

NON-CONVENTIONAL ENERGY SOURCES

Unit-1 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 10 years 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 of vegetable 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.

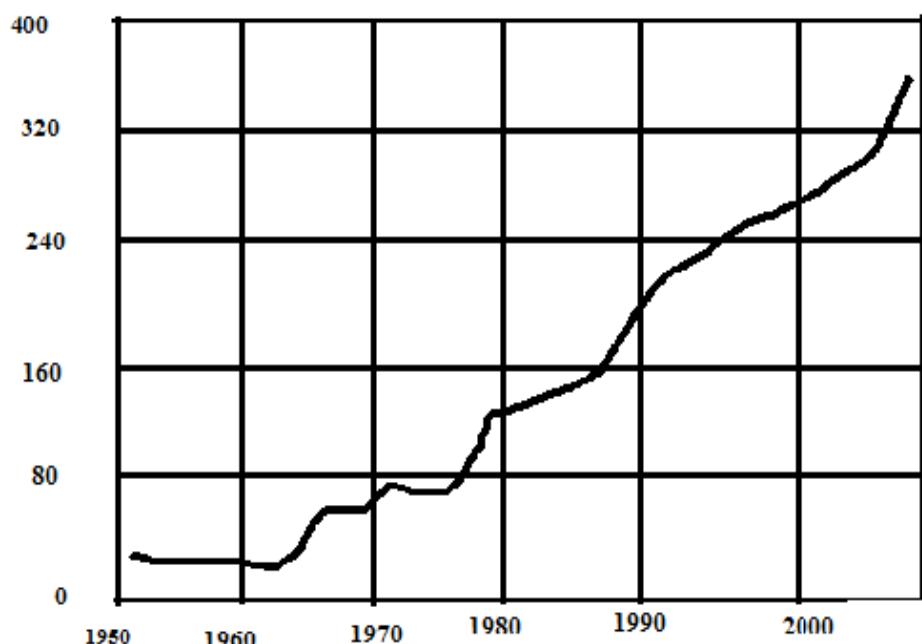


Fig.1. Annual production of coal in India [production rate (Mt/Year] v/s Year

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.

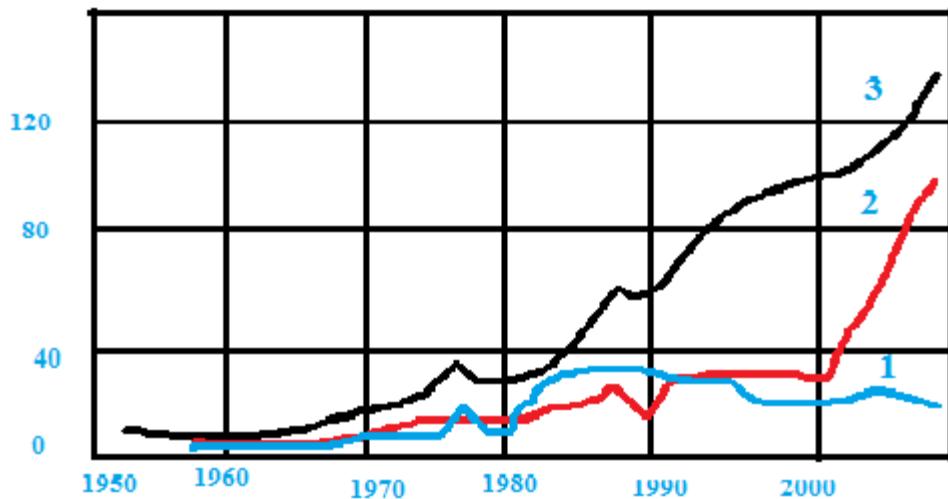


Fig.2. Annual production, import & consumption of oil in India [Production Rate (Mt/Year) v/s Year]

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

Natural gas: 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.

