve 2.*Import of crude, *Curve 3.* Consumption of products

<u>Natural gas:</u> presents data on the annual useful production of natural gas in India from 1969 onwards. In 1969, the production was only 0.516 billion m³. It did not change much till 1973. However, subsequently the production increased rapidly. It was 8.913 billion m³ in 1989, 13.5% from 1989 to 1997 & 3.1% from 1997 to 2005.

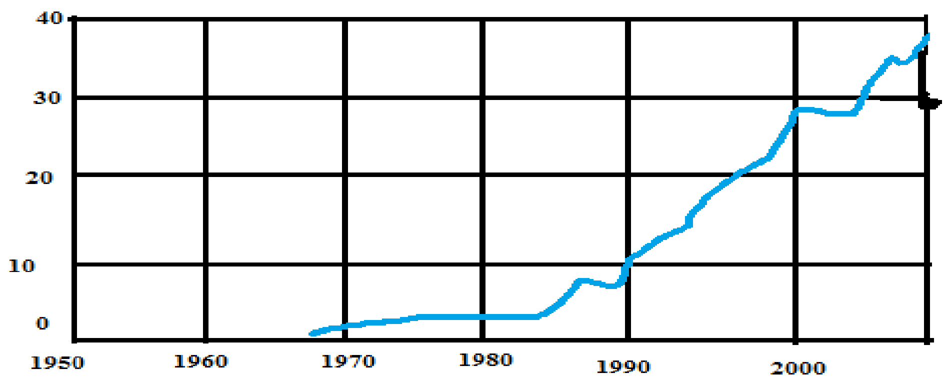


Fig.3. Annual production of natural gas in India [Production rate (10^9 m³/Year) v/s Year]

<u>Water –power:</u>

It is one of the indirect ways in which solar energy is being used. Water-power is developed by allowing water to fall under the force of gravity. It is used almost exclusively for electric power generation. Data on the installed capacity of hydro power in India & the electricity produced from it from 1947 onwards is presented in below fig. 4.

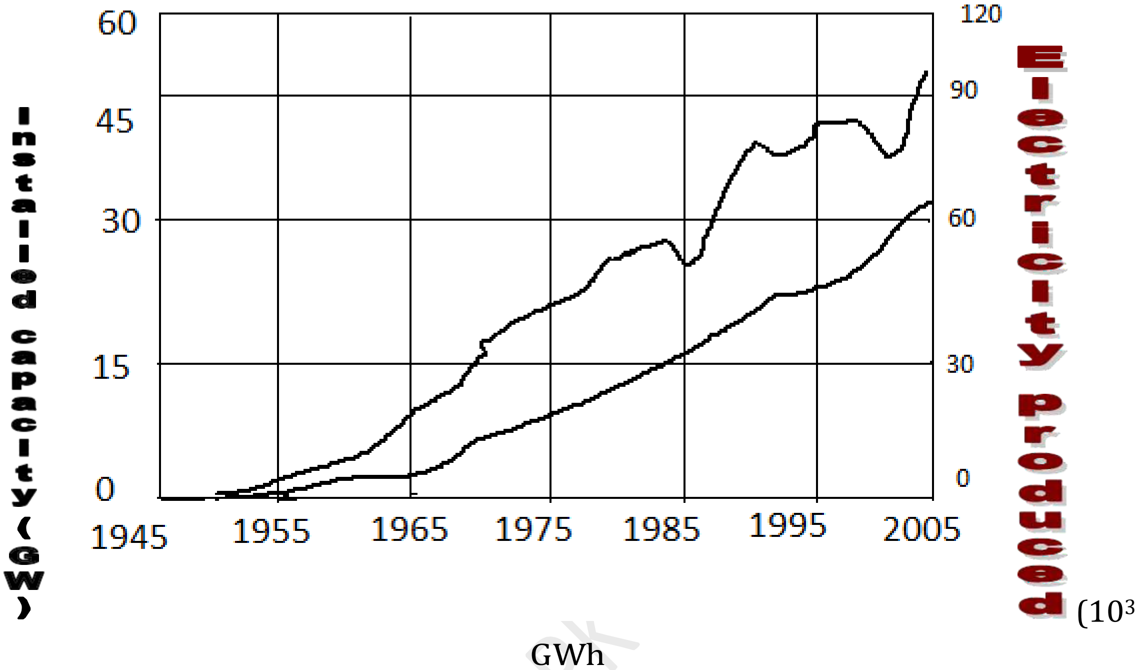


Fig.4. installed capacity & electricity generation from water-power in India.

Nuclear power:

Data on the electricity production from nuclear power is plotted in below fig .5. It is seen that the electricity produced has been generally increasing over the years, as more units are getting commissioned. The higher amount, viz 19242 GWh was produced in 2002. The fall in certain years is because of some units being down for maintenance.

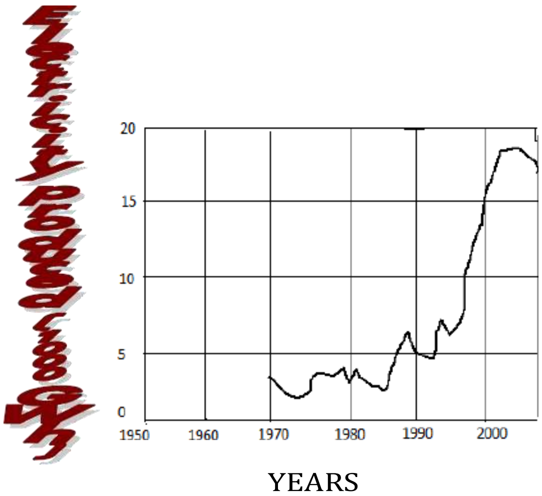


Fig.5. Electricity produced from nuclear power in India

Miscellaneous Sources:

In India, the miscellaneous sources are renewable source like wind energy, biomass, small hydro-power. As was the case for the world, in India also, wind energy is the main contributor. The growth in installed capacity for wind energy & along with data on the electricity produced from the wind is as shown in below fig. 6.

The growth of installed capacity for wind energy in India has been very impressive. At the end of 1990, the capacity was only 37 MW. 15 years later, at the end of 2005, it was 5342 MW & India now ranks 4th in the world in terms of wind power installed capacity.

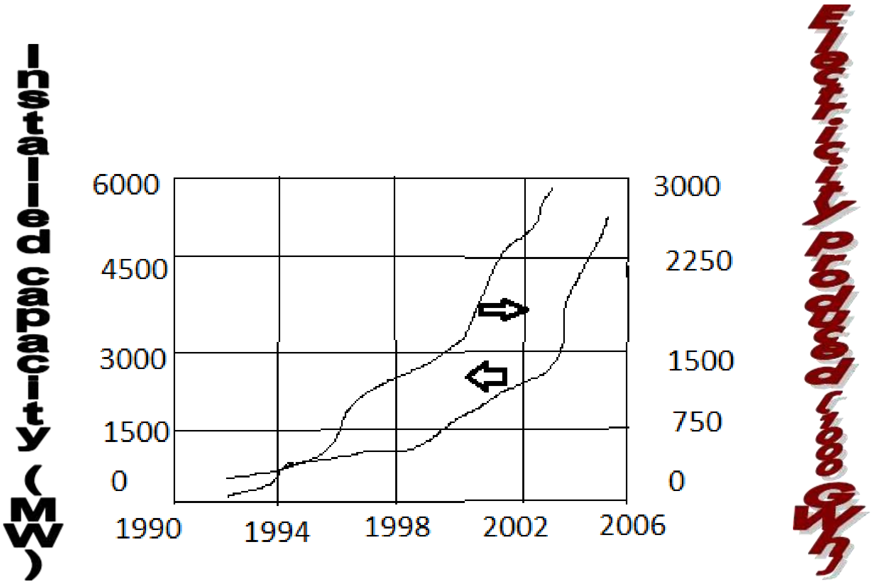


Fig.6. Installed capacity & electricity generation from wind power in India

The contribution of small hydro-power & biomass are also significant. Table 2 presents data on the growth of small hydro power & biomass power capacity in the country.

Table 2: Installed capacity of small hydro-power units & biomass power in India

Year	Capacity	
	Small hydro-power	Biomass power
Up to 2001	1438.89	379.50
2002	80.39	103.00
2003	84.04	129.50
2004	102.27	137.60

2005	120.84	117.93
Total (up to 2005)	1826.43	867.53

Electricity production in India:

The below fig .7. data shows that the installed capacity has increased from 1362 MW in 1947 at the time of independence to 16664 MW in 1973 & to 124287 MW in 2005. These correspond to an impressive average annual growth rate of 10.1 % from 1947 to 1973 & to a rate of 6.5% from 1973 to 2005

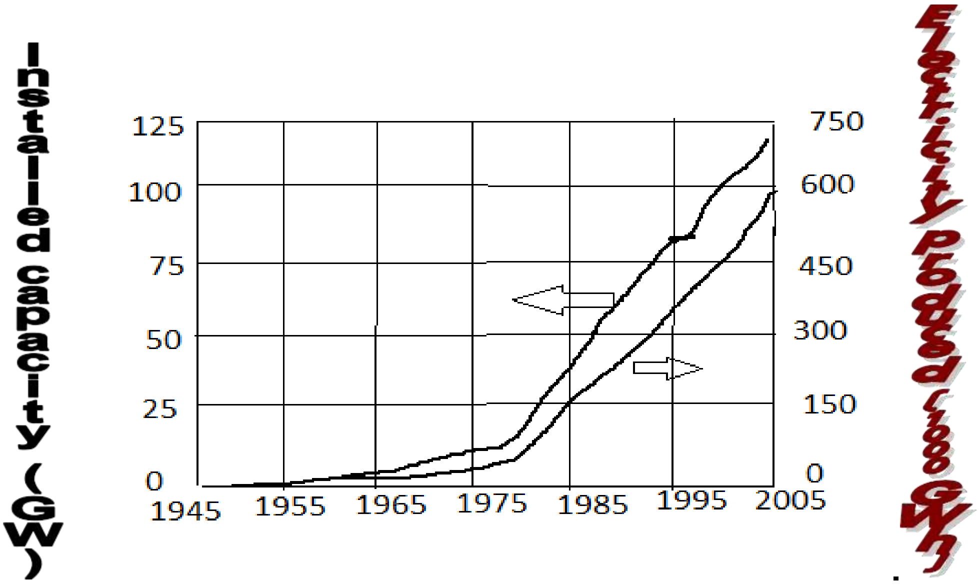


Fig.7. The total installed capacity & electricity generation in India from all commercial sources

Annual production of energy:

Table 3: Energy production from commercial energy sources in India-Year 2000

Energy source	Production/consumption	Energy equivalent(in 10^{15} J)	Percent contribution
Coal	310 Mt	8177	56.16
Oil	103.44 Mt	4331	29.75
Natural gas	27.860×10^{9} m^3	1087	7.47
Water-power	74362 GWh	765	5.25

Nuclear power	16621GWh	199	1.37
Total		14559	100.00

The calculations are performed for the year 2000 & are presented in table 3. It is seen that the total energy production is 14559×10^{15} J. Once again the dominant role played by fossil fuels in the energy sector is apparent. 93% of India‘s requirement of commercial energy is being met by fossil fuels, with coal contributing 56%, & oil & natural gas contributing 37%. Water power & nuclear power contribute only about 7% to the total energy production. Comparing the total energy production in India from commercial sources with that of the world. We see that it is only 3.5% of the total world production.

India's reserves & production relative to world data:

Energy source	Proved reserves			Production (2004)		
	World	India	% of world	World	India	% of world
Coal (Mt)	980000	95866	9.8	5516	377	6.8
Oil(billion barrels)	1300	5.75	0.4	26.36	0.25	0.9
Natural gas(billion m^3)	175000	1101	0.6	2792.6	30.775	1.1
Nuclear power	3.62	0.061	1.7	2619180	16709	0.6
Water power	3×10^6	148700	5.0	2746880	84495	3.1

Classification of energy resources:

1. **Based on usability of energy:**

   a) Primary resources: Resources available in nature in raw form is called primary energy resources. Ex: Fossil fuels (coal, oil & gas), uranium, hydro energy. These are also known as raw energy resources.

   b) Intermediate resources: This is obtained from primary energy resources by one or more steps of transformation & is used as a vehicle of energy.

c) Secondary resources: The form of energy, which is finally supplied to consume for utilization. Ex: electrical energy, thermal energy (in the form of steam or hot water), chemical energy (in the form of hydrogen or fossil fuels).

Some form of energies may be classified as both intermediate as well as secondary sources. Ex: electricity, hydrogen.

2. Based on traditional use:

a) Conventional: energy resources which have been traditionally used for many decades. Ex: fossil fuels, nuclear & hydro resources

b) Non-conventional: energy resources which are considered for large scale & renewable. Ex : solar, wind & bio-mass

3. Based on term availability:

a) Non-renewable resources: resources which are finited, & do not get replenished after their consumption. Ex : fossil fuels, uranium

b) Renewable resources: resources which are renewed by nature again & again & their supply are not affected by the rate of their consumption. Ex : solar, wind, bio-mass, ocean (thermal, tidal & wave), geothermal, hydro

4. Based on commercial application:

a) Commercial energy resources: the secondary useable energy forms such as electricity, petrol, and diesel are essential for commercial activities. The economy of a country depends on its ability to convert natural raw energy into commercial energy. Ex : coal, oil, gas, uranium, & hydro

b) Non-commercial energy resources: the energy derived from nature & used –directly without passing through commercial outlet. Ex: wood, animal dung cake, crop residue.

5. Based on origin :

a) Fossil fuels energy
b) Nuclear energy
c) Hydro energy
d) Solar energy
e) Wind energy
f) bio-mass energy
g) geothermal energy
h) tidal energy
i) ocean thermal energy
j) ocean wave energy

Consumption trend of primary energy resources

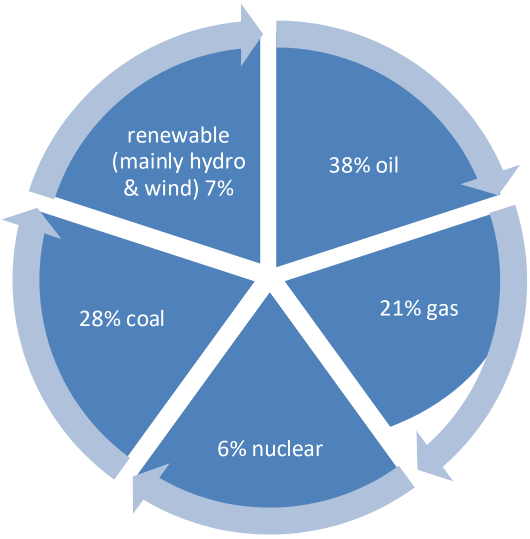


Fig.8. percentage consumption of various primary energy resources

The average % consumption trend of various primary energy resources of the world is indicated in the above fig, though the trend differs from country to country. Looking at figure the heavy dependence on fossil fuels stands out clearly. About 87% of the world's energy supply comes mainly from fossil fuels. The share of fossil fuels is more than 90% in case of India.

Importance of Non-commercial energy resources:

The concern for environmental due to the ever increasing use of fossil fuels & rapid depletion of these resources has lead to the development of alternative sources of energy, which are renewable & environmental friendly. Following points may be mentioned in this connection.

1) The demand of energy is increasing by leaps & bounds due to rapid industrialization & population growth, the conventional sources of energy will not be sufficient to meet the growing demand.
2) Conventional sources (fossil fuels, nuclear) also cause pollution; there by their use degrade the environment.
3) Conventional sources (except hydro) are non-renewable & bound to finish one day.
4) Large hydro-resources affect wild-life, cause deforestation & pose various social problems, due to construction of big dams.
5) Fossil fuels are also used as raw materials in the chemical industry (for chemicals, medicines, etc) & need to be conserved for future generations.

Due to these reasons it has become important to explore & develop non-conventional energy resources to reduce too much dependence on conventional resources. However, the present trend development of nces indicates that these will serve as supplements rather than substitute for conventional sources for some more time to time.

SALIENT FEATURES OF NON-CONVENTIONAL ENERGY RESOURCES

Merits:

1. NCES are available in nature, free of cost.
2. They cause no or very little pollution. Thus, by and large, they are environmental friendly.
3. They are inexhaustible.
4. They have low gestation period.

Demerits:

1) Though available freely in nature, the cost of harnessing energy from NCES is high, as in general, these are available in dilute forms of energy.
2) Uncertainty of availability: the energy flow depends on various natural phenomena beyond human control.
3) Difficulty in transporting this form of energy.

ADVANTAGES & DISADVANTAGES OF CONVENTIONAL ENERGY RESOURCES:

ADVANTAGES:

1) Coal: as present is cheap.
2) Security: by storing certain quantity, the energy availability can be ensured for a certain period.
3) Convenience: it is very convenient to use.

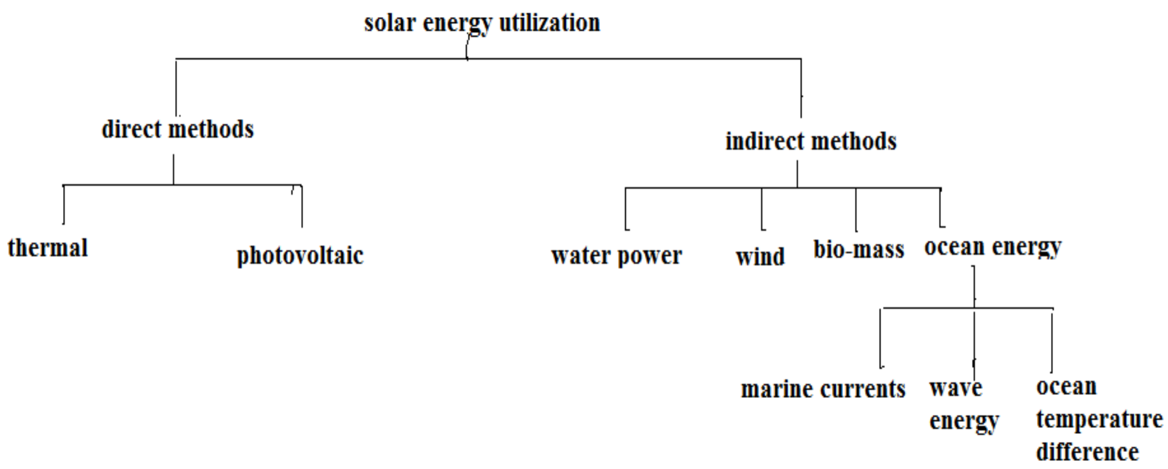
DISADVANTAGES:

1) Fossil fuels generate pollutants: CO, CO_2, NO_X, SO_X. Particulate matter & heat. The pollutants degrade the environment, pose health hazards & cause various other problems.
2) Coal: it is also valuable petro-chemical & used as source of raw material for chemical, pharmaceuticals & paints, industries, etc. From long term point of view, it is desirable to conserve coal for future needs.
3) Safety of nuclear plants: it is a controversial subject.
4) Hydro electrical plants are cleanest but large hydro reservoirs cause the following problems
a) As large land area submerges into water, which leads to deforestation
b) Causes ecological disturbances such as earthquakes
c) Causes dislocation of large population & consequently their rehabilitation problems.

SOLAR ENERGY:

- Solar energy is a very large, inexhaustible source of energy. The power from the Sun intercepted by the earth is approximately **1.8×10^{11}** MW which is many thousands of time larger than the present consumption rate on the earth of all commercial energy sources. Thus, in principle solar energy could supply all the present & future energy needs of the world on a continuing basis. This makes it one of the most promising of the unconventional energy sources.
- Solar energy is received in the form of radiation, can be converted directly or indirectly into other forms of energy, such as heat & electricity. This energy is radiated by the Sun as electromagnetic waves of which 99% have wave lengths in the range of 0.2 to 4 micro meters.
- Solar energy reaching the top of the Earth's atmosphere consists about 8% U.V radiation, 46% of visible light, 46% Infrared radiation.

Classification of methods for solar energy utilisation:



Merits of solar energy:

- It is an environmental clean source of energy
- It is free & available in adequate quantities in all most all parts of world where people live.

Demerits of solar energy:

- It is a dilute source of energy because even in hottest region the radiation flux is available only 1 KW/m^2 & total radiation over a day is 7 KW/m^2. These are low values from the point of view of technological utilization.
- It is required large collecting areas are required in many applications & these results increase of cost.

- Solar energy availability varies widely with time, it occurs because of the day-night cycle & also seasonally because of the Earth‘s orbit around the Sun [even local weather condition].

Solar applications:

- ✓ Solar heating
- ✓ Solar cooling
- ✓ Solar pumping
- ✓ Solar furnace
- ✓ Solar production of hydrogen
- ✓ Solar green houses
- ✓ Solar distillation
- ✓ Solar energy
- ✓ Solar cooking

Thermal Energy:

Thermal energy refers to the internal energy present in a system in a state of thermodynamic equilibrium by virtue of its temperature. The average transitional kinetic energy possessed by free particles in a system of free particles in thermodynamic equilibrium. This energy comes from the temperature of matter.

Thermal energy is the total energy of all the molecules in an object. The thermal energy of an object depends on the 3 things:

1. The number of the molecules in the object
2. The temperature of the object (average molecular motion)
3. The arrangement of the object molecules (states of matter)

There are 3 modes of thermal energy

1. Conduction, 2.convection, 3.radiation

1. **Conduction:** Heat is transferred from one molecule to another without the movement of matter.
2. **Convection:** Fluids (liquids & gases) transfer heat by convection, a process that causes mixing of the warmer regions with the cooler regions of liquid or gas.

   The main difference between convection & conduction is that convection involves the movement of matter & conduction does not.
3. **Radiation:** it is the transfer of energy by electromagnetic waves.

ADVANTAGES:

- It is eco friendly
- Renewable sources
- No/less pollution
- By using this produce electricity
- Its help full for oil refining in Industry & home heating

DISADVANTAGES:

- Producing green house gas
- Collecting of energy is a big problem, it requires sophisticated technology hence cost is more.

Applications:

- Steam engine
- Gasoline engine

Photovoltaic (PV) or Solar Cell:

It is a device that converts solar energy into electric current using the photoelectric effect. The first PV was introduced by Charles Frilt in the 1880's. In 1931 a German engg Dr.Bruno Lange developed PV by using Silver Solenoid in place of Copper oxide.

Photovoltaic power generation employs solar panels, composed of number of solar cells containing photovoltaic material. Photovoltaics are made up of semiconductors & it converts solar radiation into direct current electricity.

Photovoltaic system consists of

a) Solar cell array, b) load leveler, c) storage system, d) tracking system(where necessary)

Working Principle:

PV's are made up of semiconductors that generate electricity when they absorb light. As photons are received, free electrical charges are generated that can be collected on contacts applied to the surface of the semiconductors. Because of solar cells are not heat engines, & therefore, do not need to operate at higher temperature, they are adapted to the weak energy flux of solar radiation, operating at room temperature.

Advantages:

- Compare to fossil fuels nuclear energy sources, very little research money has been invested in the development of solar cells.
- It gives long duration period(operation)
- Operating costs are extremely low compared to existing power technologies.