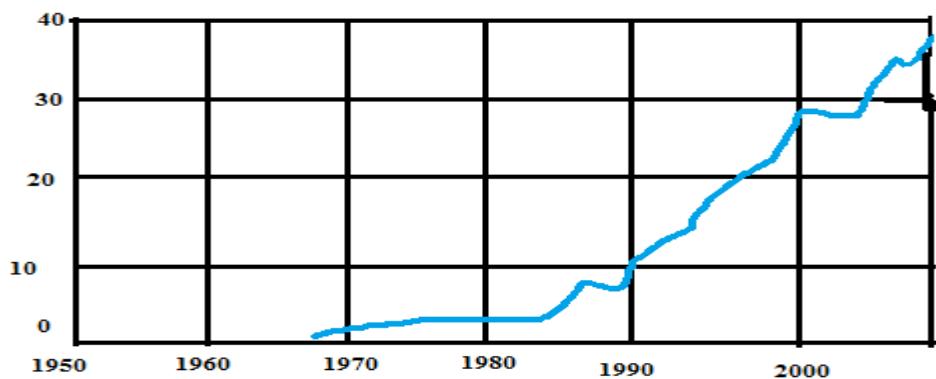


Fig.3. Annual production of natural gas in India [Production rate (10⁹ m³/Year) v/s Year]

Water -power:

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.

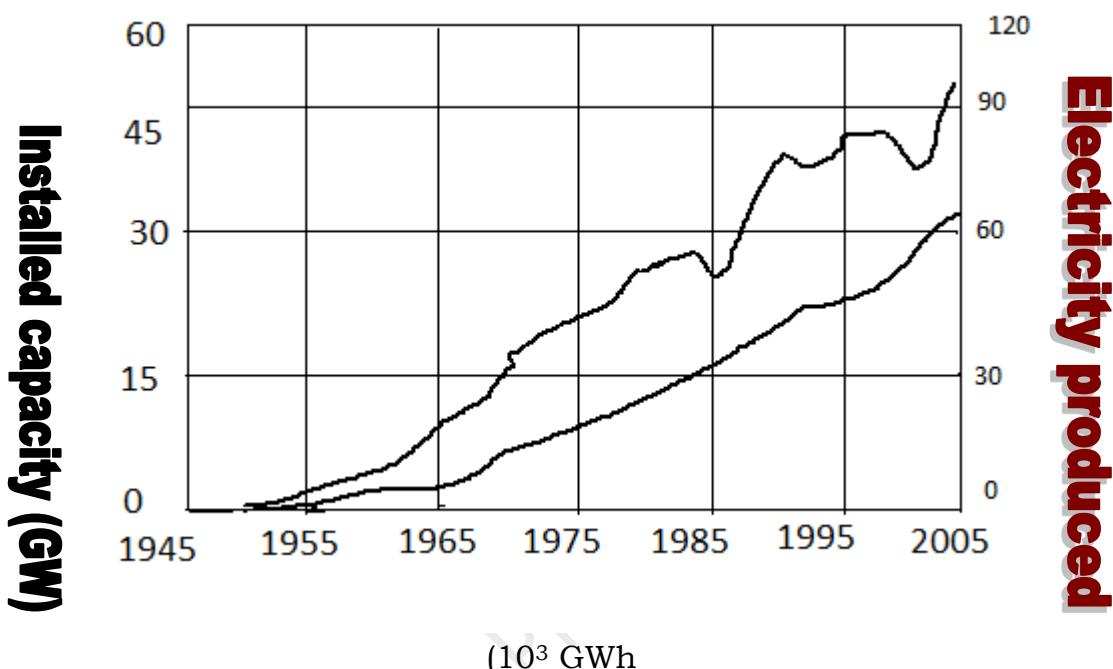
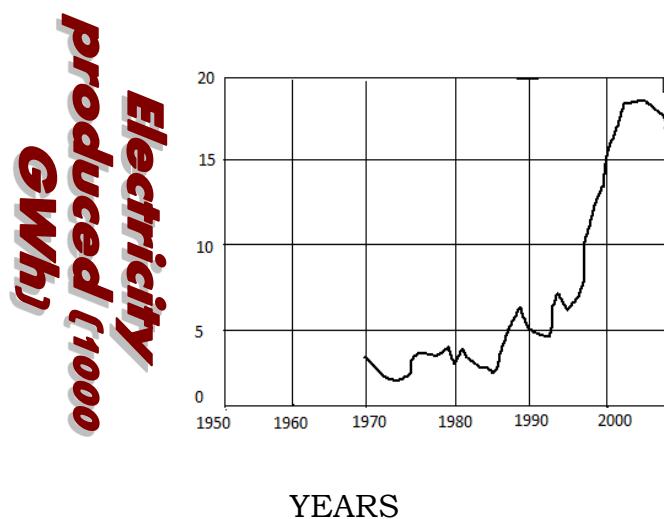


Fig.4. installed capacity & electricity generation from water-power in India.

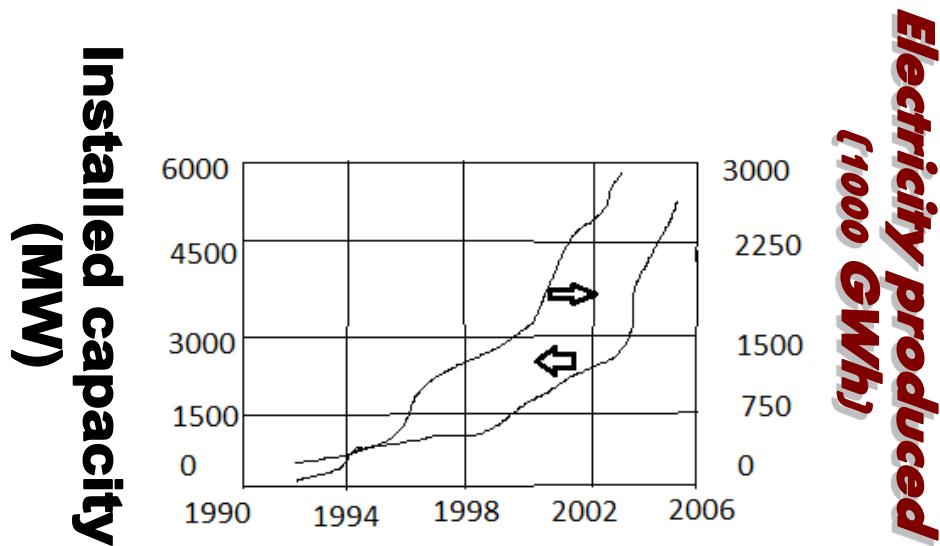
Nuclear power:

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

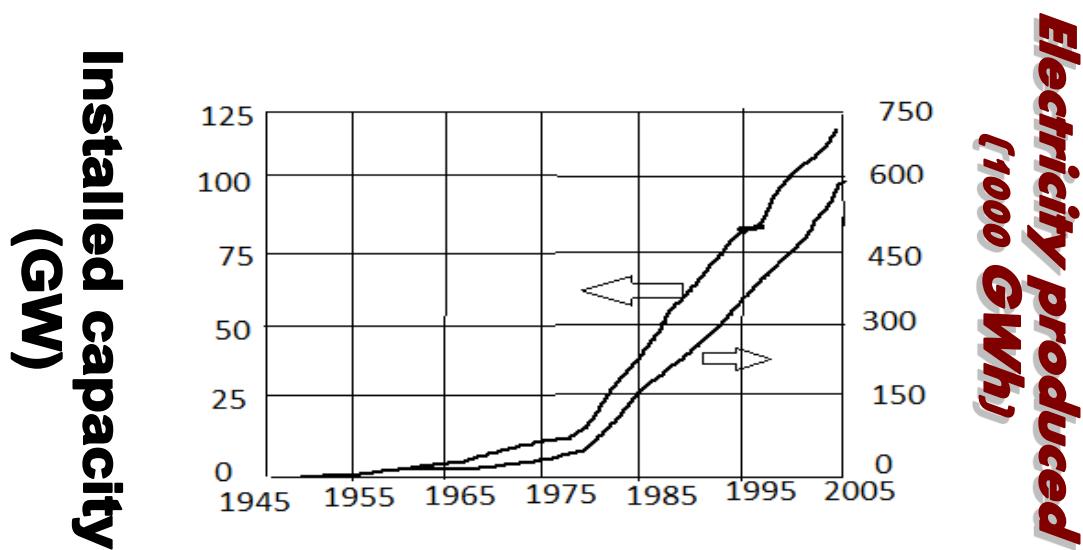


Fig.7. The total installed capacity & electricity generation in India from all commercial sources

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

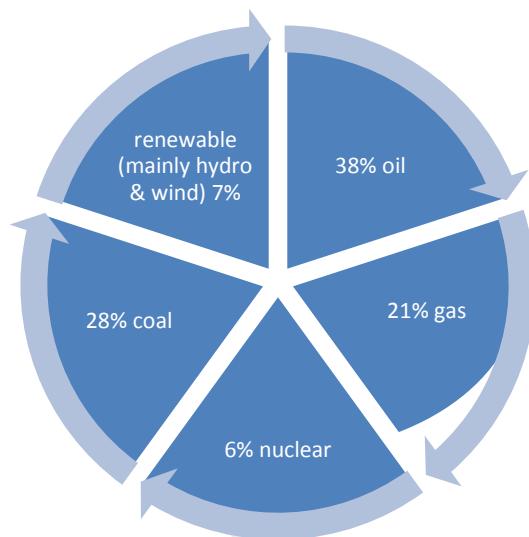
Consumption trend of primary energy resources