Applications:

- Space craft (silicon solar cell)
- It can be applicable to either small or large power plants
- These solar cells are used to operate irrigation pumps, navigational signals, highway emergency call systems, rail road crossing warnings & automatic metrological station.

WATER POWER (HYDRO POWER):

Power derived from the energy of falling water & running water, which may be harnessed for useful purposes. In ancient years hydro-power has been used for irrigation & the operation of various mechanical devices such as water mills, saw mills, textile mills, domestic lifts, power house & paint making.

How the generator works: A hydraulic turbine converts the energy of flowing water into mechanical energy. A hydro-electric generator converts this mechanical energy into electricity. The operation of generator is based on the principle discovered by Faraday. He found that when a magnet is moved past a conductor it causes electricity to flow.

In a large generator electro magnets are made by circulating d.c through loops of wire wound around stacks of magnetic steel laminations. These are called field poles & are mounted on the perimeter of the rotor.

The rotor is attached to the turbine shaft & rotates at a fixed speed. When rotor turns, it causes the field poles (electromagnetic) to move past the conductors mounted in the stator. This is turn causes electricity to flow & a voltage to develop at the generation output terminals.

Classification of hydro power:

- ✓ Conventional hydro electric, referring hydroelectric dams
- ✓ Run of the river hydroelectricity, which captures the kinetic energy in rivers or streams without use of dams.
- ✓ Small hydro projects are 10 MW or less & often have no artificial reservoirs.
- ✓ Micro hydro projects a few KW to a few hundred KW isolated homes, villages or small industries.

The power available from falling water can be calculated from the flow rate & density of water, the height of fall & the local acceleration due to gravity.

$$P = \eta \rho Q g h$$

Where, P – Power in Watts

η- dimension less efficiency of the turbine

ρ –density of water in Kg/m^3

Q- Flow in m^3/sec

g- Acceleration due to gravity

h- Height difference between inlet & outlet

WIND ENERGY:

Energy of wind can be economically used for the generation of electricity.

Winds are caused from 2 main factors:

1. Heating & cooling of the atmosphere which generates convection currents. Heating is caused by the absorption of solar energy on the Earth‘s surface & in the atmosphere.
2. The rotation of the Earth with respect to atmosphere & its motion around the sun

- The energy available in the wind over the Earth‘s surface is estimated to be 1.6×10^7 MW

- In India, high wind speeds are obtainable in coastal areas of Saurashtra, Western Rajasthan & some parts of Central India.
- Wind energy which is an indirect source of solar energy conversion can be utilized to run wind mill, which in turn drives a generator to produce electricity.
- The combination of wind turbine & generator is sometimes referred as an *AERO-GENERATOR*.
- A step up transmission is usually required to match the relatively slow speed of the wind rotor to the higher speed of an electric generator.
- Data quoted by some scientists that for India wind speed value lies between 5 Km/hr to 15-20 Km/hr
- Wind forms are operating successfully & have already fed over 150 lakh units of electricity to the respective state grids.
- Wind speed increases with height.

The power in wind:

Wind possesses energy by virtue of its motion. There are 3 factors determine the output from a wind energy converter, 1] the wind speed, 2] The cross section of wind swept by rotor & 3] The overall conversion efficiency of the rotor, transmission system & generator or pump.

- Only 1/3rd amount of air is decelerating by the rotors & 60% of the available energy in wind into mechanical energy.
- Well designed blades will typically extract 70% of the theoretical max, but losses incurred in the gear box, transmission system & generator or pump could decrease overall wind turbine efficiency to 35% or loss.
- The power in the wind can be computed by using the concept of kinetics. The wind mill works on the principle of converting kinetic energy of the wind to mechanical energy.

Kinetic energy = k.E= $\frac{1}{2} mv^2$

But m = ρAv

Available wind Power =$\mathbf{P_a = 1/8\ \rho\pi D^2V^3}$…………Watts

Major factors that have lead to accelerated development of the wind power are as follows:

- Availability of high strength fiber composites for constructing large low-cost rotor blades.
- Falling prices of power electronics
- Variable speed operation of electrical generators to capture maximum energy
- Improved plant operation, pushing the availability up to 95%
- Economy of scale, as the turbines & plants are getting larger in size.

- Accumulated field experience (the learning curve effect) improving the capacity factor.
- Short energy payback (or energy recovery) period of about year,

Power coefficient:

The fraction of the free flow wind power that can be extracted by a rotor is called the power coefficient.

Power coefficient = $\frac{power\ of\ wind\ rotor}{power\ available\ in\ t\ \ e\ wind}$

The max theoretical power coefficient is equal to 16/27or 0.593.

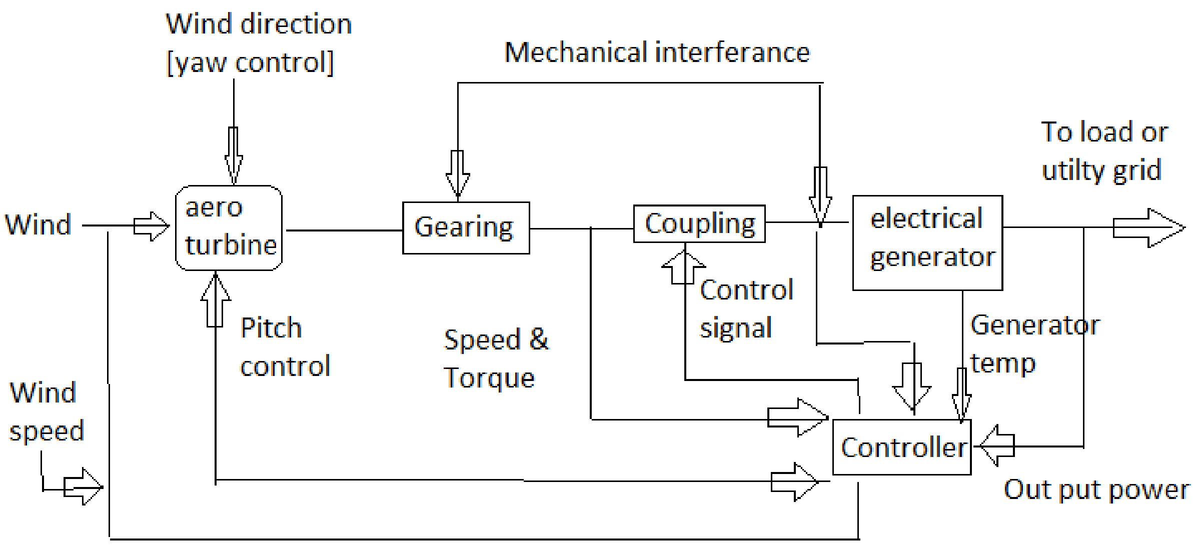


Fig.9.Basic components of wind electric system

Applications:

A] Applications require mechanical power

i] Wind power, ii] Heating, iii] Sea transport

B] As of grid electrical power source

Types of wind turbines:

1] Horizontal axis wind turbines
2] Vertical axis wind turbines

BIO MASS:

- Bio-mass means organic matter.
- *The energy obtained from organic matter, derived from biological organisms (plants & animals)* is known as bio-mass energy.
- The average efficiency of photosynthesis conversion of solar energy into bio mass energy is estimated to be 0.5% - 1.0%.
- To use biomass energy, the initial biomass maybe transformed by chemical or biological processes to produce intermediate bio-fuels such as methane, producer gas, ethanol & charcoal etc.

- ✓ It is estimated that the biomass, which is 90% n tress, is equivalent to the proven current extractable fossil fuel reserves in the world. The dry matter mass of biological material cycling in biosphere is about 250 × 10^9 tons/Y.
- ❖ Animals feed on plants, & plants grow through the photosynthesis process using solar energy. Thus, photosynthesis process is primarily responsible for the generation of bio mass energy.
- ❖ In simplest form the reaction is the process of photosynthesis in the presence of solar radiation, can be represented as follows

$$H_2O + CO_2 \xrightarrow{\text{Solar energy}} CH_2O + O_2$$

- In the reaction, water & carbon dioxide are converted into organic material i.e., CH_2O, which is the basic molecule of forming carbohydrate stable at low temperature, it breaks at high temperature, releasing an amount of heat equal to 112,000 Kcal/mole (469 KJ/mole).
- $CH_2O + O_2 \longrightarrow CO_2 + H_2O + 112$ Kcal/mole

  - ✓ The biomass energy is used directly by burning or is further processed to produce more convenient liquid & gaseous fuels.

Bio-mass resources fall into three categories:
1] bio-mass in its traditional sold mass (wood & agricultural residue), &
2] bio-mass in non-traditional form (converted into liquid fuels)
- o The first category is to burn the bio-mass directly & get the energy.
- o In the second category, the bio-mass is converted into ethanol & methanol to be used as liquid fuels in engines.

3] The 3rd category is to ferment the biomass an aerobically to obtain a gaseous fuel called bio- gas (bio-gas contains 55to 65% Methane, 30-40% CO_2 & rest impurities i.e., H_2, H_2S, & some N_2).

<u>Bio-mass resources include the following</u>:

1] Concentrated waste- - municipal solids, sewage wood products, industrial waste, and manure of large lots.
2] Dispersed waste residue—crop residue, legging residue, disposed manure.
3] Harvested bio-mass, standby bio-mass, bio-mass energy plantation.

ADVANTAGES:

1] It is renewable source.
2] The energy storage is an in-built feature of it.
3] It is an indigenous source requiring little or no foreign exchange.
4] The forestry & agricultural industries that supply feed stocks also provide substantial economic development opportunities in rural areas.

5] The pollutant emissions from combustion of biomass are usually lower than fossil fuels.

DISADVANTAGES:

1] It is dispersed & land intensive source.
2] Low energy density
3] Labour intensive & the cost of collecting large quantities for commercial applications are significant.

Bio-mass conversion technologies:
A] Incineration,
B] Thermo-chemical,
C] Bio-chemical
i] Ethanol fermentation, ii] Anaerobic fermentation.

TIDAL ENERGY:

The tides in the sea are the result of the universal gravitational effect of heavenly bodies like SUN & MOON on the Earth.

- *Periodic rise & fall of the water level of sea* is called TIDE.
- These tides can be used to produce electrical power which is known as tidal power.
- When the water is above the mean sea level called ***flood tide***.
- When the water is below the mean sea level called ***ebb tide***

Basic principal of tidal power:

Tides are produced mainly by the gravitational attraction to the moon & the sun on the water of solid earth & the oceans. About 70% of the tide producing force due to the moon & 30% to the sun. The moon is thus the major factor in the tide formation.

Surface water is pulled away from the earth on the side facing the moon & at the same time the solid earth is pulled away from the water on the opposite side. Thus high tides occur in these two areas with low tides at intermediate points.

As the earth rotates, the position of a given area relative to the moon changes, & so also do the tides.

- The difference between high & low water level is called the range of the tide.

Limitations of tidal energy:

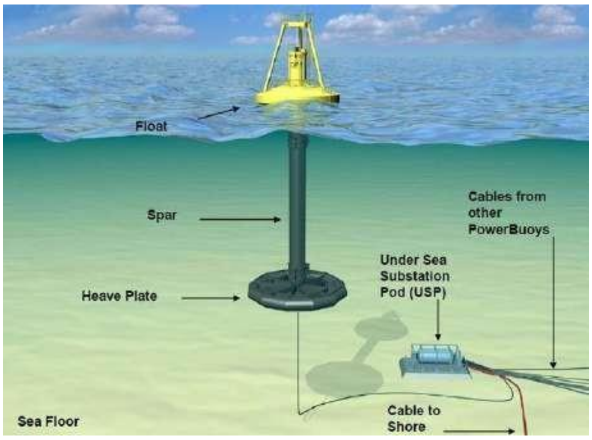
1) Economic recovery of energy from tides is feasible only at those sites where energy is concentrated in the form of tidal range of about 5m or more, & geography provide a favorable site for economic construction of tidal plant, thus it is site specific.
2) Due to mis-match of lunar driven period of 12 hrs 25 min & human (solar) period of 24 hrs, the optimum tidal power generation is not in phase with demand,
3) Changing tidal range in 2 weeks period produces changing power,

4) The turbines are required to operate at variable head.
5) Requirement of large water volume flow at low head necessitates parallel operation of many times &
6) Tidal plant disrupts marine life at the location & can cause potential harm to ecology.

- To hardness the tides, a dam would be built, across the mouth of the bay. It will have large gates in it & also low head hydraulic reversible turbines are installed in it.
  The constructed basin is filled during high tide & emptied during low tide passing thorough sluices turbine respectively.
- By using reversible water turbine, turbine can run continuously, both during high & low tide.
- The turbine is coupled to generator, potential energy of the water stored in the basin as well as energy during high tide, is used to drive the turbine, which is couple d to generator, generate electricity.
- Above arrangement of harnessing tidal energy called *single basin plant*. The plant continues generate power till the tide reaches, its lower level.
- By using bypass valve to drain the remaining basin water to sea.
- Single basin plant cannot generate power continuously.
- The potential in ocean tides resource is estimated as 550 billion KWh/year [120,000 MW power.]

WAVES ENERGY:

- *Waves are caused by the transfer of energy from surface winds to sea*. The rate of energy transfer depends upon the wind speed & the distance over which interacts with water.
- The energy flux in waves is more than that available from solar, wind & other renewable sources. The power in the waves is proportional to the square if its amplitude & to the period of its motion. The energy stored is dissipated through friction at shore & turbulence at rates depending on characteristics of wave & water depth.
- Wave energy in open oceans is likely to be inaccessible. The resource potential near coastlines is estimated as in excess of 20, 00,000 MW. Wave power is usually expressed in KW/m, repressing the rate at which energy is transferred across a line of 1 m length parallel to the wave front.



ADVANTAGES:

- The availability of large energy fluxes
- Productivity of wave conditions over periods of days,

DIFFICULTIES:

- Irregularity of wave patterns in amplitude, phase & direction, which makes it difficult to extract power efficiently
- The power extraction system is exposed to occasional extreme stormy conditions.
- Peak power of deep water waves is available in open sea, where is difficult to construct, operate & maintain a system & transmit power to the store,
- The slow & irregular motion of wave is required to be coupled to be electrical generator requiring high & constant speed motion.

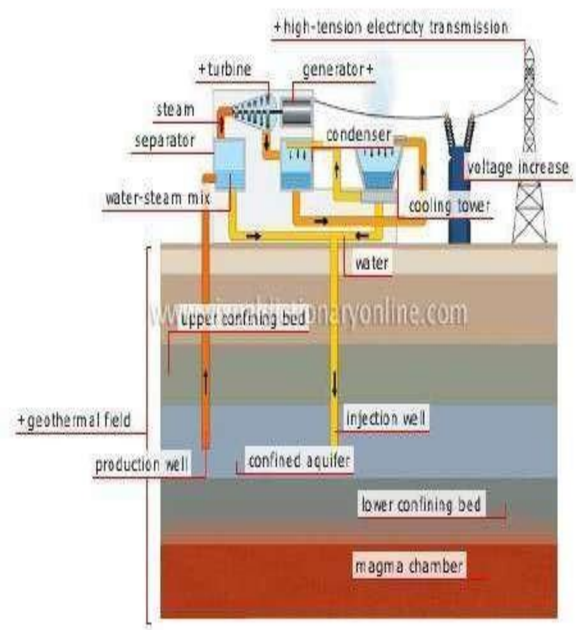
GEOTHERMAL ENERGY:

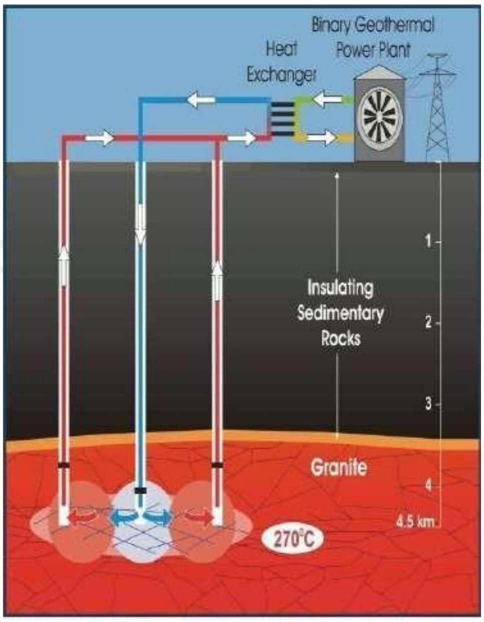
- Geothermal energy is energy coming out of the molten interior (in the form of heat) of the earth towards the surface. Volcanoes, Geysers, Hot springs & boiling mud pots are visible evidence of the great reservoirs of heat that lies within the earth.
- Most Geothermal energy produces low grade heat at about 50-70˚c which can be used directly for thermal applications.
- Occasionally, geothermal heat is available at temperature about 90˚c & so electrical power production from turbines can be contemplated.
- Because of non-homogeneous in the earth crust, there are numerous local hot spots just below the surface where the temperature is in fact much higher than the average value expected. Ground water comes into contact with the hot rocks in some of those locations & as a result, dry steam wet & hot water or hot water alone is formed. A well drilled to these locations causes the steam/water to emerge at the surface where its energy can be utilised either for generating electricity or for space heating.

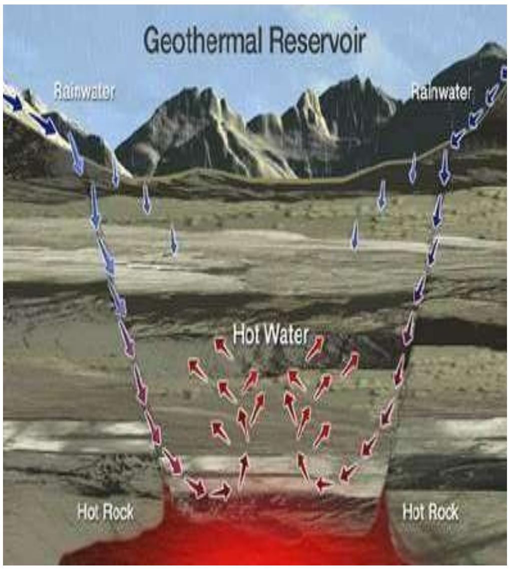
Two ways of electrical power production from geothermal:

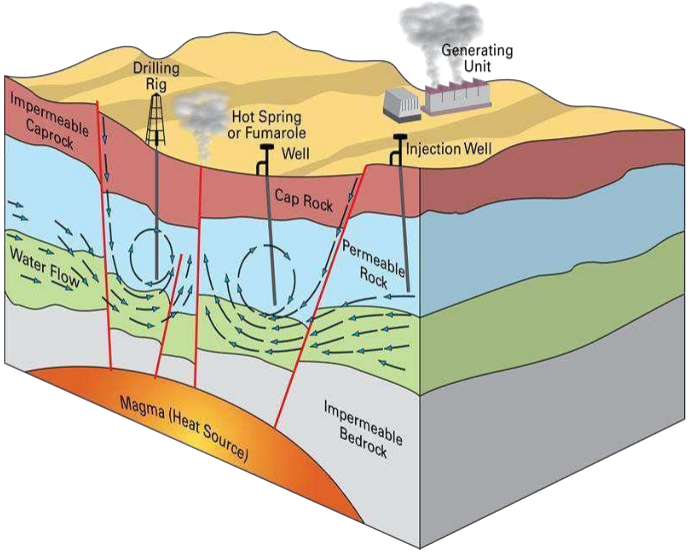
1] Heat energy is transformed to a working fluid which operates the power cycle. This may be particularly useful at a place of fresh volcanic activity. Where the molten interior mass of earth vents to the surface through fissures & substantially at high temperature, such as between 450 to 550 °c can be found. By embedding coil of pipes & sending water through them can be raised.

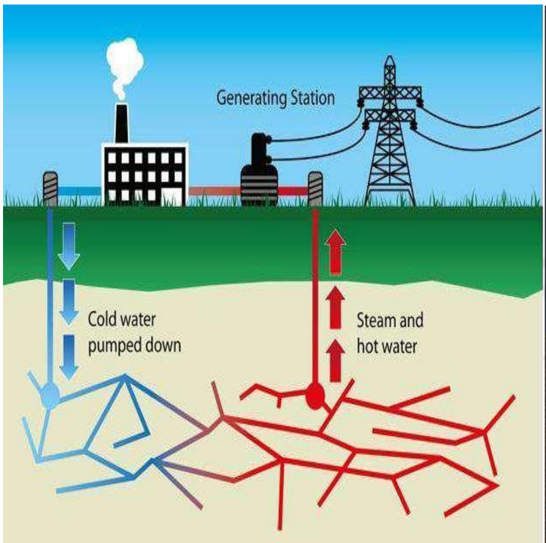
2] Hot geothermal water & or steam is used to operate the turbines directly. From the well head of the steam is transmitted by pipe lines up to 1 m in dia over distance up to about 3 Km to the power station. Water separators are usually required to separate the moisture & solid particles from steam.

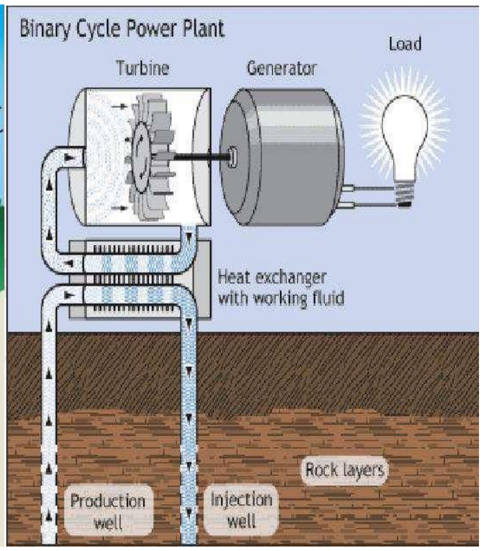












- The earth‘s heat content is about 10^{31} J. This heat naturally flows to the surface by conduction at a rate of 44.2 Tetra watts.
- The heat inside the earth is intense enough to melt rocks. Those molten rocks are called Magma. Because magma is less dense than the rocks so it rises to the surface. Sometimes magma escapes through cracks in the earth‘s crust, empting out of volcanoes as part of lava.
- But most of the time magma stays beneath the surface, heating surrounding rocks & the water that has become trapped within these rocks. Sometimes that water escapes through cracks in the earth to form pools of hot water [hot springs] or burst of hot water & steam [geysers].

The rest of the heated water remains in pools under the earth's surface is called geothermal reservoirs.

Types of geothermal reservoirs:

a] Dry steam power plant, b] Flash steam power plant, c] Binary cycle power plant.

ADVANTAGES:

- ✓ It is reliable source of energy
- ✓ It is available 24 hours/day
- ✓ It is available is independent of weather
- ✓ It has an inherent storage future, so no extra storage facility is required
- ✓ Geo thermal plants require little land area.