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; thereby 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:

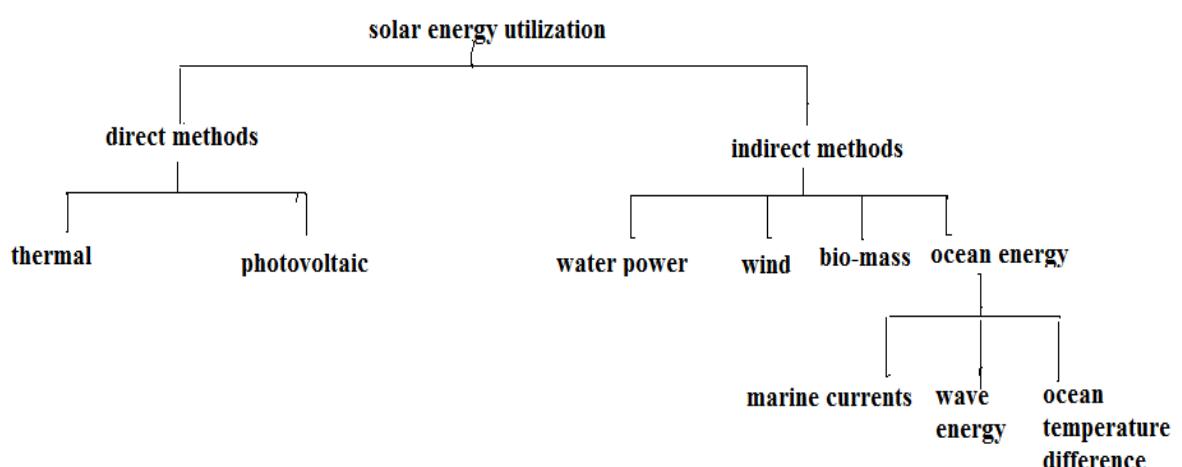
- 1) Fossil fuels generate pollutants: CO, CO₂, NO_x, SO_x. Particulate matter & heat. The pollutants degrade the environment, pose health hazards & cause various other problems.

- 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 Fritl 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 in 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.

$$P = \eta \rho Q gh$$

Where, P – Power in Watts

η - dimension less efficiency of the turbine

ρ -density of water in Kg/m³

Q- Flow in m³/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 farms 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 less.
- ❖ 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.

$$\text{Kinetic energy} = k.E = \frac{1}{2} m v^2$$

$$\text{But } m = \rho A v$$

$$\text{Available wind Power} = P_a = \frac{1}{8} \rho \pi D^2 V^3 \dots \text{Watts}$$

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.

$$\text{Power coefficient} = \frac{\text{power of wind rotor}}{\text{power available in the wind}}$$

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

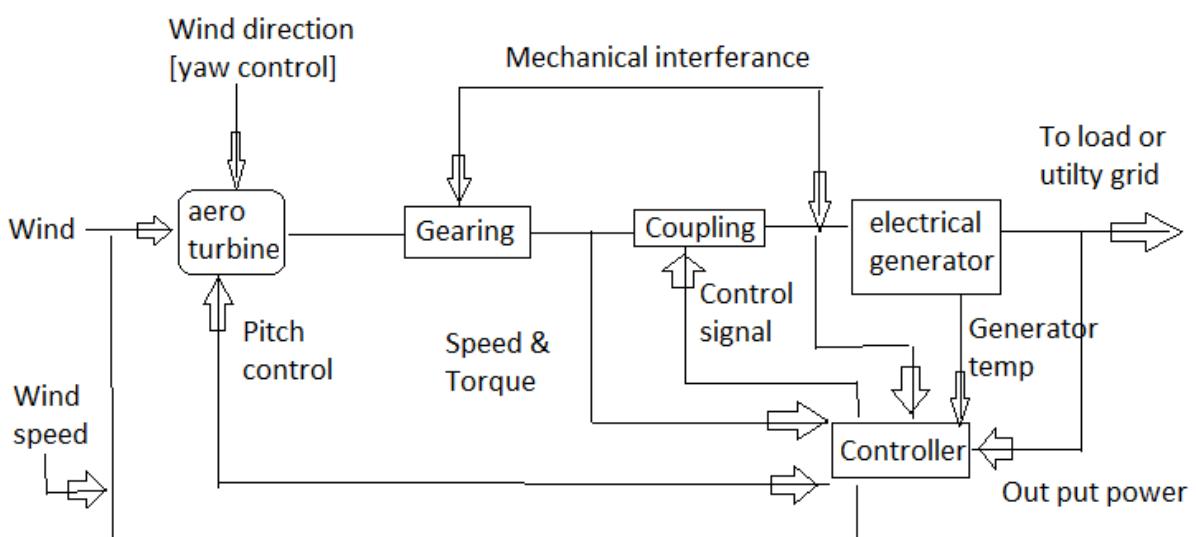


Fig.9.Basic components of wind electric system

Applications:

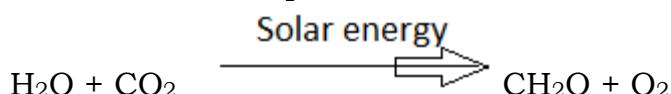
- A] Applications require mechanical power
 - i] Wind power, ii] Heating, iii] Sea transport
- B] As of grid electrical power source

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% in trees, 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



- In the reaction, water & carbon dioxide are converted into organic material i.e., CH₂O, 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).
- $\text{CH}_2\text{O} + \text{O}_2 \longrightarrow \text{CO}_2 + \text{H}_2\text{O} + 112 \text{ Kcal/mole}$
- ✓ 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 solid mass (wood & agricultural residue), &
- 2] bio-mass in non-traditional form (converted into liquid fuels)
 - The first category is to burn the bio-mass directly & get the energy.
 - 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 aerobically to obtain a gaseous fuel called bio-gas (bio-gas contains 55to 65% Methane, 30-40% CO₂ & rest impurities i.e., H₂, H₂S, & some N₂).

Bio-mass resources include the following:

- 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:

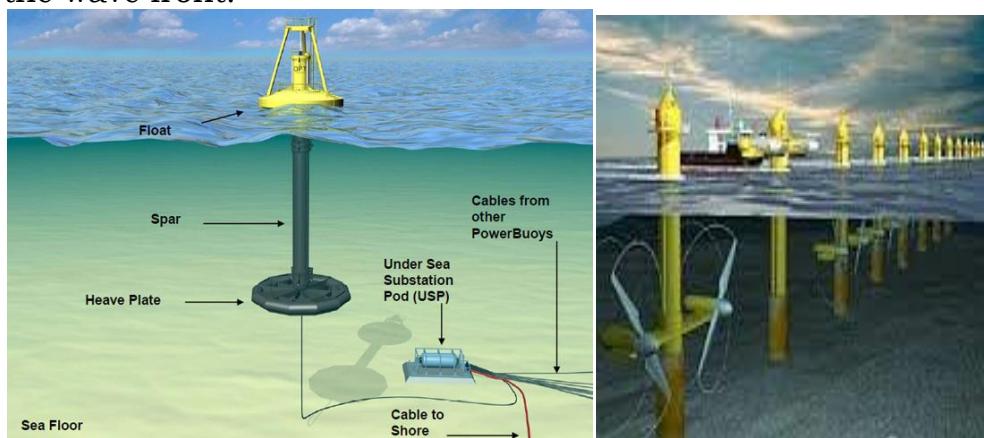
- 1) Economic recovery of energy from tides is feasible only at those sites where energy is concentrated in the form of tidal range of about 5m or more, & geography provide a favorable site for economic construction of tidal plant, thus it is site specific.
- 2) Due to mis-match of lunar driven period 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 harness 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 it is difficult to construct, operate & maintain a system & transmit power to the shore,
- The slow & irregular motion of wave is required to be coupled to an electrical generator requiring high & constant speed motion.