DISADVANTAGES:

- Generally, energy is available as low grade heat
- Continuous extraction of heated ground water may leads to subsidence[setting or slumping of land]
- Geo thermal fluid also brings with it the dissolved gases & solute [as high as 25 Kg/m^3] which leads to air & land pollution.
- Drilling operation leads to noise pollution
- Thermal energy cannot be distributed easily over long distances [longer than ~ 30 Km]
- Corrosive & abrasive geo thermal fluid reduces the life of plants.

Applications:

1] Direct heat use, 2] Electric power generation.

TAR SANDS:

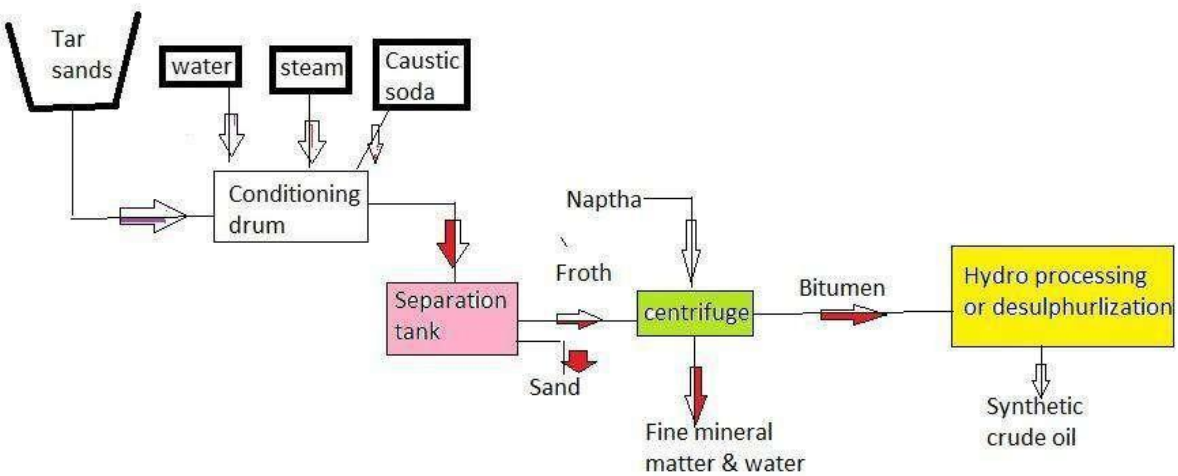


Fig.10.production of synthetic crude oil from tar sands

- Tar sand or oil sands is an expression used to describe porous sandstone deposits impregnated with heavy viscous oils called *bitumen or simply deposits of heavy oils*.
- The above schematic diagram indicating the processes involved in producing synthetic crude oil from tar sands made up of sand stone deposits containing bitumen.
- The sands obtained from surface mining are first passed through a conditioning drum where water, steam & *caustic soda* are added & *slurry* is formed. The slurry passes into a separation tank where the coarse sand settles at the bottom & a froth of bitumen, water & fine mineral matter forms on the top.
- The froth is diluted with *naptha* & subjected to *centrifugal action*. As a result, fine mineral matter & water is removed. After this, the naptha is recovered & recycled, & the bitumen obtained is

subjected to hydro processing & desulphurization to produce synthetic crude oil.

OIL SHALE:

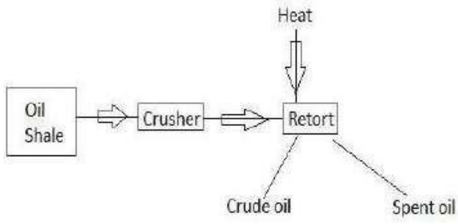


Fig.11.a. Oil shale **Fig.11.b. Production of crude oil from oil shale**

Oil shale [a sedimentary rock] refers to a finely textured rock mixed with a *solid organic material* called *kerogen*. When crushed, it can be burnt directly [like coal] & has a heating value ranging from 2000 to 17,000 KJ/Kg. It is used in this manner for generating electricity & supplying heat.

Alternatively, the oil shale can be converted to oil. This is done by heating crushed oil shale to about 500 ˚c in the absence of air. Under the conditions, *pyrolysis* occurs & the kerogen is converted to oil.

Demerits:

1] The use of oil shale is the environmental degradation associated with surface mining & with the disposal of large amounts of sand & spent shale rock which remains after the crude oil is obtained.
2] A large amount of energy is consumed in producing oil from these sources.

NUCLEAR POWER:

Under the nuclear option, the 2 alternatives under study are, 1] the breeder reactor, 2] nuclear fusion

1] The breeder reactor: In order to understand the working of a breeder reactor, it is necessary to understand the fission reactions. Naturally occurring uranium contains 3 isotopes, U^{234}, U^{235} & U^{238}. The relative % of these isotopes is U^{234} – 0.006%, U^{235}- 0.711% & U^{238} -99.283% of these isotopes, only U^{235} undergoes spontaneous fission when subjected to bombardment by slow neutrons. It is in fact that only naturally occurring fissile material.

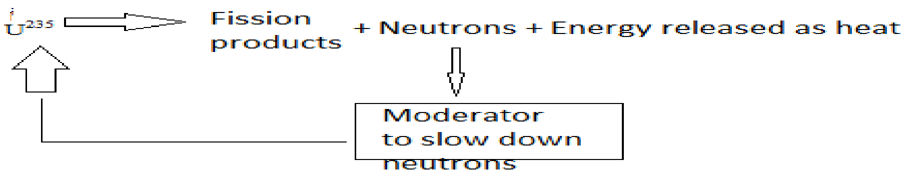


Fig.12. Fission reaction of U^{235}

The break-up of U^{235} when subjected neutrons & the release of a large amount of energy as heat [8.2 $\times 10^7$ KJ/gm of U^{235}]. The neutrons are slowed down by a moderator, & used to bombard the U^{235} nucleus again, there by setting up a controlled chain reaction. Although U^{238} is not a fissile material, it is a fertile material, i.e., it can be converted by neutron bombardment into a fissile material, plutonium-239. Similarly, naturally-occurring thorium-232 is also a fertile material. It can be converted into U^{233} which is a fissile material.

It will be seen that the neutrons generated by the fission reaction serve two purposes. They help in converting a fertile material to a fissile material & also sustain the fission reaction for the fissile material formed. The above reactions are called *breeder reactions* if they produce more fissile material than they consume & the nuclear reactor in which they are caused to occur is called a *breeder reactor*.

Breeding is achieved by having both fissile & fertile materials in the reactor core under conditions which provide enough neutrons to propagate chain reactions in the fissile material as well as to convert more fertile material into fissile material than was originally present.

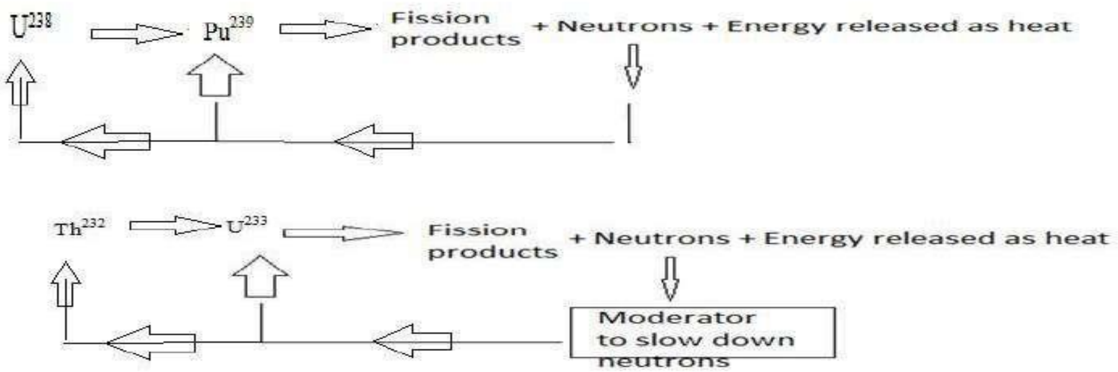


Fig.13. Breeder reactor for U^{238} & Th^{232}

Reactors working on various breeder cycles have been built. However, the major effort has been on liquid-metal cooled, fast breeder reactors working on the U^{238} to Pu^{239} cycle.

NUCLEAR FUSION:

In nuclear fusion, energy is released by joining very light atoms. The reactions of interest involve the fusing of the heavy isotopes of hydrogen [deuterium D & tritium T] into the next heavier element, viz, helium. They are as follows.

$D + D \longrightarrow T + P + 4.0$ MeV……………………………………………………… [1]

$D + D \longrightarrow He^3 + n + 3.2$ MeV……………………………………………………… [2]

$D + T \longrightarrow He^4 + n + 17.6$ MeV……………………………………………………… [3]

$D + He^3 \longrightarrow He^4 + p + 18.3$ MeV……………………………………………… [4]

$6D \longrightarrow 2\ He^4 + 2p + 2n + 43.1$ Me ………….[5]

Equation [1] & [2] show that 2 nuclei of deuterium can fuse in 2 ways. Both ways are equally probable. In the first, tritium & one proton are formed, while in the second, helium-3& one neutron are formed. The energy released by the fusion reaction is indicated. Tritium is unstable & combines with deuterium to form helium-4& one neutron, Equation [3], while helium-3 combines with deuterium to form helium-4& one proton, Equation [4]. The net result Equation [5], is the addition of all the 4 reactions. It indicates that 6 deuterium nuclei are converted to 2 helium-4 nuclei, 2 protons & 2 neutrons with an energy release of 43.1 MeV.

Deuterium occurs naturally in sea water & it is estimated that the fusion of all the deuterium in just one cubic metre of sea water would yield energy of 12×10^9 KJ.

The development of nuclear fusion reactor are the attainment of the required high temperature by initially heating the fuel charge & the confinement of the heated fuel for a long enough time for the reaction to become self-sustaining.

The research being conducted to solve these problems is proceeding broadly along 2 conceptual directions- magnetic confinement & laser induced fusion.

In the first concept, the fuel charge [in the form of a charged particle gas composed of positively charged nuclei & free electrons] is contained in a hermetically sealed vacuum chamber & is heated to the required high temperature by passing an electric current through it. At this temperature, the fusion reaction takes place successfully only if the gas is confined within a certain volume for a specified time & not allowed to come into contact with containing chamber‘s walls. This confinement is achieved by the application of a very strong, specially shaped magnetic field.

In the second concept, the fuel charge in the form of very small pellets. These are positioned one by one at a specific location & subjected to intense focused laser beams which heat the pellets to the required temperature & cause fusion to occur. By adopting this method, the confinement time is substantially reduced & the need for a magnetic field is removed.

Of the reactions given in equation [1] to [4], the D-T reaction takes place at the lowest temperature; about 10^7 K. since tritium does not occur naturally, the D-T reaction should be supplemented by one using lithium as follows:

$D + T \Rightarrow He^4 + n + 17.6$ MeV.. [6]

$N + Li6 \Rightarrow He^4 + T + 4.8$ MeV.. [7]

$D + Li6 \Rightarrow 2\ He^4 + 22.4$ MeV... [8]

Solar Radiation

Solar Radiation Outside The Earth’s Surface:

Sun is a large sphere of very hot gases, the heat being generated by various kinds of fusion reactions. It’s diameter is $1.39X10^6$km, while that of the earth is $1.27X10^4$ km. It subtends an angle of 32minutes at the earth’s surface. This is because it is also at large distance. Thus the beam radiation received from the sun on the earth is almost parallel. The brightness of the sun varies from it’s center to it’s edge. However for engineering calculations. It is customary to assume that the brightness all over the solar disc uniform.

Solar Constant(I_{sc}):

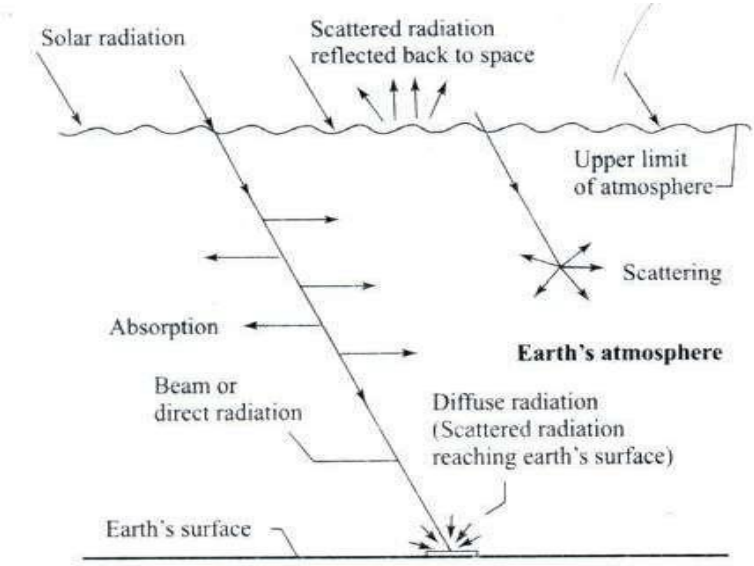
It is the rate at which energy is received from the sun on a unit area perpendicular to the ray’s of the sun , at the mean distance of the earth from the sun. Based on the measurements made up to 1970 a standard value of 1353 W/m^2 was adopted in 1971. However based on subsequent measurements, a revised value of 1367 W/m^2 has been recommended.

The earth revolves around the sun in an elliptical orbit having a very small eccentricity and the sun at the foci. Consequently, the distance between earth and sun varies a little through the year. Because of this variation, the extra terrestrial flux also varies. The value on any day can be calculated from the equation.

$$I'_{sc} = I'_{sc}\left\{I + 0.033\cos\frac{360n}{365}\right\}$$

Solar Radiation Received at the Earth’s surface:

Solar radiation received at the earth’s surface is in the attenuated form because it is subjected to the mechanisms of absorption and scattering as it passes through the earth’s atmosphere (Figure below).



Absorption occurs primarily because of the presence of ozone and water vapour in the atmosphere and lesser extent due to other gases(like CO_2, NO_2, CO,O_2 and CH_4) and particulate matter. It results in an increase in the internal energy of the atmosphere. On the other hand, scattering occurs due to all gaseous molecules as well as particulate matter in the atmosphere. The scattered radiation is redistributed in all directions, some going back to the space and some reaching the earth's surface.

Solar radiation received at the earth's surface without change of direction i.e, in line with the sun is called *direct radiation* or *beam radiation*. The radiation received at the earth's surface from all parts of sky's hemisphere (after being subjected to scattering in the atmosphere) is called *diffuse radiation*. The sum of beam radiation and diffuse radiation is called as *total* or *global radiation*.

Instruments used for measuring solar radiation:

Pyranometer:

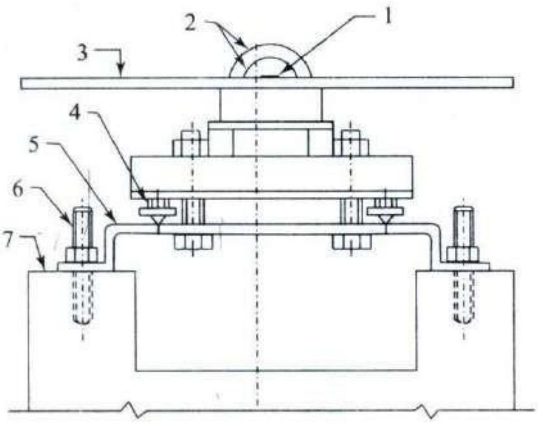
A pyranometer is an instrument which measure's either global or diffuse radiation falling on a horizontal surface over a hemispherical field of view.A sketch of one type of pyranometer as installed for measuring global radiation is shown in the following figure.

1.Black surface, 2. Glass domes ,

3. Guard plate 4. Leveling screws,

5.mounting plate, 6. Grouted bolts,

7.platform.



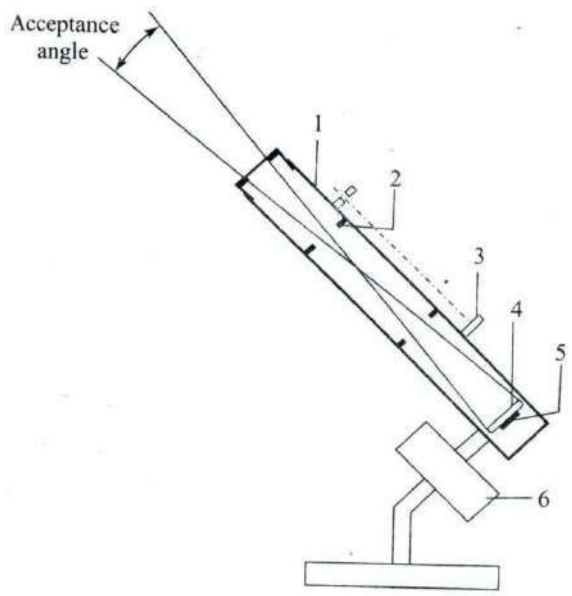
Pyranometer consists of a black surface which heats up when exposed to solar radiation. It's temperature increases until the rate of heat gain by solar radiation equals the rate of heat loss by convection, conduction and radiation. The hot junctions of thermopile are attached to the black surface, while the cold junctions are located under a guard plate so that they do not receive the radiation directly. As a result an emf is generated. This emf which is usually in the range of 0 t0 10mv can be read, recorded or integrated over a period of time and is a measure of global radiation.

The pyranometer can also be used for measurement of diffuse radiation. This is done by mounting it at the center of a semi circular shading ring. The shading ring is fixed in such a way that it's plane is parallel to the plane of path of sun's daily movement across the sky and it shades the thermopile element and two galss domes of pyranometer at all the times from direct sun shine. Consequently the pyranometer measures only the diffuse radiation received from the sky.

Pyrheliometer:

This is an instrument which measures beam radiation falling on a surface normal to the sun's rays. In contrast to a pyranometer, the black absorber plate (with hot junctions of a thermopile attached to it) is located at the base of a collimating tube. The tube is aligned with the direction of the sun's rays with the help of a two-axis tracking mechanism and alignment indicator. Thus the black plate receives only beam radiation and a small amount of diffuse radiation falling within the acceptance angle of the instrument.

The Following figure shows a pyrheliometer.



1. tube blackened on inside surface,

2. baffle, 3.Alignment indicator,

4. Black absorber plate

5.thermopile junctions

6.two-axis tracking mechanism

Solar Radiation Geometry

Definations:

(a) **Solar altitude angle(α)**:
Altitude Angle is the angle between the Sun's rays and projection of the *Sun's rays* on the horizontal plane

(b) **Zenith angle(θ_z):**
It is Complementary angle of Sun's Altitude angle
It is a vertical angle between Sun's rays and line perpendicular to the horizontal plane through the point i.e. angle between the beam and the vertical
$\Theta_z = \pi/2 - \alpha$

(c) **Solar Azimuth Angle(γ_s):**
It is the solar angle in degrees along the horizon east or west of north

or

It is the horizontal angle measured from north to the horizontal projection of sun's rays.

(d) **Declination(δ):**
It is the angle between a line extending from the centre of the Sun and center of the earth and projection of this on earth's equatorial plane.

- Declination is the direct consequence of earth's tilt and It would vary between 23.5^o on June 22 to -23.5^o on December 22. On equinoxes of March21 & Sept22 declination is zero.
- The declination is given by the formula

$$\delta = 23.45\, Sin\left\{\frac{360}{365}(284+n)\right\}$$

Where n is the day of the year

(e) **Meridian:**

Meridian is the immaginery line passing through a point or place on earth and north and south poles of the earth‘.

(f) **hour angle(ω):**

Hour angle is the angle through which the earth must turn to bring meridian of the point directly in line with the sun‘s rays. Hour angle is equal to 15^o per hour.

(g) **slope(β):**

Angle between the collector surface with the horizantal plane is called slope(β).

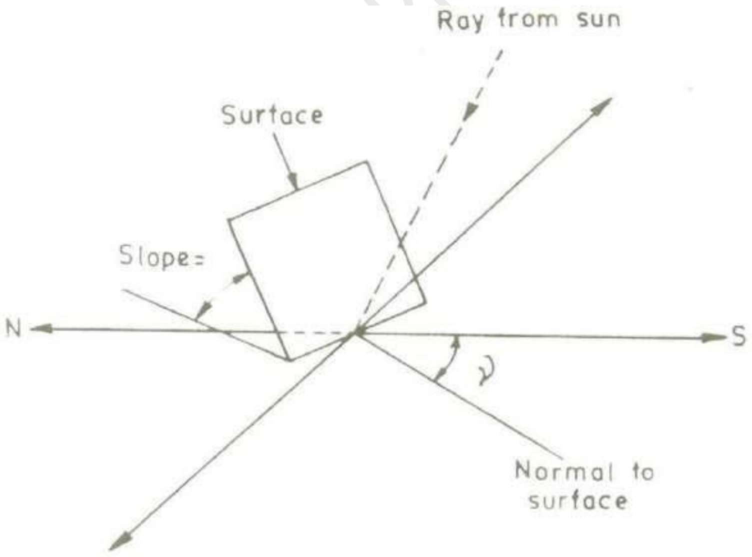
(h) **surface azimuth angle(γ):**

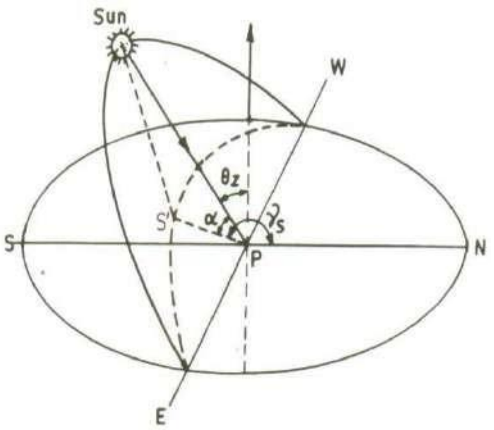
Angle between the normal to the collector and south direction is called surface azimuth angle(γ)

(i) **Solar Incident angle(θ):**

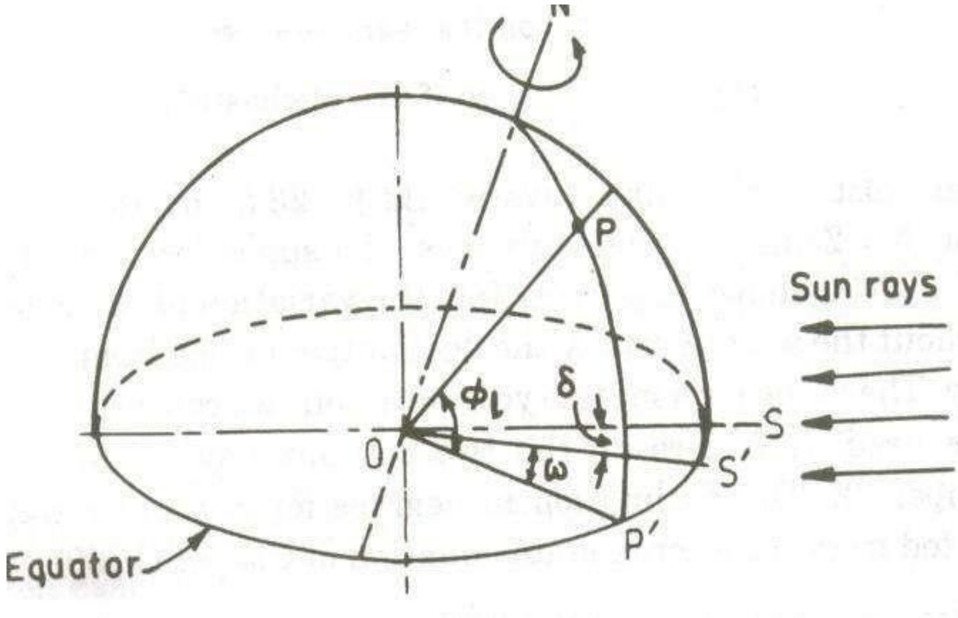
It is the angle between an incident beam radiation falling on the collector and normal to the plane surface

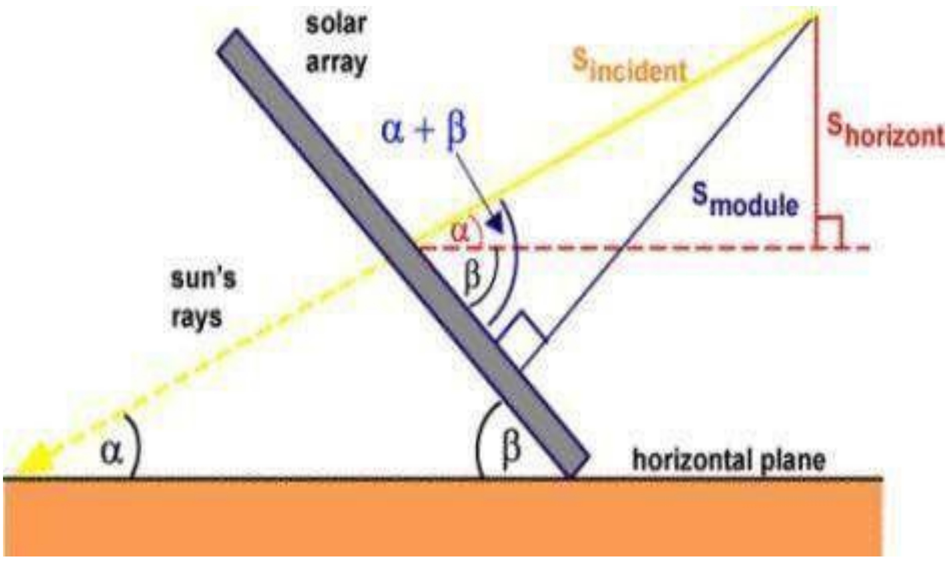
Figures:





he plane surface.