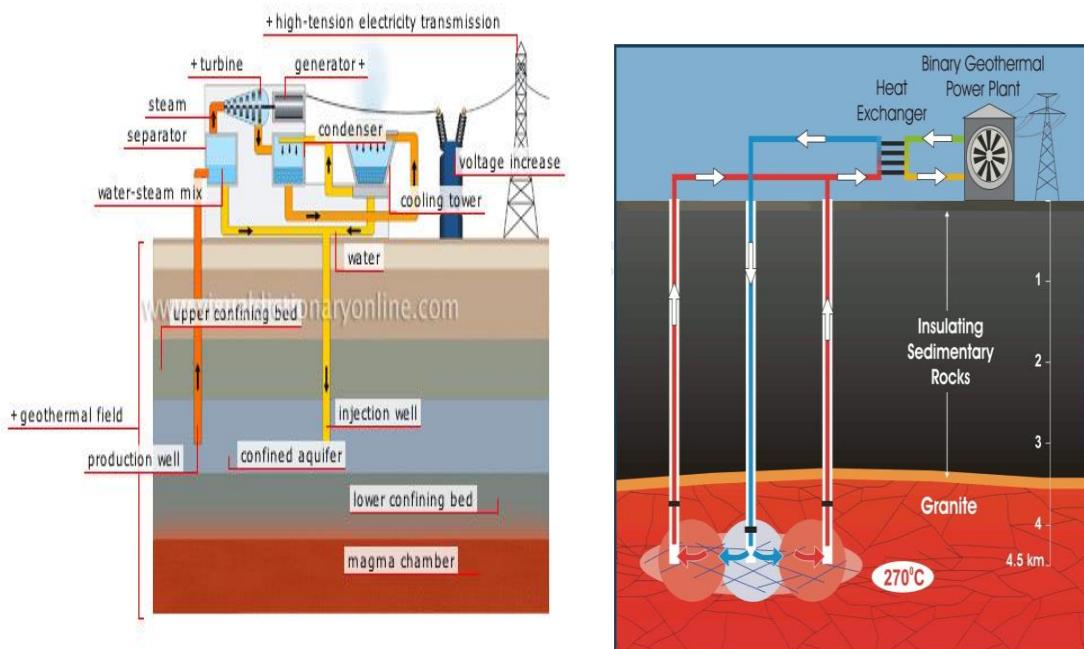
GEOTHERMAL ENERGY:

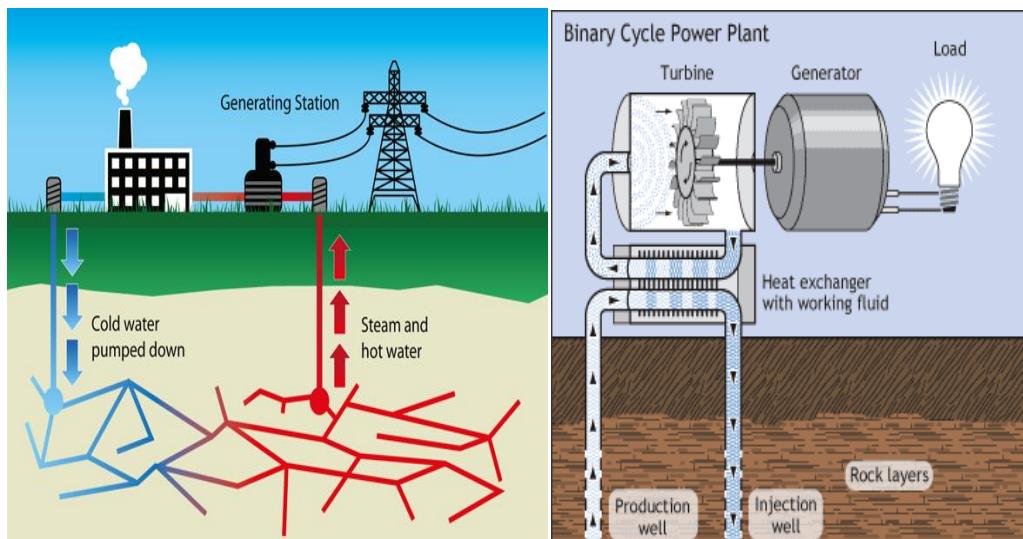
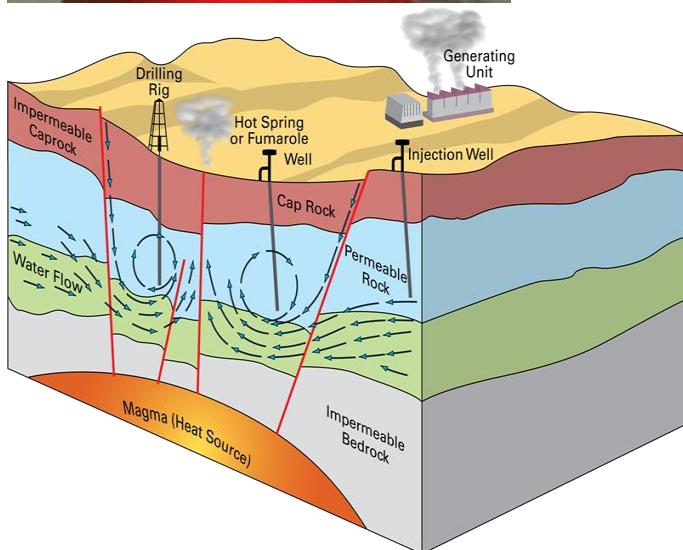
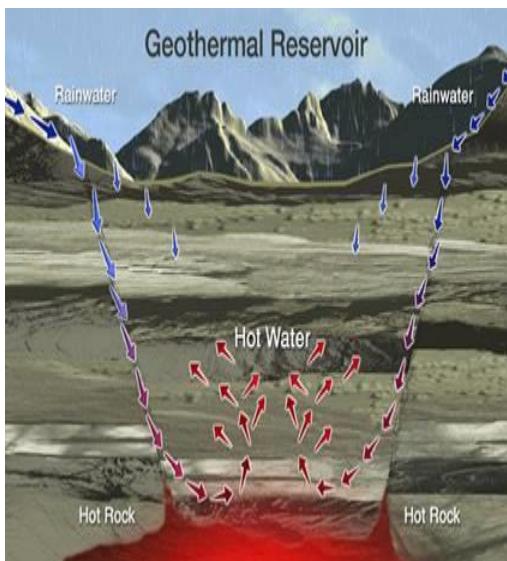
- Geothermal energy is energy coming out of the molten interior (in the form of heat) of the earth towards the surface. Volcanoes, Geysers, Hot springs & boiling mud pots are visible evidence of the great reservoirs of heat that lies within the earth.
- Most Geothermal energy produces low grade heat 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, emptying 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/m³] 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:

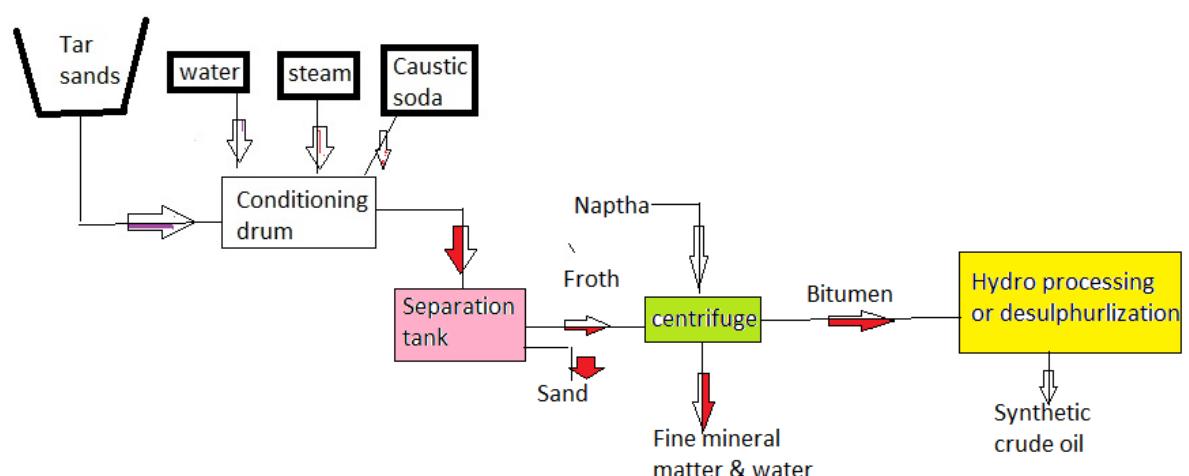


Fig.10. production of synthetic crude oil from tar sands

- ❖ 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:

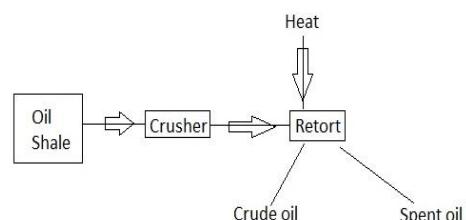


Fig.11.a. Oil shale Fig.11.b. Production of crude oil from oil shale

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, U²³⁴, U²³⁵ & U²³⁸. The relative % of these isotopes is U²³⁴ – 0.006%, U²³⁵- 0.711% & U²³⁸ -99.283% of these isotopes, only U²³⁵ undergoes spontaneous fission when subjected to bombardment by slow neutrons. It is in fact that only naturally occurring fissile material.