Relation between θ and other angles is as follows

$\cos\theta = \sin\phi_l(\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta) + \cos\phi_l(\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta) + \cos\delta\sin\gamma\sin\omega\sin\beta$----- Eqn(1)

ϕ_l=Latitude(north positive)

δ=declination(north positive)

ω=solar hour angle(Positive between midnight and solar noon)

- Case1

Vertical Surface:

$\beta=90^o$ Eqn (1) becomes

$\cos\theta = \sin\phi\cos\delta\cos\gamma\cos\omega - \cos\phi\sin\delta\cos\gamma + \cos\delta\sin\gamma\sin\omega$ --- Eqn(2)

- Case2

Horizantal surfaces

$\beta=0^o$ Eqn(1) becomes

$\cos\theta = \sin\phi\sin\delta + \cos\delta\cos\phi\cos\omega = \sin\alpha = \cos\theta_z$----- Eqn(3)

- Case3

Surface facing south $\gamma=0$

$\cos\theta_T = \sin\phi(\sin\delta\cos\beta + \cos\delta\cos\omega\sin\beta)$

$= \cos\phi(\cos\delta\cos\omega\cos\beta - \sin\delta\sin\beta)$

$= \sin\delta\sin(\phi-\beta) + \cos\delta\cos\omega\cos(\phi-\beta)$------ Eqn(4)

- Case4

Vertical surfaces facing south($\beta=90^o$, $\gamma=0$)

$\cos\theta_z = \sin\phi\cos\delta\cos\omega - \cos\phi\sin\delta$-------- Eqn(5)

Day Length:

At the time of sunset or sunrise the zenith angle $\theta_z=90^o$, we

obtain sunrise hour angle as

$$\cos\omega s = -\frac{\sin\phi\sin\delta}{\cos\phi\cos\delta} = -\tan\phi\tan\delta$$

$$\omega s = Cos^{-1}\{-\tan\phi \ tan\delta\}$$

Since 15^0 of the hour angle are equivalent to 1 hour

The day length(hrs) is given by

$$td = \frac{2\omega}{15} = \frac{2}{15} cos^{-1} - \{tan\phi \ tan\delta\}$$

Local Solar Time(Local Apparent Time (LAT):

Local Solar Time can be calculated from standard time by applying two corrections. The first correction arises due to the difference in longitude of the location and meridian on which standard time is based. The correction has a magnitude of 4minutes for every degree difference in longitude. Second correction called the equation of time correction is due to the fact that earth‘s orbit and the rate of rotation are subject to small perturbations. This is based on the experimental observations.

Thus,

Local Solar Time=Standard time± 4(Standard time Longitude-Longitude of the location)+(Equation of time correction)

Example 1:

Determine the local solar time and declination at a location latitude $23^0 15'$N, longitude $77^0 30'$E at 12.30 IST on june 19. Equation of Time correction is =

-(1‘01‖).

Solution:

The Local solar time=IST-(standard time longitude-longitude of location)+ Equation of time correction.

$=12^h 30' - 4(82^0 30' - 77^0 30') - 1'01''$

$=12^h 8' 59''$

Declination δ can be calculated Cooper‘s Equation i.e,

$$\delta = 23.45 \ Sin\left\{\frac{360}{365}(284 + n)\right\}$$

$$= 23.45 \sin\{\frac{360}{365}(284 + 170)\} = 23.45 \ \sin 86^0 = 23.43^0$$

Example 2:

Calculate an angle made by beam radiation with normal to a flat plate collector on December 1 at 9.00 A.M, Solar time for a location at $28^0 35'$N. The collector is tilted at an angle of latitude plus 10^0, with the horizontal and is pointing due south.

Solution:

Here γ=0 since collector is pointing due south. For this case we have equation.

$\cos\theta_T$= Sinδ Sin(ϕ-β)+Cosδ cosω Cos(ϕ-β)

Declination δ can be calculated Cooper's Equation on December 1st i.e, n=335

$$\delta = 23.45\ Sin\left\{\frac{360}{365}(284+n)\right\}$$

$$= 23.45 \sin\{\frac{360}{365}(284+335)\} = -22^0 11''$$

Hour angle ω corresponding to 9.00hr=45^0

Hence,

$$\cos\theta_T = \cos(28.58^0 - 38.58^0)\cos(-22.11^0)\cos 45^0 +$$

$$\sin(-22.11^0)\sin(28.58^0 - 38.58^0)=0.7104$$

$\theta_T = 44.72^0$

UNIT-II : SOLAR ENERGY COLLECTION

Beam Radiation:

TILTFACTOR(r_b): The ratio of beam radiation flux falling on the tilted surface to that of horizontal surface is called the *TILT FACTOR* for beam radiation.

For case of tilted surface facing due south γ=0

$$\cos\theta = \sin\delta \sin(\phi - \beta) + \cos\delta \cos\omega \cos(\phi - \beta)$$

while for a horizontal surface

$$\cos\theta_z = \sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega$$

Hence $$r_b = \frac{\cos\theta}{\cos\theta_z} = \frac{\sin\delta \sin(\phi - \beta) + \cos\delta \cos\omega \cos(\phi - \beta)}{\sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega}$$

Diffuse Radiation:

TILT FACTOR (r_d):The ratio of diffuse radiation flux falling on the tilted surface to that of horizontal surface is called the *TILT FACTOR* for diffuse radiation.

Its value depends on the distribution of diffuse radiation over the sky and the portion of the sky dome seen by the tilted surface.

Assuming that the sky is an isotropic source of diffuse radiation, for a tilted surface with slope β, we have

$$r_d = \frac{1 + \cos\beta}{2}$$

(1+ cosβ)/2 is the shape factor for a tilted surface w.r.t. sky

For Total radiation, let H_b=Hourly beam radiation and H_d=Hourly diffuse radiation.

Thus the total beam radiation incident on a tilted surface is given as,

$$H_T = H_b R_b + \frac{Hd(1+\cos S)}{2} \pm \frac{(Hb+Hd)\,(1-\cos S)}{2}\rho$$

ρ = diffuse reflectance which is used to account for the reradiated

Solar collectors:

Solar collectors are the devices used to collect solar radiation. Generally there are two types of solar collectors. They are 1) Non-conventional type or Flat plate collector and 2) Concentrating or Focusing collector.

In a non-concentrating type the area of the absorber is equals the area of the collector and since the radiation is not focused, the maximum temp achieved in this type is about 100° C. on the other hand in a concentrating type the area of the absorber is very small (50-100 times) as compared to the collector area. This results in less loss of heat and also since the radiation is focused to a point or a line the maximum temp achieved is about 350°C.

Principle of solar energy conversion to heat:

The principle on which the solar energy is converted into heat is the ―greenhouse effect‖ . The name is derived from the first application of green houses in which it is possible to grow vegetation in cold climate through the better utilization of the available sunlight. The solar radiation incident on the earth‘s surface at a particular wavelength increases the surface temp of the earth. As a result of difference in temp between the earth‘s surface and the surroundings, the absorbed radiation is reradiated back to the atmosphere with its wavelength increased. The Co2 gas in the atmosphere is transparent to the incoming shorter wavelength solar radiation, while it is opaque to the long wavelength reradiated radiation. As a result of this the long wavelength radiation gets reflected repeatedly between the earth‘s atmosphere and the earth‘s surface resulting in the increase in temp of the earth‘s surface. This is known as the ―Green House Effect‖ . This is the principle by which solar energy is converted to thermal energy using collector.

In a flat plate collector the absorber plate which is a black metal plate absorbs the radiation incident through the glass covers. The temp of the absorber plate increases and it begins to emit radiation of longer wavelength (IR). This long wavelength radiation is blocked from the glass covers which act like the Co2 layer in the atmosphere. This repeated reflection of radiation between the covers and the absorber plate results in the rise of the temp of the absorber plate.

Flat plate collector (FPC):

The schematic diagram of a FPC is as shown in fig. it consists of a casing either made up of wood or plastic having an area of about 2m*1m*15cm. in the casing insulator is provided at the bottom to check conductive heat transfer. Mineral wool, glass wool, fibre glass, asbestos thermocol etc. are used as insulator. Above the insulator the absorber plate is fixed. The absorber plate is made of good conducting material like aluminum or copper. It is coated black to increase its absorption property. Usually the black coating is done by chemical treatment. Selective coatings which allow for maximum absorption of radiation and minimum amount of emission are applied on to the absorber plate. The underside of the plate consists of absorber tubes which run along the length of the plate. These plates are also made of the same material as that of the absorber plate. Sometimes the plate itself is bent into the form of tubes. Through these tubes the heat absorbing medium (water) is circulated. This medium will absorb the heat from the plates and the tubes and its temp increases. This medium will absorb the heat from the plates and the tubes and its tempincreases. This way solar energy is collected as heat energy. Above the absorber plate glass covers are provided.

These glass covers help to bring out the greenhouse effect, thus increasing the η of the collector. More than one cover is used to

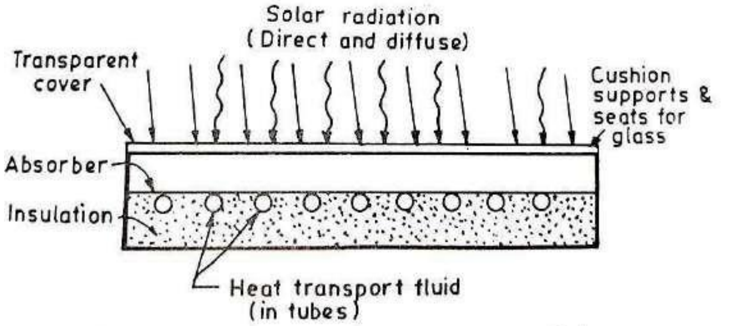


Fig. 3.3.1. Selection through typical flat-plate collector.

prevent the loss of radiation by refraction.

Energy balance equation and collector efficiency: The performance of solar collector is described by an energy balance equation that indicates the distribution of incident solar radiation into the useful energy gain and various losses.

The energy balance equation is given as

$Q_u = A_c$ [HR (τ, α) – U_L $(t_p - t_a)$]

Where Q_u is the useful energy gained by the collector in watts, A_c is the collector area in m^2, HR is the solar energy received on the upper surface of the inclined collector, τ is the fraction of incoming radiation that is transmitted through the cover system and is known as transmissivity, α is the fraction of solar energy reaching the surface that is absorbed and is known as absorptivity. (τ,α) is the effective transmittance and absorptance product of cover system for beam and diffuse radiation. U_L is the overall heat transfer coefficient. It is the rate of heat transfer to the surroundings per sq.meter of exposed collector surface per deg C Difference between average collector surface temp and the surrounding air temp in w/m^2 C.

t_p is the absorber plate temp in °C, t_a is the atmospheric temp in °C.

Thus the total incident radiation on the collector is $Q_T = A_c HR[(\tau,\alpha)]$

The total losses from the collector is $A_c U_{L[}(t_p - t_a)]$

In order to increase the η of the collector Q_u has to be increased. This is done by decreasing the losses as it is not possible to vary the incident radiation.

The losses that occur are

1) **Conduction loss:** This loss is prevented by introducing an insulating material between the absorber plate and the casing where there is contact between the two and also by using a low conducting material like wood or plastic for the casing. Thus the conduction loss is reduced.

2) **Convection loss:** It takes place both from the top and the bottom of the absorber plate. The bottom loss is reduced by providing insulation between the absorber tubes and the base of the casing. The top side loss is prevented by providing glass covers and maintaining the distance between the covers by about 1.25 to 2.5 cm. Also convection loss is prevented by evacuating the top and the bottom side of the absorber plate.
3) **Radiation losses:** It is prevented by applying a selective coating on to the top side of the absorber plate. This coating allows 90% of the radiation to be incident on to the absorber plate while transmissivity of the plate is reduced to only 10%. The usual material used for the coating is ―black chromel‖ . The radiation loss also prevented by treating the underside of the glass covers by coating which are opaque to the reradiated infrared radiations but are transparent to the incident visible radiation. The materials used for this coating are tin oxide or indium oxide.
4) **Reflection and refraction losses:** These losses are prevented by providing more than one glass covers so that the reflected and refracted radiation is incident back on the absorber plate.

Thus the collector efficiency is given as,

$$\eta = \frac{\int Qu\ dt}{\int HR\ dt} = \frac{t\ \ e\ total\ \ useful\ \ eat\ \ gain\ \ in\ t\ \ e\ collector}{t\ e\ total\ incident\ \ radiation\ \ on\ t\ \ e\ collector}$$

<u>Parameters affecting the performance of the FPC:</u>

1) Selective coating
2) No. of covers
3) Spacing between the covers
4) Tilt of the collector
5) Incident radiation
6) Inlet fluid temperature
7) Dust collection on the cover plate

1) **<u>Selective coating:</u>** The η of the collector can be maximized by coating the absorber plate by materials which will absorb maximum amount of radiation but emit minimum amount of radiation. Such a coating is known as selective coating. By applying the selective coating on the absorber plate,

input to the collector is maximized while the loss is minimized by this the η of the collector will improve. The selective coating

Parameter	Non selective absorber $\alpha = \varepsilon = 0.95$	Selective Absorber $\alpha=0.95, \varepsilon = 0.12$	Selective Absorber $\alpha=0.85, \varepsilon = 0.11$
T_{pm} (K)	356.1	359.3	357
U_L (W/m^2K)	3.87	2.56	2.51
Q_U (W)	593.6	682.9	616.1
T_{fo} (K)	341.7	342.95	342
η (%)	43.3	49.8	44.9

Should have maximum absorptivity for a wavelength of less than 4µm, because the incident radiation will be having a wavelength less than 4µm. Similarly the coating should have minimum transmissivity for λ greater than 4µm, because the radiation emitted from the absorber plate will be having a λ of greater than 4µm.

The effect of selective coating on the performance of the collector is studied with the help of following data.

From the above data it is seen that the η of the collector having a non-selective absorber is minimum because of the maximum loss. As the loss increases, the useful heat gain decreases resulting in decreased η. A collector having a selective absorber coating will have less loss and more useful heat gain because of its improved absorptivity and reduced emissivity. As result of this the useful heat gain will increase resulting in the increased η of the collector.

The commercially used selective coating are copper oxide on copper (α=0.89, ε=0.17) nickel black on galvanized iron (α=0.868, ε=0.088).

Desirable properties of selective coatings: The selective coatings should withstand the continuous exposed to high temperature without losing the absorbing and emitting characteristics. These should be less expensive. These coatings should not get corroded or eroded by the atmosphere.

2) **Effect of no. of covers:** The effect of no. of covers is well understood by studying the foll. data

Parameter	No. of covers (1)	No. of covers (2)	No. of covers (3)
$(\tau\alpha)_b$	0.8156	0.7305	0.6447
$(\tau\alpha)_d$	0.7567	0.6424	0.5631
$U_L (W/M^2K)$	6.39	3.87	2.72
η %	40.6	43.9	41.8

Effect of No. of covers on GI absorber with selective coating (α=0.86, ε = 0.11).

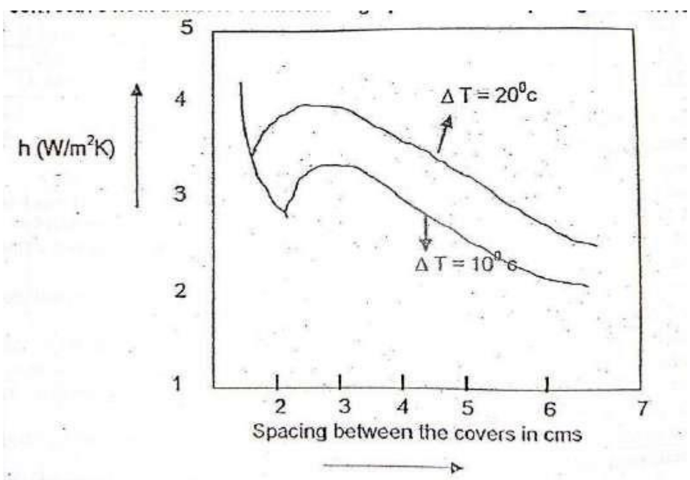
Parameter	No. of covers (1)	No. of covers (2)
$(\tau\alpha)_b$	0.7563	0.6999
$(\tau\alpha)_d$	0.6882	0.5891
$U_L (W/M^2K)$	3.61	2.51
η %	47.0	44.9

In a FPC normally one or two glass covers are used to prevent convective, reflective and refractive losses. The effect of no. of covers on the performance is studied with the help of above data.

From the above data it is seen that for two covers the η will increase while it decreases when a third cover is added. The increase in η is due to the decrease in the overall heat loss coefficient.

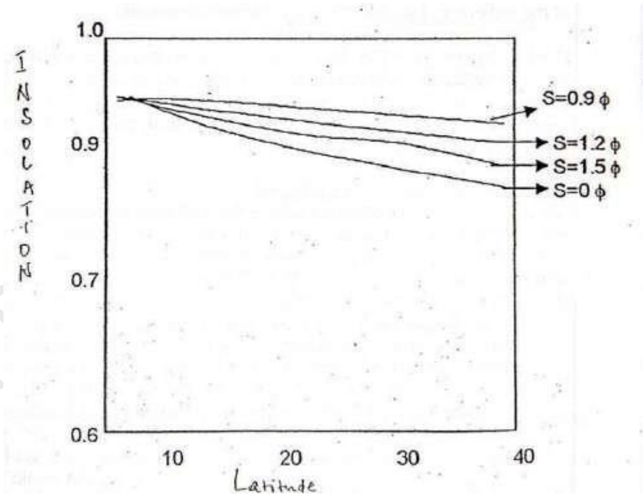
The decrease in η when the third cover is added is due to decrease in (τ α) product which decreases the available incident radiation. This decrease in input affects decrease in loss coefficient resulting in the decreased η. When the selective coating is used with only one cover, the η achieved is maximum. When a second cover is added the (τ α) product decreases resulting in the decrease in input energy thus reducing the η.

3) **Spacing between the covers:** Since convective heat transfer is proportional to the convective heat transfer coefficient, a graph of ‗h' versus the spacing is drawn for two temperature difference of 10 and 20°C as shown in the fig. (The temp difference is between the absorber plate and the ambient air). The objective here is to decrease the heat loss or to decrease the ‗h'-loss.



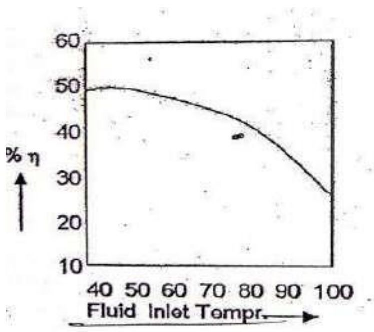
From the graph it is seen that ‗h‘ decreases continuously upto about 2cm spacing and then increases with the spacing, reaches a maximum continuously decreases their after. From the above graph it is observed that minimum value of ‗h‘ is achieved with spacing 0-2cm and 5-7cm. When the spacing 5-7cm is provided it results in shadowing of the absorber plate which in turn reduces the input, hence reducing the η of the collector. Thus the best spacing for minimum heat loss is about 2cm.

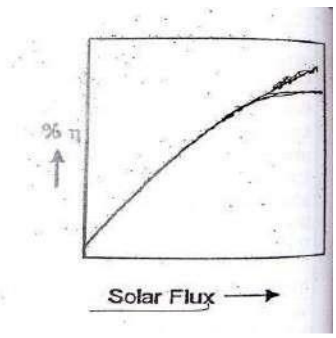
4) **<u>Tilt of the collector:</u>** The collector is tilted in order to improve its η. The η is improved by increase in the amount of solar radiation that is absorbed by the collector. A graph of insolation versus latitude for different tilt angles [S] is as shown in the fig. from the graph it is observed when ‗s‘ is 0.9 times the latitude, the solar insolation absorbed is maximum. Hence the best tilt for maximum η of the collector is equal to the latitude of the place.



5) **<u>Fluid inlet temperature</u>:** The foll. Graph suggests the variation of η wrt inlet fluid temp. From the graph it is observed that the η will decrease with the increase in inlet temp. This is because, as the inlet temp of the fluid increases the loss from the collector increases due to increase in the temp diff between the collector and the atmosphere. This increase in loss decreases the output resulting in reduced η.

6) <u>Incident solar flux:</u> As seen from the graph, the η of the collector increases with the incident flux to certain extent after which the η ceases to increase. This is because at this instant the loss from the collector equals the gain of the collector. Hence η remains constant.





7) <u>Dust on top cover:</u> The dust accumulation on the top cover acts as an insulator for incident radiation. This decreases the η of the collector. In order to take care of this correction factor ranging from 0.92 to 0.99 is used. The selection of which depends on the location, the density of the dust, the collector orientation, cleaning frequency, and the season.

<u>Concentrating collectors:</u> These are the solar collectors where the radiation is focused either to a point (focal point of the collector) or along a line (focal axis of the collector). Since the radiation is focused, the η of concentrating collector is always greater than that of non-focusing or FPC. This is because of the following reasons,

1) In case of focusing collector the area of the absorber is many times smaller than that of the area of the collector. Where as in a non-concentrating type the area of the absorber equals area of the collector. Hence here the loss of absorbed radiation is more compared to the concentrating type.
2) In a concentrating collector since the radiation is focused, its intensity is always greater than that in the non-focusing type. Because of these reasons the concentrating collectors are always used for high temp applications like power generation and industrial process heating.

<u>Classification of concentrating collectors:</u>

- Focusing type
  - Line focusing
    - 1) Parabolic trough collector
    - 2) cylindrical parabolic
    - 3) Mirror strip collector
    - 4) Fresnal lense collector
  - Point focusing
    - 1) Parabolidal collector
    - 2)central tower concept
- Non-focusing type
  - Mirror boosting collector
  - Compound parabolic concentrator

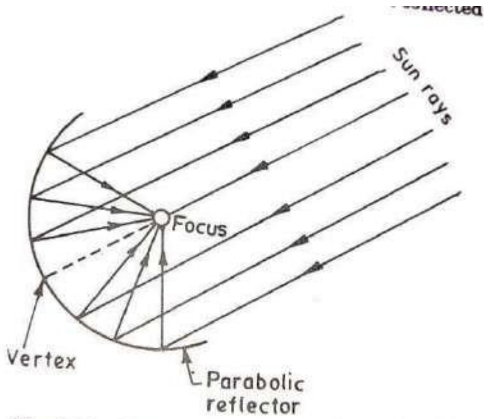
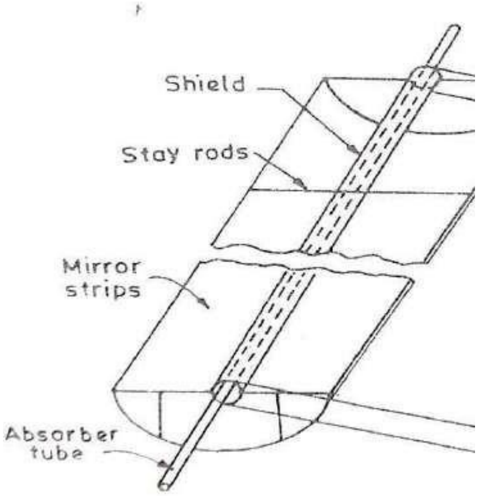


Fig. 3.7.1. Cross-section of parabolic-trough collecto



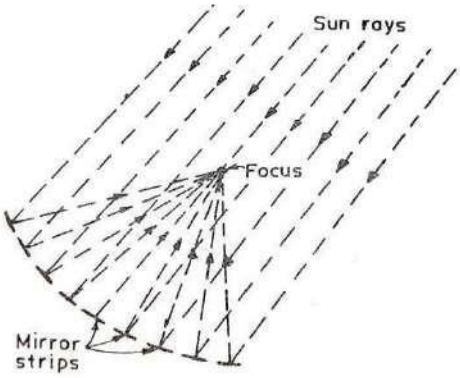
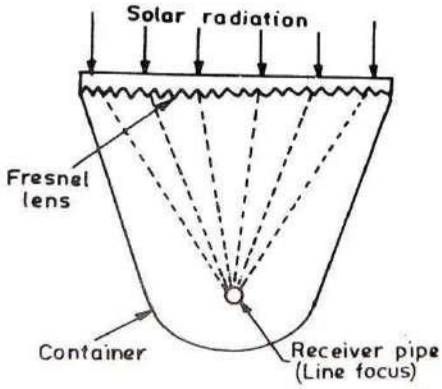


Fig. 3.7.3. Mirror-strip solar collector.



3.7.4. Cross-section of Fresnel lens through collector.

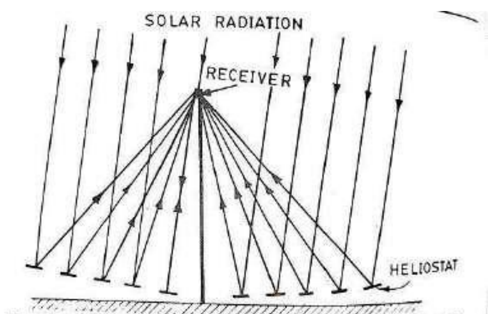


Fig. 5.5.4. Schematic arrangement of central receiver heliostat array.

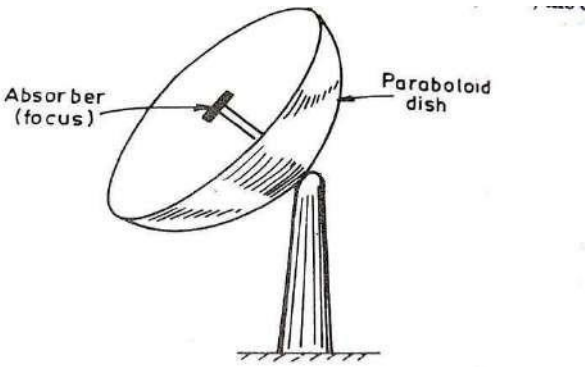


Fig. 3.7.7. Point focus solar collector (Paraboloid).

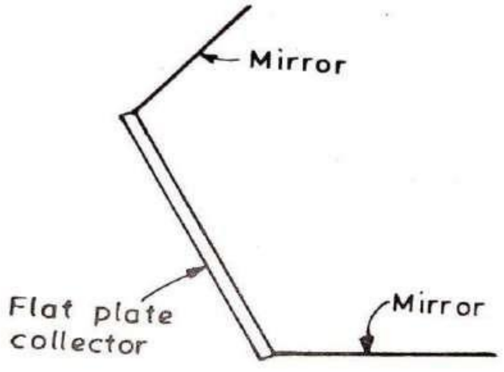


Fig. 3.7.9. Flat-plate collector augmented with mirrors.

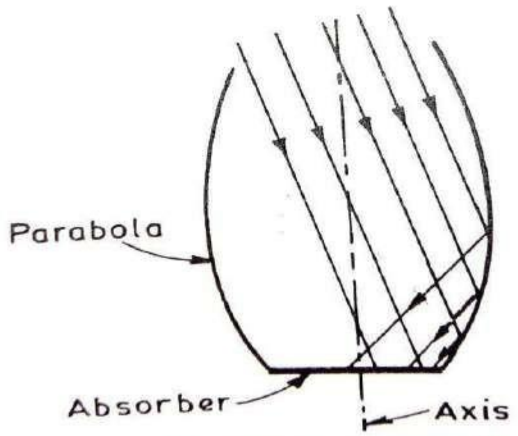


Fig. 3.7.10. Compound parabolic concentrator.

Compound Parabolic Concentrator (CPC):

Compound Parabolic Concentrator consists of two parabolic mirror segments, attached to a flat receiver. The segments are oriented such that the focus of one is located at the bottom end point of the other in contact with the receiver. It has a large acceptance angle and needs to be adjusted intermittently. Rays in the central region of the aperture reach the absorber directly whereas, those near the edges undergo one or more reflections before reaching the absorber. The concentration ratio achieved from this collector is in the range of 3-7.

Cylindrical Parabolic Concentrator:

It consists of a cylindrical parabolic through reflector and a metal tube receiver at its focal line as shown in figure above. The receiver tube is blackened at the outside surface to increase absorption. It is rotated about one axis to track the sun. The heat transfer fluid flows through the receiver tube, carrying the thermal energy to the next stage of the system. This type of collector may be oriented in any one of the three directions: East-West, North-South or polar. The polar configuration intercepts more solar radiation per unit area as compared to other modes and thus gives best performance. The concentration ratio in the range of 5-30 may be achieved from these collectors.

Fixed Mirror Solar Concentrator:

Due to practical difficulty in manufacturing a large mirror in a single piece in cylindrical parabolic shape, long narrow mirror strips are used in this concentrator. The concentrator consists of fixed mirror strips arranged on a circular reference cylinder with a tracking receiver tube as shown in Figure above. The receiver tube is made to rotate about the center of curvature of reflector module to track the sun. The image width at the absorber is ideally the same as the projected width of a mirror element; the concentration ratio is approximately the same as the number of mirror strips.

Linear Fresnel Lens Collector:

In this collector a Fresnel lens, which consists of fine, linear grooves on the surface of refracting material (generally optical quality plastic) on one side and flat on the other side, is used. The angle of each groove is designed to make the optical behavior similar to a spherical lens. The beam radiation, which is incident normally, converges on focal line, where a receiver tube is provided to absorb the radiation. A concentration ratio of 10-30 may be realized which yields temperatures between 150-300^{0}C.

Paraboloidal Dish Collector:

When a parabola is rotated about its optical axis a paraboloidal surface is produced. Above figure shows the details of this type of collector. Beam radiation is focused at a point in the paraboloid. This requires two axis tracking. It can have concentration ratio ranging from 10 to few thousands and can yield temperature up to 3000^{o}C. Paraboloidal dish collectors of 6-7m in diameter are commercially manufactured.

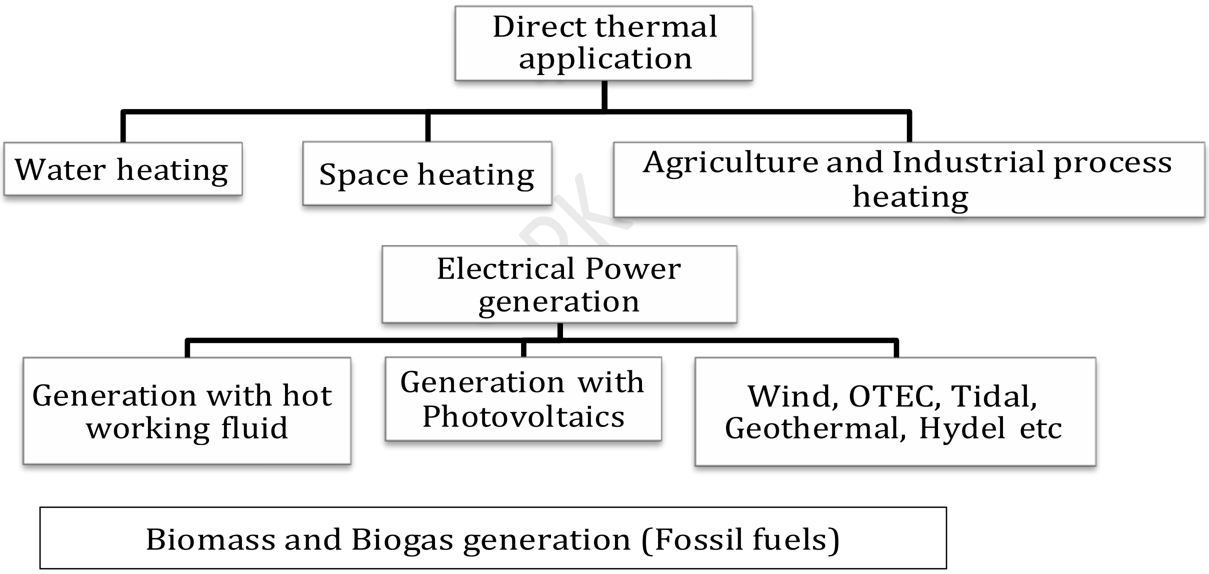
Hemispherical Bowl Mirror Concentrator:

It consists of hemispherical fixed mirror, a tracking absorber and supporting structure, as shown in Figure. All rays entering the hemisphere after reflection cross the paraxial line at some point between the focus and the mirror surface. Therefore, a linear absorber pivoted about the center of curvature of the hemisphere intercepts all reflected rays. The absorber is to be moved so that its axis is always aligned with solar rays passing through the center of the sphere. This requires two-axis tracking. The absorber is either driven around a polar axis at a constant angular speed of 15 degrees/hour or adjusted periodically during the day. This type of concentrator gives lesser concentration, owing to spherical aberration, than that obtained in paraboloidal concentrator.

Central Tower Receiver:

In central tower receiver collector, the receiver is located at the top of a tower. Beam radiation is reflected on it from a large number of independently controlled; almost flat mirrors, known as heliostats, spread over a large area on the ground, surrounding the tower. Thousands of such heliostats track the sun to direct the beam radiation on the receiver from all sides. The heliostats, together act like a dilute paraboloid of very big size. Concentration ratio of as high value as 3,000 can be obtained. The absorbed energy can be extracted from the receiver and delivered at a temperature and pressure suitable for driving turbines for power generation. The schematic view of central tower receiver is shown in figure above.

Applications of solar Energy:



Thermal applications:

1) Water heating
2) Space heating or cooling
3) Process heating
4) Refrigeration
5) Distillation
6) Furnace heating
7) Electric power generation
8) Cooking
9) Pumping

WATER HEATING SOLAR SYSTEM

NATURAL CIRCULATION SOLAR WATER HEATER (PRESSURIZED):

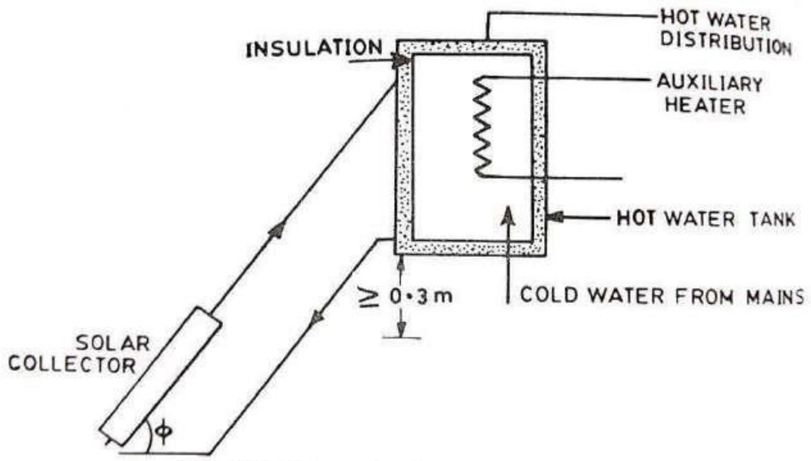


Fig. 5.2.1. Schematic of a neutral circulation solar water heater (pressurized).

A natural circulation system is shown in Fig. 5.2.1. It consists of a titled collector with transparent cover glasses, a separate highly insulated water storage tank, and well insulated pipes connecting the two. The bottom of the tank is at least 1ft the top of the collector, and no auxiliary energy is required to circulate water through it. The density difference between the hot and cold water thus provides the driving force for the circulation of water through the collector and the storage tank. Hot water is drawn off from the top of the tank as required and is replaced by cold water from the service system. As long as the sun shines the water will quietly circulate, getting warmer. After sunset, a thermosiphon system can reverse its flow direction and loss heat to the environment during the night. The thermosiphon system is one of the least expensive solar hot-water systems and should be used whenever possible.

Thermosiphon solar water heaters are passive systems and do not require a mechanical pump to circulate the water. Such heaters can be used extensively in rural areas, where electricity is expensive and there is little danger of freezing.

NATURAL CIRCULATION SOLAR WATER HEATER (NON-PRESSURIZED):

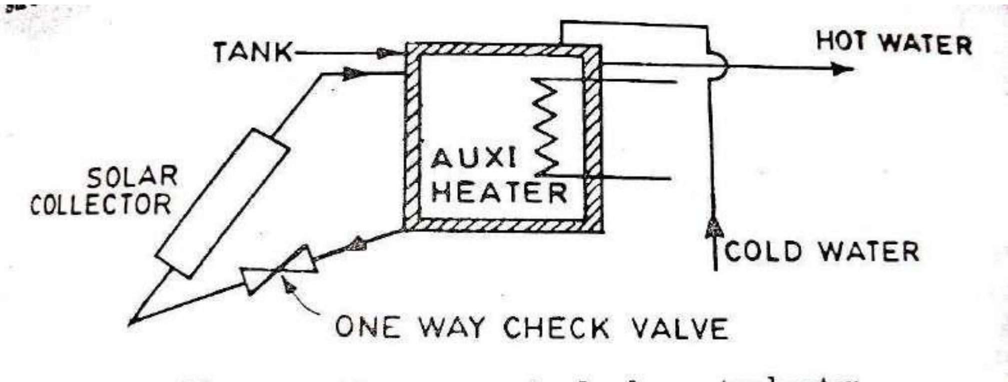


Fig. 5.2.2. Non-pressurized solar water heater.

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. The non-pressurized systems supply hot water by gravity flow only to users lower than tank. If pressurized hot water is required (for showers, or appliances) the difference in height will have to be large enough to meet the requirements. If the height of difference cannot be accommodated, the only solution is to install a separate pump and pressure tank. The stresses within non-pressurized system are lower which allows cheaper and easier construction. In this type also mechanical pump is not required as shown in Fig.5.2.2, however, a oneway check valve may be desirable to prevent reverse circulation and thus loss of heat at night. A typical system for domestic water heating is shown in Fig.5.2.3.

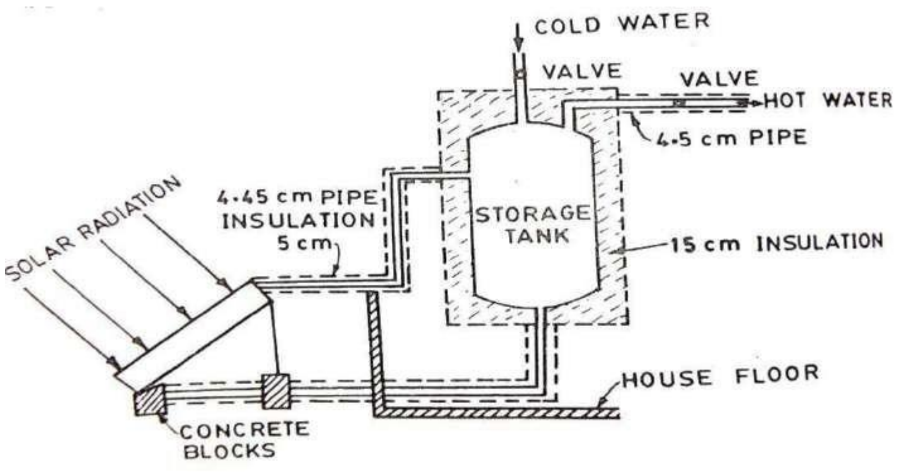


Fig. 5.2.3. A typical solar water heater.

FORCED CIRCULATION SOLAR WATER HEATER (WITHOUT ANTIFREEZE):

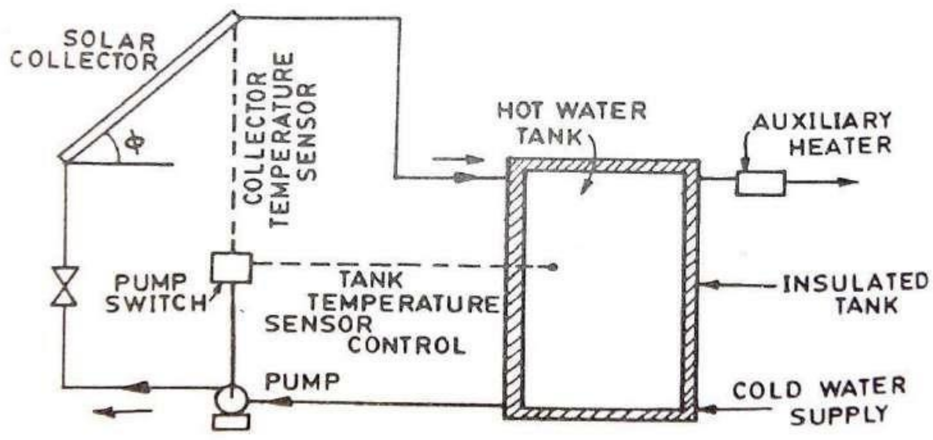


Fig. 5.2.4. Schematic of a forced circulation solar water heater.

Fig.5.2.4 shows schematically an example of forced circulation system. By including an electric pump in the return circuit between the bottom of the storage tank and the lower header of the collector, the tank can be placed at a more convenient level (e.g. in the house basement). This is now an active system. A control unit permits the pump to operate only when the temperature of the water at the bottom of the tank is below that of the water in the upper header.

A check valve is needed to prevent reverse circulation and resultant night time thermal losses from the collector. In this example, auxiliary heater is shown as provided to the water leaving the tank and going to the load.

When there is a danger of freezing, the water may be drained from the collector; alternately, a slow reverse flow of the warmer water may be permitted through the collector on cold nights. The freezing danger can be overcome, although at some increase in cost, by using an antifreeze solution as the heat-transport medium, as described earlier. The heat is then transferred to water in the storage tank by way of a heat exchanger coil.

FORCED CIRCULATION SOLAR WATER HEATER (WITH ANTIFREEZE):

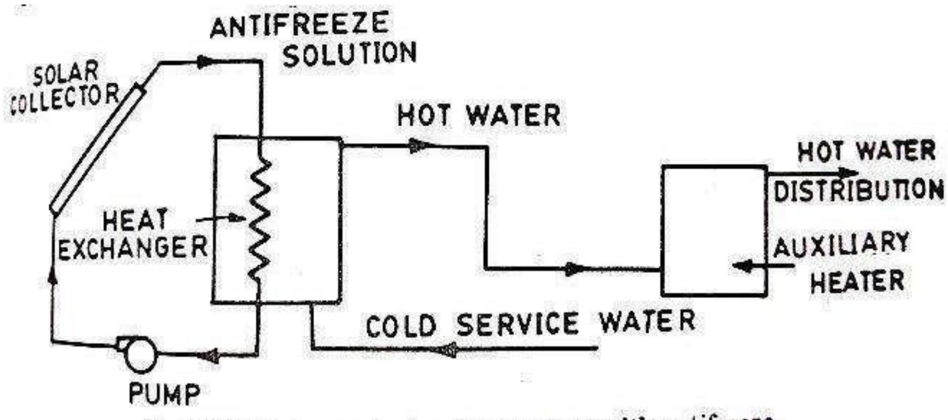


Fig. 5.2.5. Solar water heating system with antifreeze.

SPACE-HEATING:

SOLAR HEATING OF BUILDING:

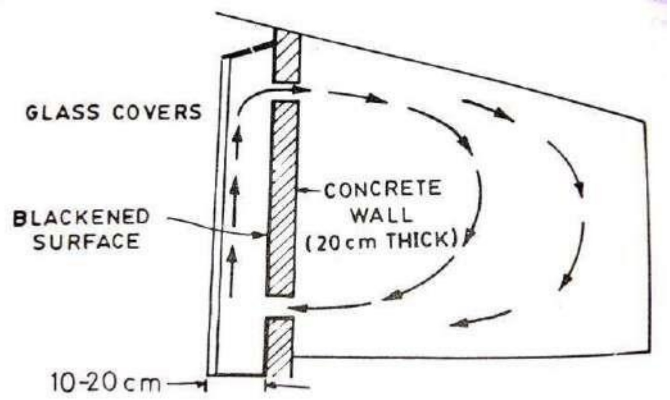


Fig. 5.3.1. A passive solar heating system.

A sunspace is any enclosed space, such as a green house or sun porch, with a glass wall on the south side. A sunspace may be attached (or built on) to a thick south wall of the building to be heated by the sun. Vents near the top and bottom of the wall, as in Fig. 5.3.1, permit circulation through the main building of the heated in the sunspace. Heat storage is provided by the thick wall, a concrete or masonry floor, water containers, and other materials in the sunspace. Thus, an attached sunspace system combines features of direct gain and storage wall concepts.

ROOF STORAGE OF SOLAR HEAT:

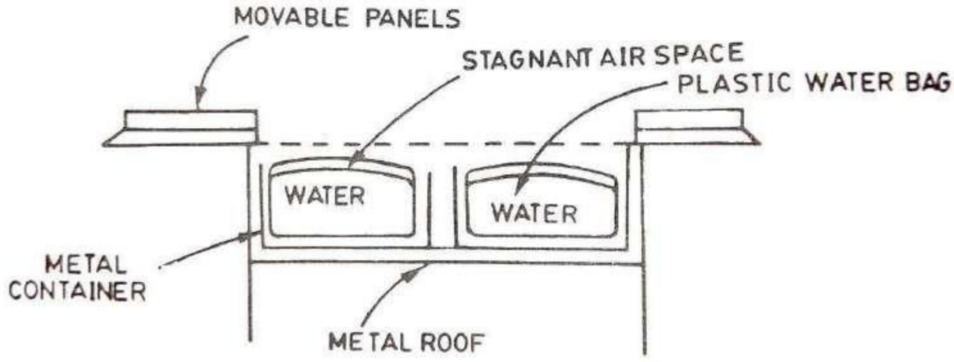


Fig. 5.3.2. Roof storage of Solar heat.

A passive solar system, trade named sky therm, was designed for house having a flat roof located in a mild climate. The heat is absorbed and stored in water about 0.25 m deep contained in plastic bags held in blackened steel boxes on the house roof. In a later design, a layer of clear plastic sealed to the top of the bag provides a stagnant airspace to reduce heat losses to the atmosphere. Heat is transferred from the heated water to the rooms below by conduction through a metal ceiling. Air circulation may be aided by means of electric fans, but this is not essential. To prevent loss of heat during the night, thermal insulator panels are moved, either manually or by a time controlled electric motor, to cover the water bags. In the day time, the panels, which are in sections, are removed and stacked one above the other.

CONVECTIVE LOOP PASSIVE SOLAR HEATING:

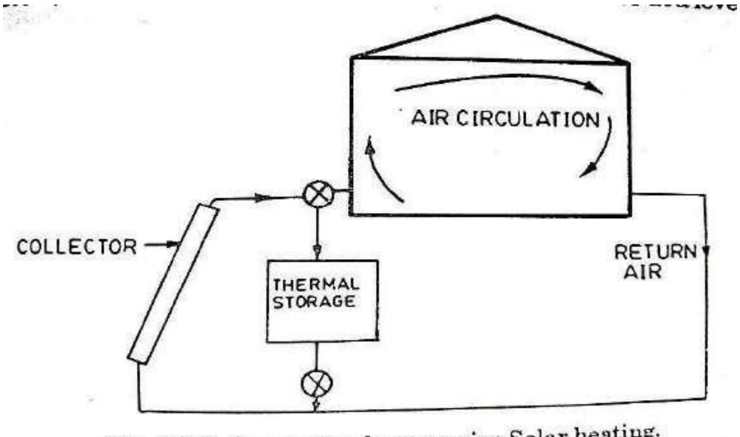


Fig. 5.3.3. Convective loop passive Solar heating.

In most passive solar space heating systems, the heated air is circulated by convection, but the term convective loop is applied to systems that resemble the thermosiphon hot-water scheme described earlier. Such a convective loop heating system is outlined in Fig.5.3.3. It includes a convectional flat-plate collector at a level below that of the main structure. A bed of rock, which may be located beneath a sunspace, provides thermal storage. In normal operation, air passing upward through the collector is heated and enters the building through floor vents. The cool, denser air leaving the building returns to the bottom of the collector and is reheated. If more solar heat is available than is required for space heating, the floor vents may be partly closed. The heated air then flows through and deposits heat in the storage bed. Heat stored in this way may be used later, as needed, by transfer to the cooler air leaving the building.

BASIC HOT WATER ACTIVE SYSTEM:

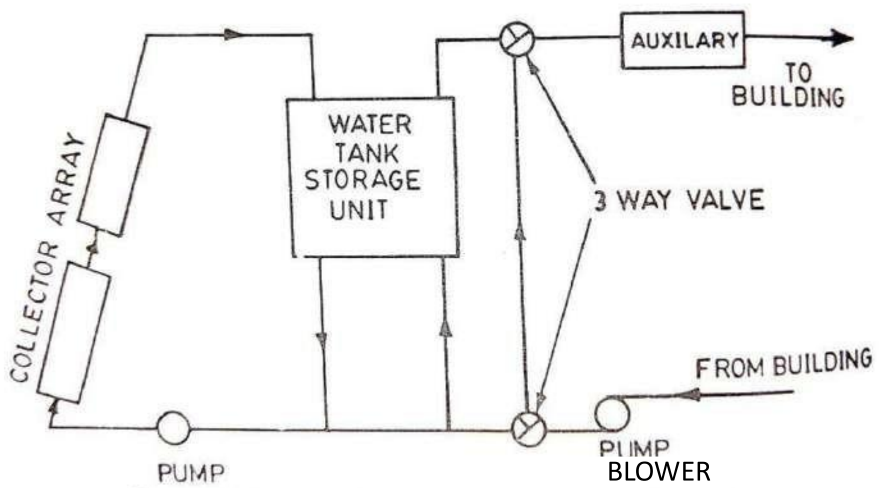


Fig. 5.3.4. Schematic of a basic hot water active system.

An outline of an active heating system with a sloping flat plate collected located on the roof of the building is given in Fig.5.3.4. This is a basic hot water heating system, with water tank storage and auxiliary energy source. Heat is transferred to the water in the storage tank, commonly located in the basement of the building. The solar heated water from the tank passes through an auxiliary heater, which comes on automatically when the water temperature falls below a prescribed level. For space heating, the water may be pumped through radiators or it may be used to heat air in a water to air heat exchanger.

During normal operation, the three way valves are set to permit solar heated water to flow from the storage tank and auxiliary heater to the distribution system and back to the tank. If after several cloudy days, the heat in storage is depleted, the valves will adjust automatically to bypass the storage tank. In this way, auxiliary heating of the large volume of water in the tank is prevented. If the temperature in the heater at the top of the collector should fall below that at the bottom of the tank, the pump would be switched off automatically.

If in this system, the heat transport medium is an antifreeze solution, then there is a closed circuit of it, with the heat exchanger coil in the storage tank. This type of solar space heating system with hot water system is shown in Fig.5.3.5.

BASIC HOT WATER ACTIVE SYSTEM (WITH ANTIFREEZE):

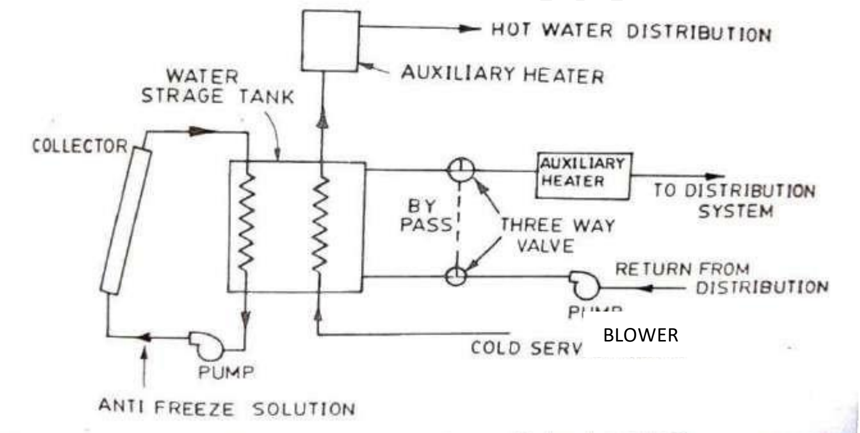


Fig. 5.3.5. Solar space heating and hot water system.

Advantages and disadvantages of basic hot water system are listed below:

Advantages:

i. In case of water heating, a common heat transfer and storage medium, water is used, this avoids temperature drop during transfer of energy into and out of the storage.

ii. It requires relatively smaller storage volume.

iii. It can be easily adopted to supply of energy to absorption air conditioners, and

iv. Relatively low energy requirements for pumping of the heat transfer fluid.

Disadvantages:

i. Solar water heating system will probably operate at lower water temperature than conventional water systems and thus require additional heat transfer area or equivalent means to transfer heat into building.

ii. Water heaters may also operate at excessively high temperature (particularly in spring and fall) and means must be provided to remove energy and avoid boiling and pressure build up.

iii. Collector storage has to be designed for overheating during the period of no energy level.

iv. Care has to be taken to avoid corrosion problems.

<u>BASIC HOT AIR SYSTEM:</u>

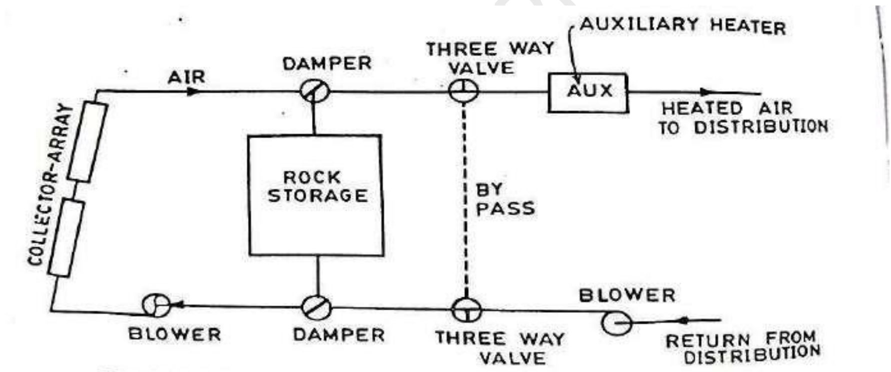


Fig. 5.3.6. Schematic diagram of a basic hot air heating system.

Schematic diagram of a basic hot air heating system is shown in Fig.5.3.6. In this system the storage medium is held in the storage unit, while air is the fluid used to transport energy from collector to the storage and to the building. By adjusting the dampers, the heated air from the collector can be divided between rock storage and the distribution system, as might be required by the conditions. For example, when the sun shines after several cloudy days it would be desirable to utilize the available heat directly in the distribution system rather than placing it in storage. Two three way valves can be used to bypass the storage tank, as explained above. An auxiliary source of heating is also provided. Auxiliary heating can be used to augment the energy supply to the building from the collector or storage if the supply of heat from it is inadequate.

The position of the blower in figure is shown at the upstream of the collector and the storage, and it forces the air through these for heating. In this case slight leakage of heated air will take place. Blower can also be placed on the downstream side of the collector and storage, so that the pressure in the collector is not above ambient pressure, which might be advantageous in controlling leakage.

<u>SOLAR SPACE COOLING OF BUILDINGS:VAPOUR ABSORPTION AIR COOLING (LiBr-H2O SYSTEM85 to 95°C with FPC /NH3-H2O COOLER 120 to 130°C with concentrating collectors):</u>

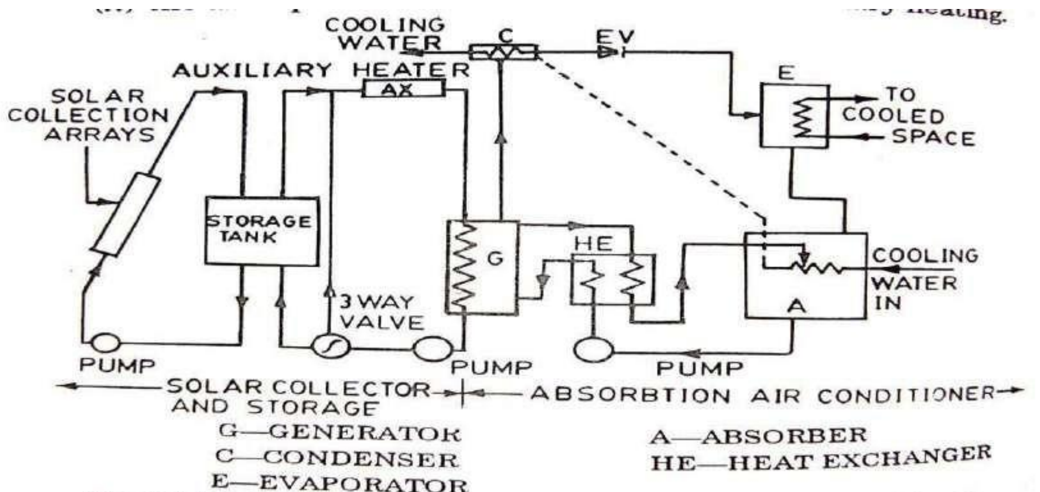


Fig. 5.4.1. Schamatic of Solar Operated Absorption Air Conditioner.

The absorption air conditioning system is shown schematically in Fig.5.4.1. The system consists of two parts

(i) The solar collector and storage, and
(ii) The absorption air conditioner and the auxiliary heating.

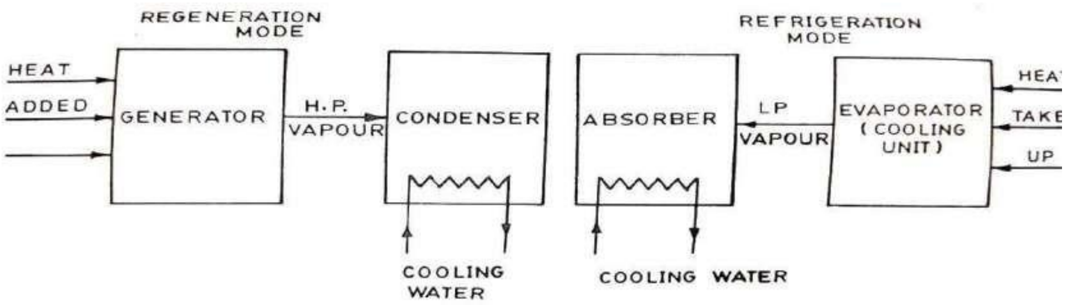
The essential components of the cooler are (i) generator (G), (ii) condenser (C), (iii) evaporator (E), (iv) absorber (A), (v) heat-exchanger (HE).

The operation of air conditioners with energy from flat-plate collector and storage systems is the most common approach to the solar cooling today. In essence cooling is accomplished as the generator of the absorption cooler is supplied with heat by a fluid pumped from the collector storage system or from auxiliary. Heat is supplied to a solution of refrigerant in absorbent in the generator, where refrigerant is distilled out of the absorbent fluid. The refrigerant is condensed and goes through a pressure reducing valve to the evaporator where it operates and cools air or water for the cooling space. The refrigerant vapor goes to the absorber where it comes in contact with the solution which is weak in refrigerant and which flows from the generator. The vapor is absorbed in the solution, which is then returned to the generator. A heat exchanger is used for sensible heat recovery and greatly improves cooler C.O.P.

From the point of view of use of a conventional energy source, there is a single index of performance for rating cooling processes, that is the COP, the ratio of the amount of cooling to the energy required. For solar operation there are two additional factors, the temperature required in the solar collector to drive the process and the ratio of cooling produced to solar energy incident on the collector. As solar processes are inevitably transient in their operation, the energy ratios and temperatures will vary with time and COP based on long term integrated performance provides an appropriate index of performance. Pumping to more absorbent solution may be by mechanical means or by vapor-lift pumping in the generator for low pressure systems like LiBr-H_2O system require water cooling of absorber and condenser. Systems of this type shown in the figure have been the basis of most of the experience to date with solar air conditioning.

The coolers used in most experiments todate are LiBr-H_2O machines water-cooled absorber and condenser. The pressure in the condenser and generator is fixed largely by temperature drops across heat transfer surfaces in the generator and condenser. The pressure in the evaporator and absorber is fixed by the temperature of the cooling fluid to the absorber and by the temperature drop across the heat transfer surfaces in the evaporator and the absorber. Thus, to keep the generator temperatures within the limits imposed by the characteristics of flat-plate collector, the critical design factors and operational parameters include effectiveness of the heat exchangers and coolant temperature. Common practice in solar experiments has been to use water cooled absorbers and condensers, which in turn requires a cooling tower.

INTERMITTENT ABSORPTION COOLING:



A modified method for absorption cooling which operates intermittently rather than continuously is based on the following principle. In it, the system consists of two vessels which function in two alternative modes. In one mode, one of the vessels is the generator and the other is the condenser of an absorption system. During this phase, heat is supplied to the generator by oil, gas, steam or solar energy. In the alternative mode, the first vessel becomes the absorber and the other the evaporator. During this phase refrigeration occurs. The system operates in the regeneration mode for a few hours and is then changed to the refrigeration mode, and so on. This technique can also be used for food preservation in rural areas, where electric power is not readily available.

In the refrigeration mode, heat is supplied to a dilute solution of lithium bromide in water contained in the generator unit. Water vapor at a moderately high pressure passes to the condenser unit and is condensed by cooling water. When sufficient liquid water has collected in the condenser, the heat supply and cooling water are shut off and the refrigeration mode becomes operative. The lithium bromide solution in the absorber unit is cooled so that its vapour pressure is lowered. This causes the water in the evaporator to vaporize, and as a result cooling occurs. The relatively low pressure water vapour is then absorbed by the solution in the absorber unit. After some time, the initial conditions are restored, and the system reverts to the regeneration mode.

The other refrigerant absorbent combinations used in this system are ammonia water (NH_3-H_2O) and ammonia-sodium thiocynanate (NH_3-NasCN).

SOLAR THERMAL ELECTRIC CONVERSION:

SOLAR POND:

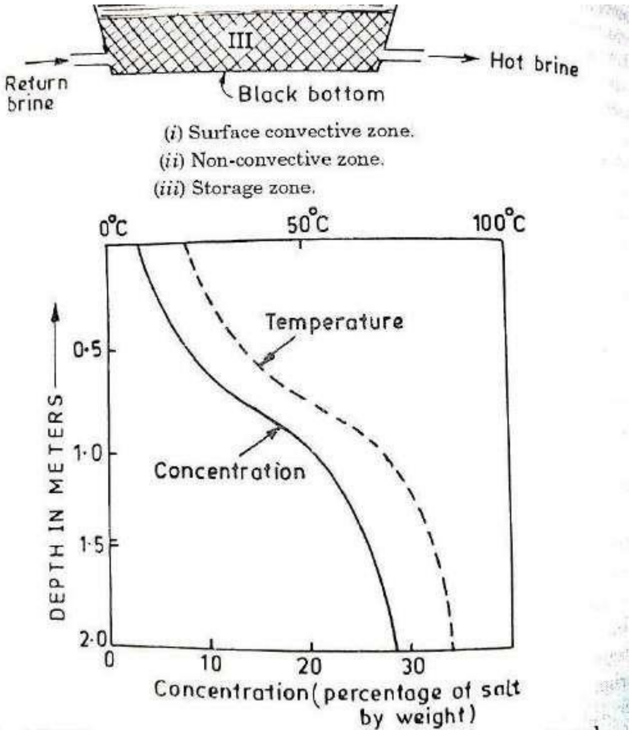


Fig. 4.3.2. Temperature and concentration profile for a typical pond.

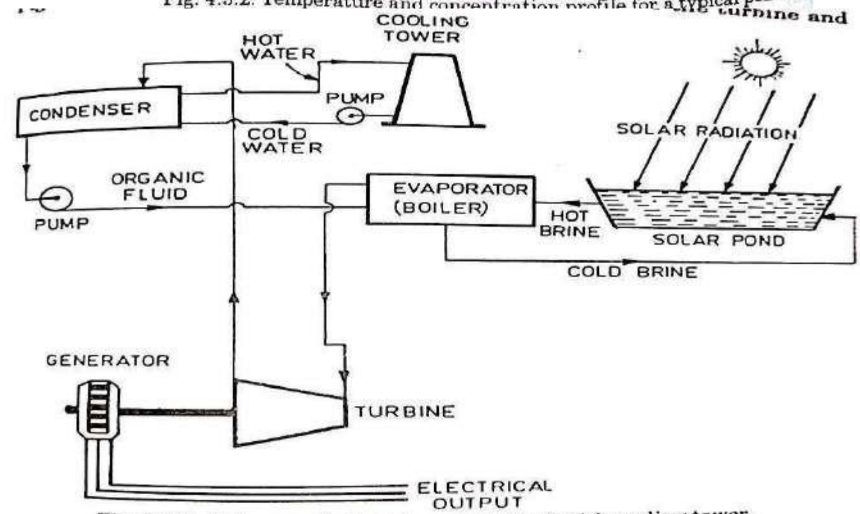


Fig. 4.3.3. Solar pond electric power plant with cooling tower.

A solar pond is a mass of shallow water about 1 or 2 metres 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 the remainder which penetrates the pond is absorbed at the black bottom. If the pond were initially filled with fresh water, the lower layers would heat up, expand and rise to the surface. Because of the convective mixing and heat loss at the surface, only a small temperature rise in the pond could be realized. On the other hand, convection can be eliminated by initially creating a sufficiently strong salt concentration gradient. In this case, thermal expansion in the hotter lower layers is insufficient to destabilize the pond. With convection suppressed, the heat is lost from the lower layers only by conduction. Because of the relatively low conductivity, the water acts as an insulator and permits high temperature (over 90°C) to develop in the bottom layers. At the bottom of the pond, a thick durable plastic liner is laid. Materials used for the liner include butyl rubber, black polyethylene and hypalon reinforced with nylon mesh. Salts like magnesium chloride, sodium chloride or sodium nitrate are dissolved in the water, the concentration varying from 20 to 30 percent at the bottom to almost zero at the top.

Solar Chimney Power Plant:

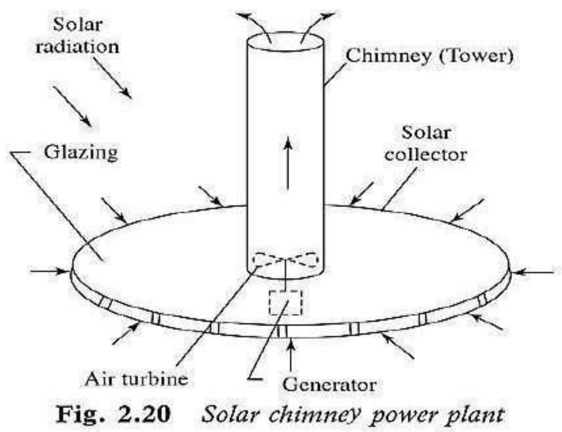


Fig. 2.20 *Solar chimney power plant*

Solar chimney is much simpler but works with much lower efficiency as compared to central tower receiver power plant. The circular field of heliostats is replaced by a circular area of land covered with glazing. The central receiver tower is replaced by a tall chimney that houses a wind turbine. The air under the glazing is heated by solar energy and drawn up through the chimney driving the turbine coupled with a generator.

<u>LOW-TEMPERATURE SOLAR POWER PLANT (Max 100°C by FPC and solar pond)):</u>

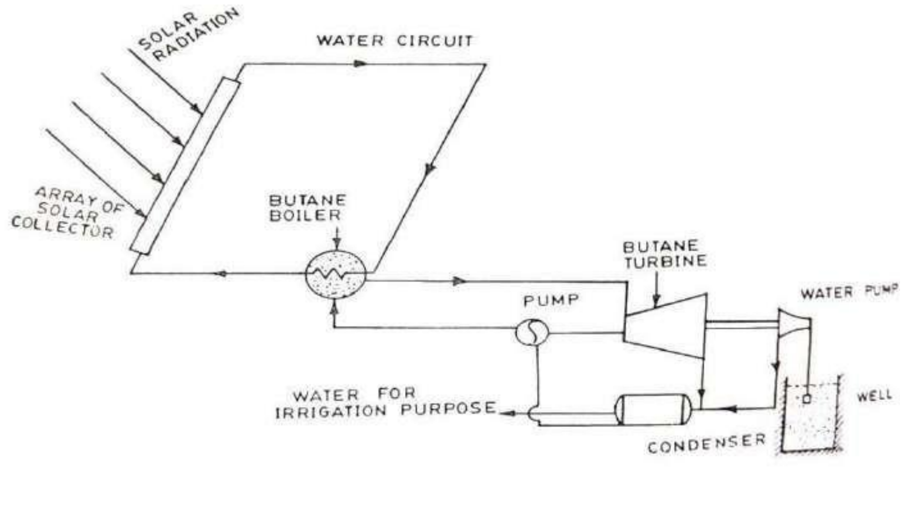


Fig. 5.5.2. Schematic of a low temperature solar power plant.

The system has a array of flat-plate collectors to heat water upto nearly 70°C and in the heat exchanger, the heat of water is used for boiling butane. The high pressure butane vapour runs a butane turbine which operates a hydraulic pump which pumps the water from well and used for irrigation. The exhaust butane vapour from butane turbine is condensed with the help of water which is pumped by the pump. This condensate is fed to the heat exchanger or butane boiler.

<u>MEDIUM TEMPERATURE SYSTEMS WITH CONCENTRATING COLLECTORS (100 - 300°C by Concentrating collectors):</u>

These systems generally employ an array of parabolic trough concentrating collectors, which give temperature above 100°C. General range of temperature is of the order of 250 to 500°C. As described earlier, a simple parabolic cylindrical concentrator for medium temperature system is shown in Figure. It consists of a parabolic cylindrical reflector to concentrate sunlight on to a collecting pipe within a pyrex or glass envelop. A selective coating of suitable material is applied to pipe to minimize infrared emission.

Proper suntracking arrangement is made so that maximum sunlight is focused on the absorber.

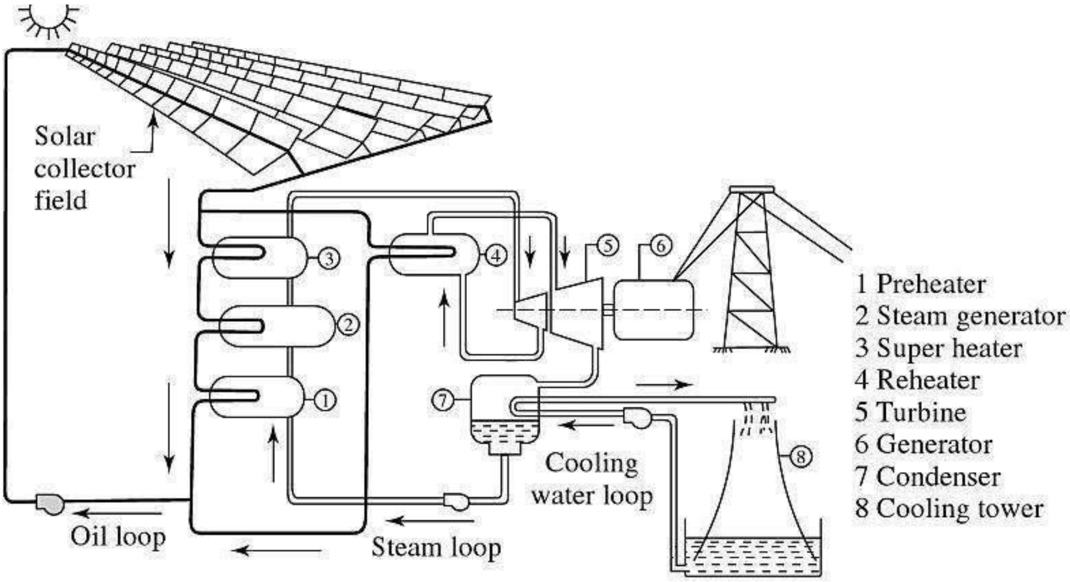


Fig. 2.21 *Medium temperature power generation cycle using cylindrical parabolic concentrating collectors*

1. Preheater, 2. Steam generator, 3. Super heater, 4. Re-heater, 5. Turbine, 6. Generator, 7. Condenser, 8. Cooling tower.

HIGH TEMPERATURE SYSTEMS (above 300°C) [CENTRAL RECIEVER SYSTEM / TOWER POWER PLANT]:

This power plant uses central tower receiver to collect solar radiation from a large area on the ground. The receiver mounted at the top of the tower, converts water into high-pressure steam at around 500°C. This high-pressure steam is expanded in a turbine coupled with an alternator. The electric power produced is fed to a grid. Thermal buffer storage is provided to continue operating the plant for some time during cloud cover and a bypass is used for starting and shutdown operations. The schematic diagram is shown in figure below.

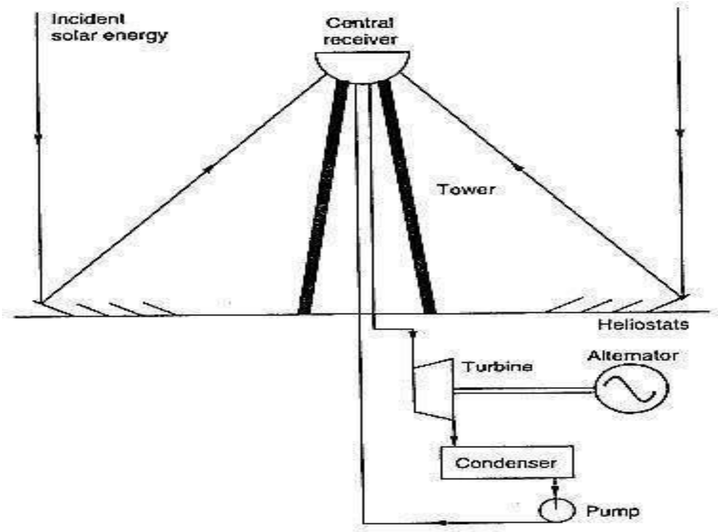


Fig. 2.16 Central Receiver Power Plant

SOLAR POWER GENERATION BY THERMAL STORAGE:

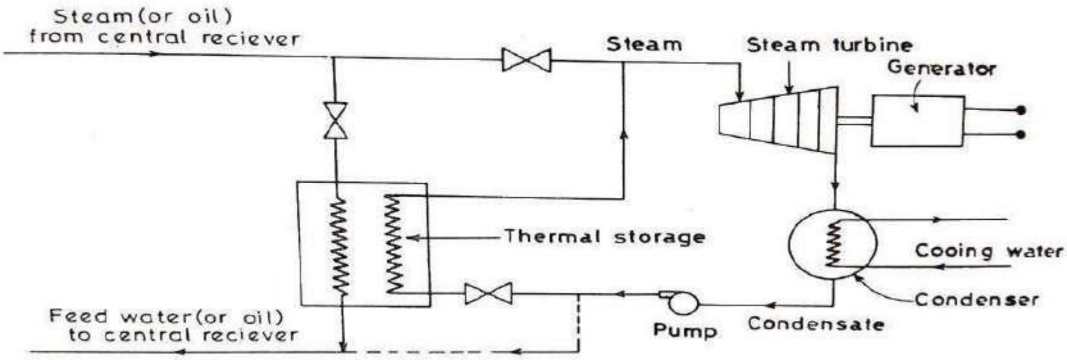


Fig. 5.5.6. Electric power generation using thermal storage.

SOLAR ELECTRIC POWER GENERATION BY SOLAR PHOTOVOLTAIC CELLS: A PVC is one which converts photons into voltage or light energy to electricity. The materials used for this is silicon which has 4 free valence e-‗s in its outermost cell. When the silicon is doped with phosphorous or arsenic having 5 valence e-‗s in the outer most cell it forms an ‗n-junction' 4 e-‗s of phosphorous with 4 e-‗s of silicon and one negative charged electron is left out in the ‗n-junction'. Similarly the ‗p-junction' is formed by doping silicon with boron having 3 valance e-‗s in its outermost cell to create positively charged hole which attracts negatively charged electron from n to p junction through external load of cell.

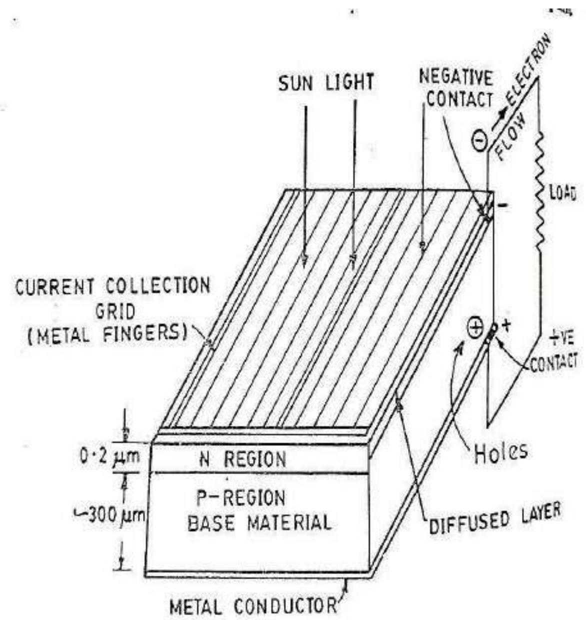


Fig. 5.6.1. Schematic view of a typical solar cell.

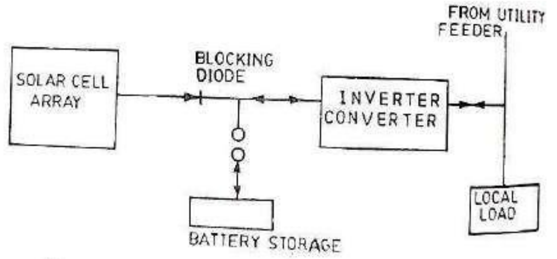


Fig. 5.6.5. Basic photovoltaic system integrated with power grid.

AGRICULTURAL AND INDUSTRIAL APPLICATIONS:

In this application there are 3 categories namely

1) Low Temp (below 100°C)

2) Intermediate Temp (100-175°C)

3) High Temp (above 175°C)

In low temp applications FPC's are used and the working fluid used is either water or air. The applications are heating and cooling of commercial green houses, space heating, dairy facilities and poultry houses, curing of bricks, drying of grains and distillation of water.

Intermediate temp applications are food processing, laundry, pickling etc

In high temp applications solar energy is used for thermal electric conversion their by generating electric power.

SOLAR DISTILLATION:

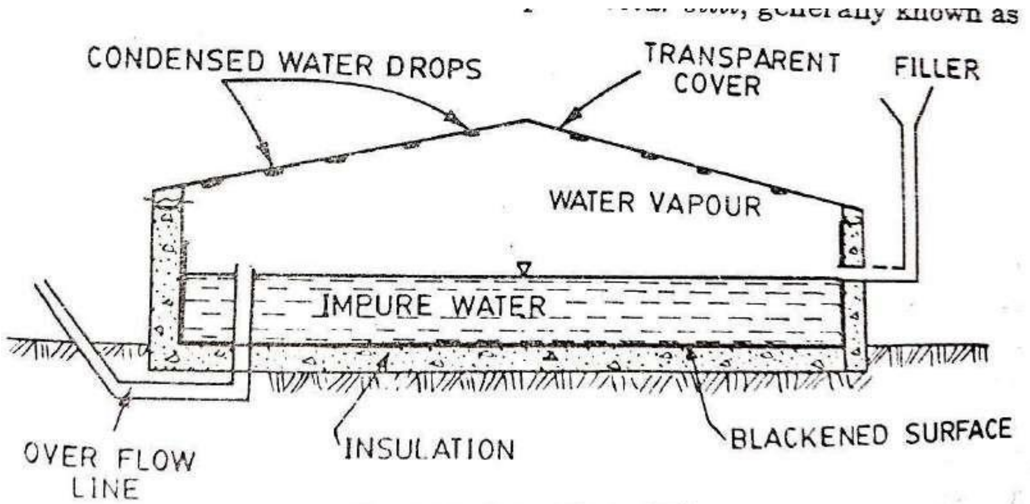


Fig. 5.8.1. Solar Water Still.

Potable or fresh water is one of the fundamental necessities of life for a man. Industries and agriculture also require fresh water without which they cannot thrive. Man has been dependent on rivers, lakes and underground water reservoir to fulfill his need of fresh water.

The use of solar energy for desalting seawater and brackish well water has been demonstrated in several moderate sized pilot plants in the Unites States, Greece, Australia and several other countries. The idea was first applied in 1982.

A simple basin type solar still consists of a shallow blackened basin filled with saline or brackish water tobe distilled. The depth of water is kept about 5-10 cm. It is covered with sloppy transparent roof. Solar radiation, after passing through the roof is absorbed by the blackened surface of the basin and thus increases the temperature of the water. The evaporated water increases the moisture content, which gets condensed on the cooler underside of the glass. The condensed water slips down the slope and is collected through the condensate channel attached to the glass. The construction is shown in figure above.

SOLAR PUMPING: working non-freezing organic fluids- Toulene, Monochlorobenzene, Trifluoro ethanol, Hexafluoro bnzene, Pyridine, Freon-11,113, Thiopene etc.

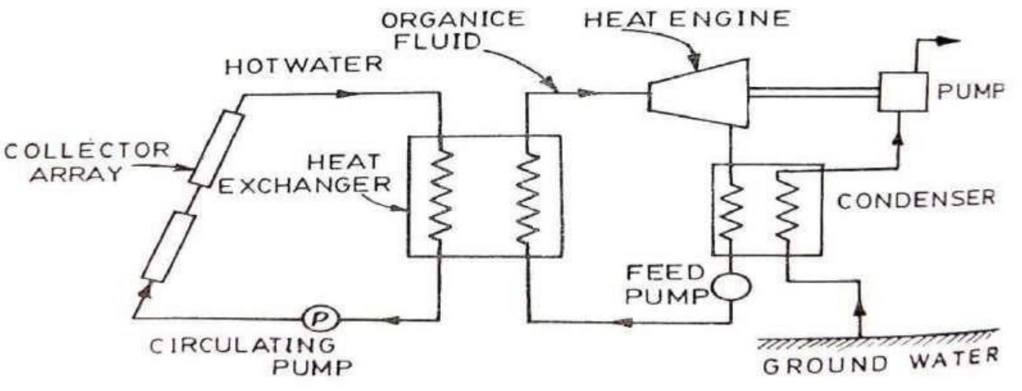


Fig. 5.9.1. Schematic of a solar pump.

The solar pump is not much different from a solar heat engine working in a low temperature cycle. The sources of heat is the solar collector, and sink is the water to be pumped. A typical solar powered water pumping system is shown in above Fig.5.9.1. The primary components of the system are an array of flat-plate collectors and an 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 and the operating conditions of the engine, the fluid will be heated in the collector to a higher temperature, the solar energy which is thus converted to the thermal energy. The fluid flows into a heat exchanger, due to temperature gradient, and comes back to the collector. This water yields its heat to an intermediate fluid in the boiler. This fluid evaporates and expands in the engine before reaching the condenser, where it condenses at low pressure. The condenser is cooled by the water to be pumped. The fluid is then reinjected in the boiler to close the cycle. The expansion engine or rankine engine is coupled to the pump and it could of course be coupled to an electric generation.

TURBINE-DRIVEN PUMP USING SOLAR ENERGY:

A simplified outline of a turbine –driven pump system utilizing solar energy is shown in Figure below. In a particular system in New Mexico, the heat transport fluid (HT - 43) is heated to 216°C in parabolic through collectors with a total operature area of 624 m². Part of the heated liquid is stored for use when the sun is not shining. The turbine working fluid (Freon type R-113) leaves the boiler and enters the turbine as vapour at a temperature of 160°C and 15 atm pressure. After expansion in the turbine, the vapor leaves at 93°C and 0.7 atm; it is converted back to liquid in the condenser and returns to the boiler.

The irrigation pump operates at a rated power of 19 kw and delivers water at 500 to 600 gal/min (32 to 38 litres/sec) from a well roughly 30m deep.

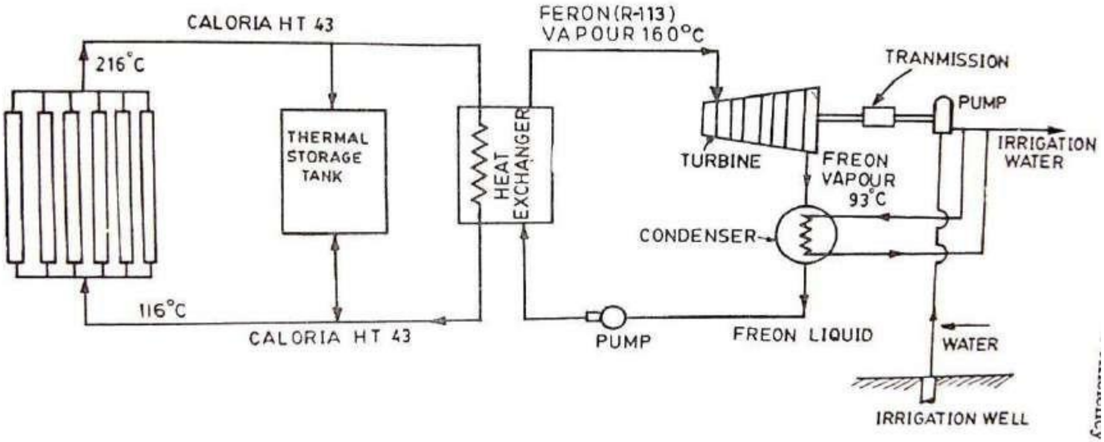


Fig. 5.9.2. A schematic of a turbine-driven pump using solar energy.

SOLAR FURNACE (3800°C):

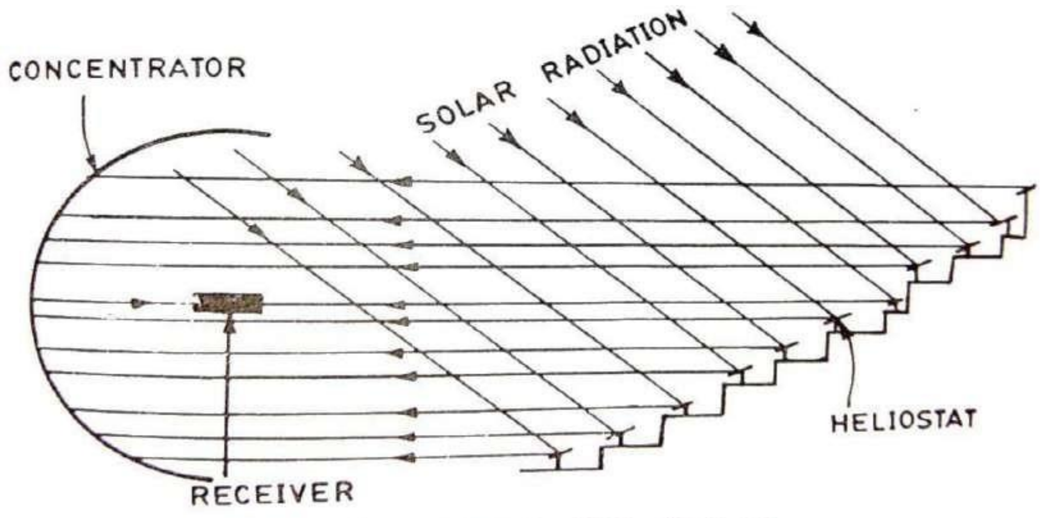


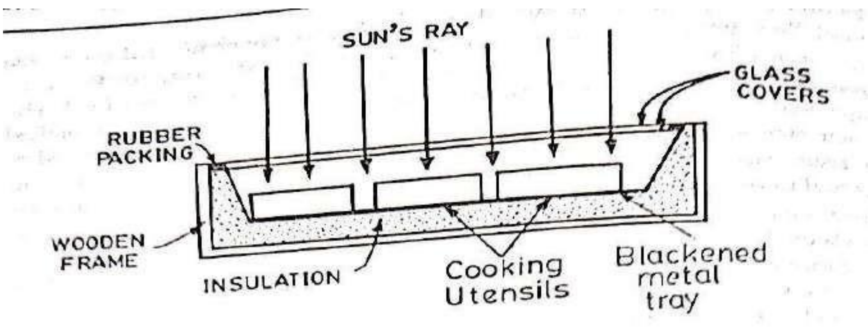
Fig. 5.10.1. Principle of Solar Furnace.

Principle of Working:

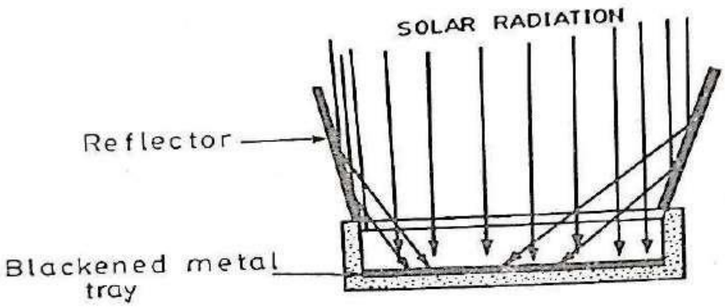
The principle of the solar furnace is outlined in Fig.5.10.1. A number of heliostates are arranged in terraces on a slopping surface so that, regardless of the sun's position, they always reflect solar radiation in the same direction onto a large paraboloid reflecting collector made up of many fixed mirrors attached to the face of a structure. The collector then brings the radiation to a focus within a small volume. In figure a heliostat type furnace with horizontal optical axis is shown which is comparatively convenient and widely used in large furnaces. The most desirable mirror is that obtained by grinding and polishing a glass plate into an optical flat, aluminizing or silvering by vacuum evaporation, and cooling with a suitable film. The change of elevation and that of azimuth can be obtained by the rotation of frame about a horizontal axis and 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 a time system for sun following. The other method is to use many heliostats to convey the solar radiation into a concentrator.

SOLAR COOKING:

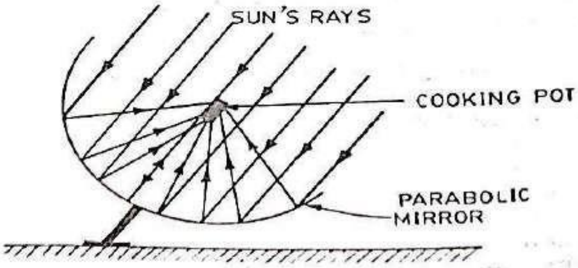
Thermal energy requirements for cooking purpose forms a major share of the total energy consumed, especially in rural areas. Variety of fuels like coal, kerosene, cooking gas, firewood, dung cakes and agricultural wastes are being used to meet the requirement. Fossil fuel is a fast depleting resource and need to be conserved, firewood for cooking causes ddeforestation and cow dung, agricultural waste etc. may be better used as a good fertilizer. Harnessing solar energy for cooking purpose is an attractive and relevant option. A variety of solar cookers have been developed, which can be clubbed in four types of basic designs: (i) box type solar cooker, (ii) dish type solar cooker (iii) community solar cooker, and (iv) advance solar cooker.



(a) Principle of box type cooker.



(b) Reflector type solar cooker.



(c) Principle of concentrating type cooker.
Fig. 5.11.1. Principle of operation of Solar cookers.

BOX TYPE SOLAR COOKER: (160°C) & Reflector type (240°C):

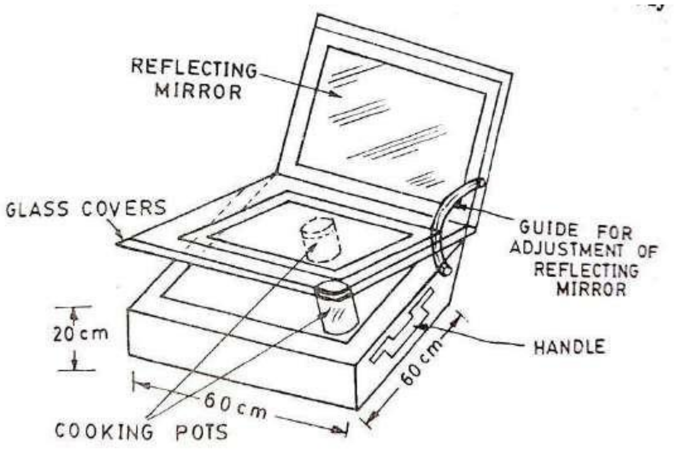


Fig. 5.11.2. Details of a box type cooker.

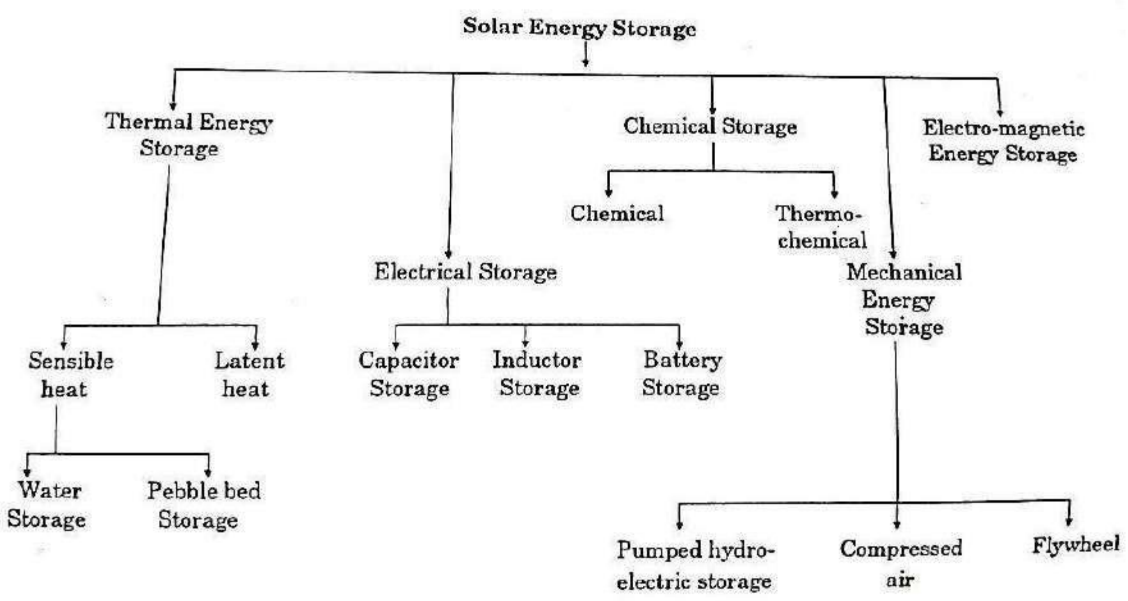
The construction of a most common, box type solar cooker is schematically shown in figure above. The external dimensions of a typical family size box type cooker are 60x60x20 cm. This cooker is simple in construction and operation. An insulated box of blackened aluminium contains the utensils with food material. The box receives direct radiation and also reflected radiation from a reflector mirror fixed on inner side of the box cover hinged to one side of the box. The angle of reflector can be adjusted as required. A glass cover consisting of two layers of clear window glass sheets serves as the box door. The glass cover traps heat due to the greenhouse effect. Maximum air temperature obtained inside the box is around 140-160^{0}C. This is enough for cooking the boiling type food slowly in about 2-3 hours.

SOLAR ENERGY STORAGE AND APPLICATIONS

The thermal energy of sun can be stored in a well-insulated fluids or solids. It is either stored as i) sensible heat – by virtue of the heat capacity of the storage medium, or as ii) Latent heat – by virtue of the latent heat of change of phase of the medium or both.

In the first type of storage the temp of the medium changes during charging or discharging of the storage whereas in the second type the temp of the medium remains more or less constant since it undergoes a phase transformation.

An overview of the major techniques of storage of solar energy is as shown in the fig. A wide range of technical options are available for storing low temp thermal energy as shown. Some of the desired characteristics of the thermal energy as shown below. Some of the different storage techniques and their main features are compared in the next table. Desired properties of phase change heat storage materials are also listed in subsequent table.

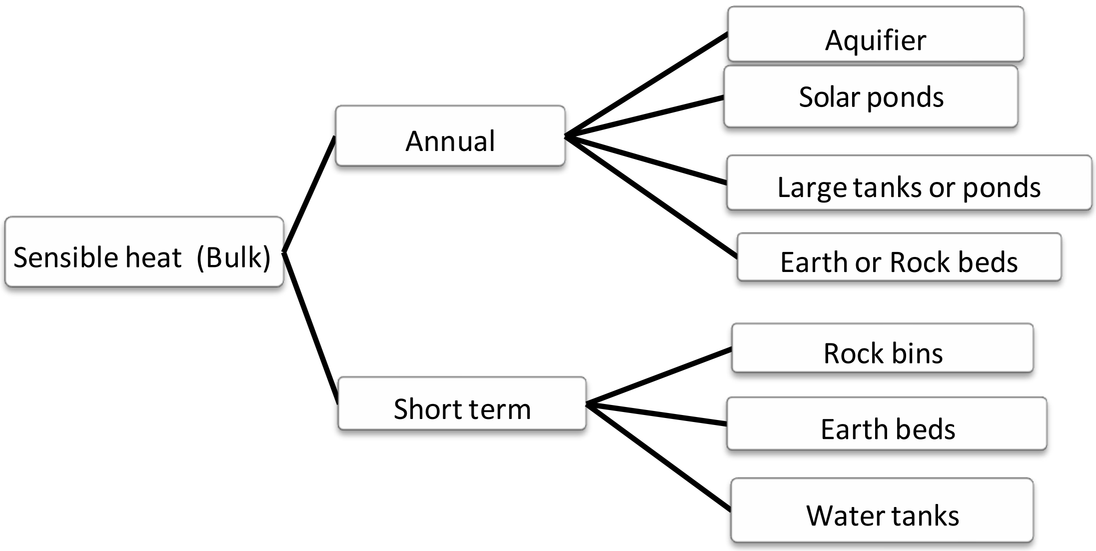


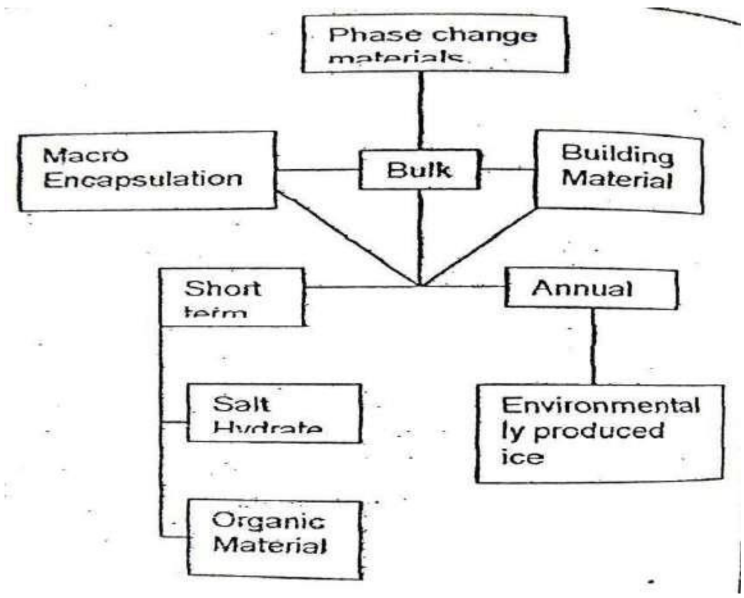
There are four main factors affecting the cost affecting the cost of solar thermal energy storage systems. They are,

1) Thermal heat storage materials,
2) Insulating material,
3) Space occupied by the storage device,
4) Heat exchange for charging and discharging the storage.

The following chart shows the different storage systems used as per the required capacity. Depending on the available energy one can select the particular storage system thus optimizing the cost and the efficiency of the storage system.

Low Temperature solar thermal energy storage technology classification:





Desired characteristics of a thermal storage system:

1) Compact, large storage capacity per unit mass and volume,
2) High storage efficiency,
3) Heat storage medium with suitable properties in the operating temperature range,
4) Uniform temperature,
5) Capacity to charge and discharge with the largest input/output rates but without temperature gradients,

6) Complete reversibility,
7) Ability to undergo large number of charges and discharge cycles without loss of performance and storage capacity,
8) Small self-discharging rates,
9) Quick charging and discharging,
10) Long life,
11) Inexpensive,
12) Non corrosive,
13) No fire and toxic hazards.

In smaller heat storage, the surface area to volume ratio is large and hence the cost of insulating is an important factor. Phase change storages with higher energy densities are more attractive for small storage. In larger heat storage, on the other hand, the cost of storage material is more important and sensible heat storage like water is very attractive.

Comparison of different storage techniques for solar space heating

Property	Sensible Heating Water	Rock	Latent heat storage (solid – liquid0
Temperature Range	$0 - 100^0$ c	Large	Large, depends on the material
Specific heat	High	low	Medium
Thermal conductivity	Low	Low	Very-low (insulating)
Storage capacity /unit mass/unit vol	Low	Low	High
Stability to thermal cycling	Good	Good	Insufficient data
Availability	Good	Good	Depend on the choice of the material
Cost	Inexpensive	Inexpensive	Expensive
Heat exchanger geometry	Simple	Simple	Complex
Temp. gradient during charging/discharging	Large	Large	Small
Simultaneous charging/discharging	Possible	Not possible	Possible with appropriate H.E.
Cost of accessories	low	High	Low
Corrosion	Corrosive	Non corrosive	Insufficient data
Life	long	long	long

Photovoltaic Solar Systems

What is a solar cell?

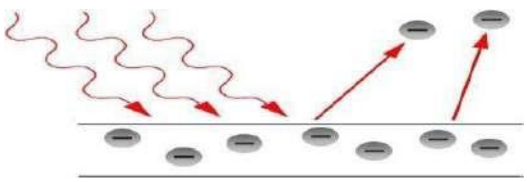
- Solid state device that converts incident solar energy directly into electrical energy

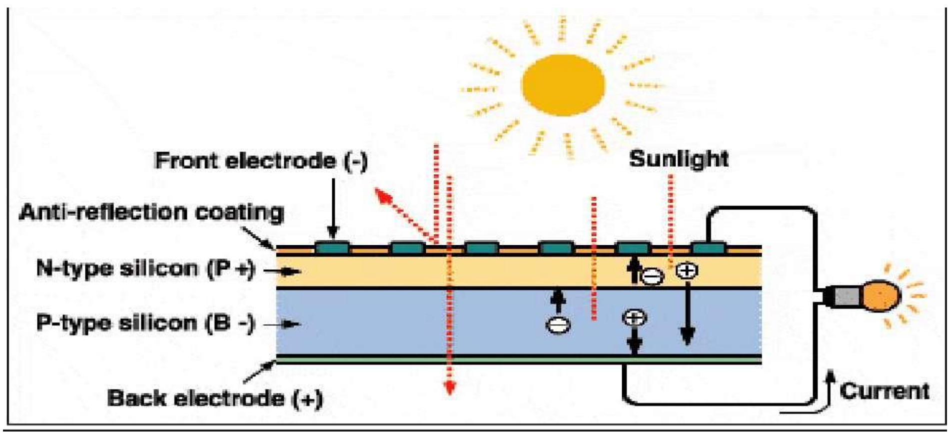
Advantages:

1. Efficiencies from a few percent up to 20-30%
2. No moving parts
3. No noise
4. Lifetimes of 20-30 years or more

How Does It Work?

- The junction of dissimilar materials (n and p type silicon) creates a voltage
- Energy from sunlight knocks out electrons, creating a electron and a hole in the junction
- Connecting both sides to an external circuit causes current to flow
- In essence, sunlight on a solar cell creates a small battery with voltages typically 0.5 v. DC

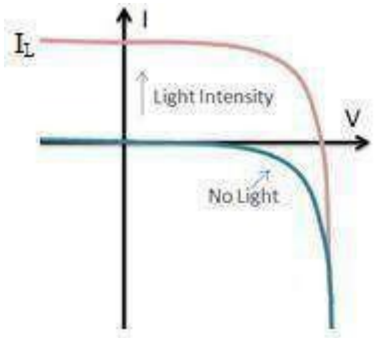


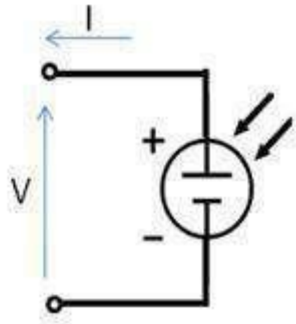


charecteristics of a solar cell:

Theory of I-V Characterization:

PV cells can be modeled as a current source in parallel with a diode. When there is no light present to generate any current, the PV cell behaves like a diode. As the intensity of incident light increases, current is generated by the PV cell, as illustrated in Figure.





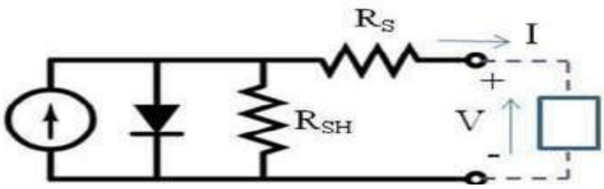
- In an ideal cell, the total current I is equal to the current I_ℓ generated by the photoelectric effect minus the diode current I_D, according to the equation:

$$I = I_\ell - I_D = I_\ell - I_o\left(e^{\frac{qV}{kT}} - 1\right)$$

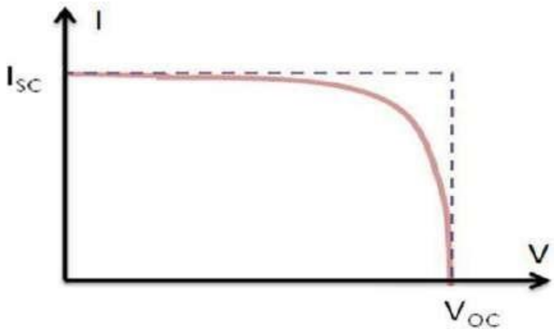
- where I_0 is the saturation current of the diode, q is the elementary charge $1.6\text{x}10^{-19}$ Coulombs, k is a constant of value $1.38\text{x}10^{-23}$J/K, T is the cell temperature in Kelvin, and V is the measured cell voltage that is either produced (power quadrant) or applied (voltage bias).

- Expanding the equation gives the simplified circuit model shown below and the following associated equation, where n is the diode ideality factor (typically between 1 and 2), and R_S and R_{SH} represents the series and shunt resistances that are described in further detail later in this document:

$$I = I_l - I_0\left(exp^{\frac{q(V+I\cdot R_S)}{n\cdot k\cdot T}} - 1\right) - \frac{V + I\cdot R_S}{R_{SH}}$$



The I-V curve of an illuminated PV cell has the shape shown in the following Figure as the voltage across the measuring load is swept from zero to V_{OC},



Short Circuit Current (I_{SC}):

The short circuit current I_{SC} corresponds to the short circuit condition when the impedance is low and is calculated when the voltage equals 0.

I (at V=0) = I_{SC}

I_{SC} occurs at the beginning of the forward-bias sweep and is the maximum current value in the power quadrant. For an ideal cell, this maximum current value is the total current produced in the solar cell by photon excitation.

$I_{SC} = I_{MAX} = I_{\ell}$ for forward-bias power quadrant

Open Circuit Voltage (V_{OC}):

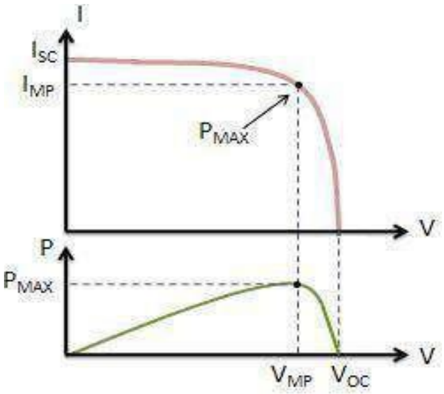
The open circuit voltage (V_{OC}) occurs when there is no current passing through the cell.

V (at I=0) = V_{OC}

V_{OC} is also the maximum voltage difference across the cell for a forward-bias sweep in the power quadrant.V_{OC}= V_{MAX} for forward-bias power quadrant

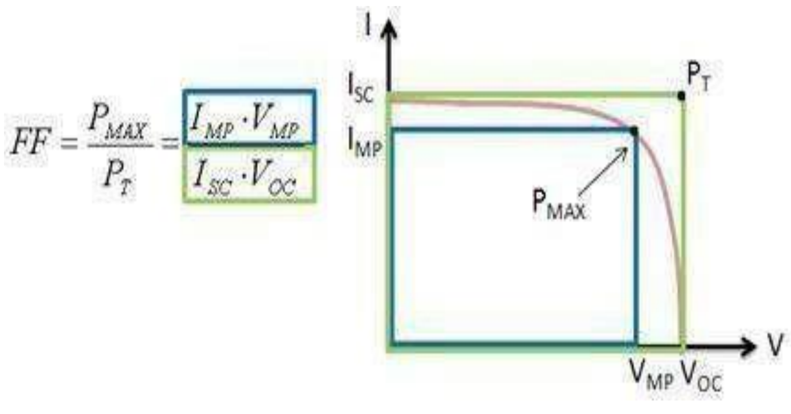
Maximum Power (P_{MAX}), Current at P_{MAX} (I_{MP}), Voltage at P_{MAX} (V_{MP}):

The power produced by the cell in Watts can be easily calculated along the I-V sweep by the equation $P=IV$. At the I_{SC} and V_{OC} points, the power will be zero and the maximum value for power will occur between the two. The voltage and current at this maximum power point are denoted as V_{MP} and I_{MP} respectively.



Fill Factor:

The Fill Factor (FF) is essentially a measure of quality of the solar cell. It is calculated by comparing the maximum power to the theoretical power (P_T) that would be output at both the open circuit voltage and short circuit current together. FF can also be interpreted graphically as the ratio of the rectangular areas depicted in Figure



A larger fill factor is desirable, and corresponds to an I-V sweep that is more square-like. Typical fill factors range from 0.5 to 0.82. Fill factor is also often represented as a percentage.

Efficiency (η):

Efficiency is the ratio of the electrical power output P_{out}, compared to the solar power input, P_{in}, into the PV cell. P_{out} can be taken to be P_{MAX} since the solar cell can be operated up to its maximum power output to get the maximum efficiency.

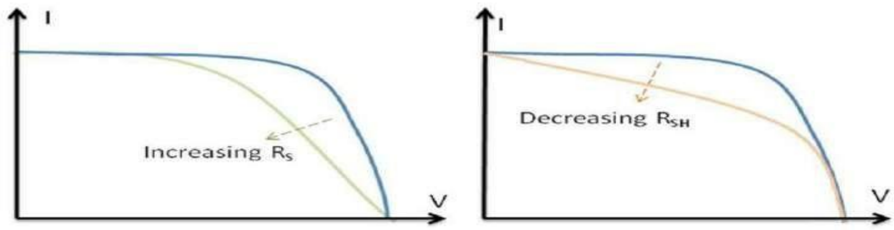
$$\eta = \frac{P_{out}}{P_{in}} \Rightarrow \eta_{MAX} = \frac{P_{MAX}}{P_{in}}$$

Shunt Resistance (R_{SH}) and Series Resistance (R_S):

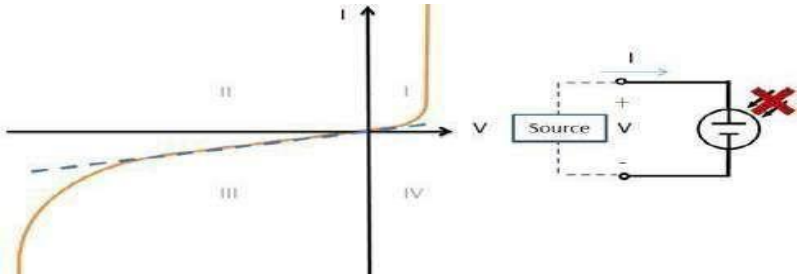
During operation, the efficiency of solar cells is reduced by the dissipation of power across internal resistances. These parasitic resistances can be modeled as a parallel shunt resistance (R_{SH}) and series resistance (R_S), as depicted in Figure previously.

For an ideal cell, R_{SH} would be infinite and would not provide an alternate path for current to flow, while R_S would be zero, resulting in no further voltage drop before the load.

Decreasing R_{SH} and increasing R_s will decrease the fill factor (FF) and P_{MAX} as shown in Figure 6. If R_{SH} is decreased too much, V_{OC} will drop, while increasing R_S excessively can cause I_{SC} to drop instead.



If incident light is prevented from exciting the solar cell, the I-V curve shown in following Figure can be obtained. This I-V curve is simply a reflection of the ―No Light‖ curve from Figure 1 about the V-axis. The slope of the linear region of the curve in the third quadrant (reverse-bias) is a continuation of the linear region in the first quadrant, which is the same linear region used to calculate R_{SH} in Figure. It follows that R_{SH} can be derived from the I-V plot obtained with or without providing light excitation, even when power is sourced to the cell. It is important to note, however, that for real cells, these resistances are often a function of the light level, and can differ in value between the light and dark tests.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