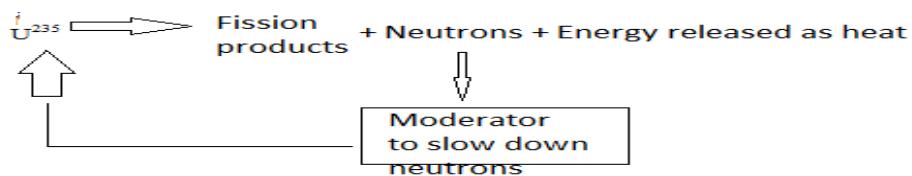


Fig.12. Fission reaction of U²³⁵

The break-up of U²³⁵ when subjected neutrons & the release of a large amount of energy as heat [8.2×10^7 KJ/gm of U²³⁵]. The neutrons are slowed down by a moderator, & used to bombard the U²³⁵ nucleus again, there by setting up a controlled chain reaction. Although U²³⁸ 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 U²³³ 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.

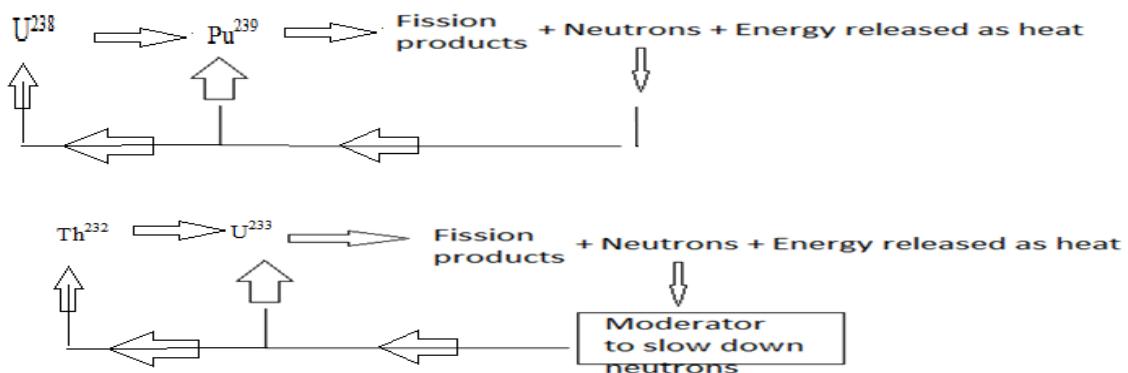
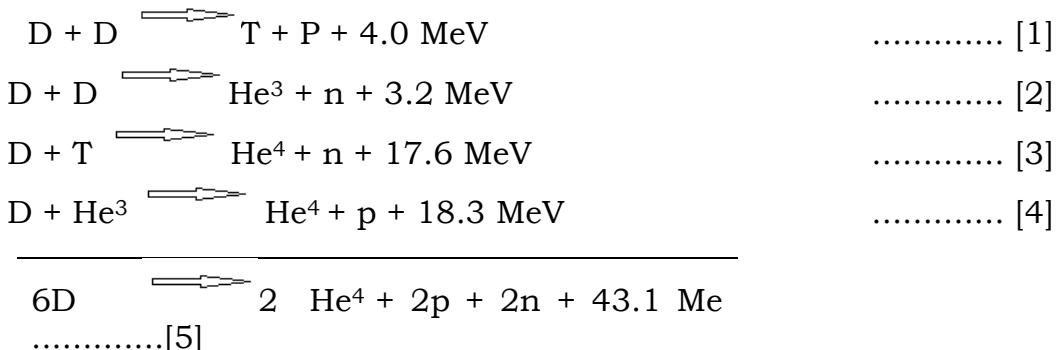


Fig.13. Breeder reactor for U²³⁸ & Th²³²

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 U²³⁸ to Pu²³⁹ 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.



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:



UNIT-2

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 1.39×10^6 km, while that of the earth is 1.27×10^4 km. It subtends an angle of 32 minutes 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 its center to its edge. However for engineering calculations. It is customary to assume that the brightness all over the solar disc uniform.

Solar Constant(I_{sc}):

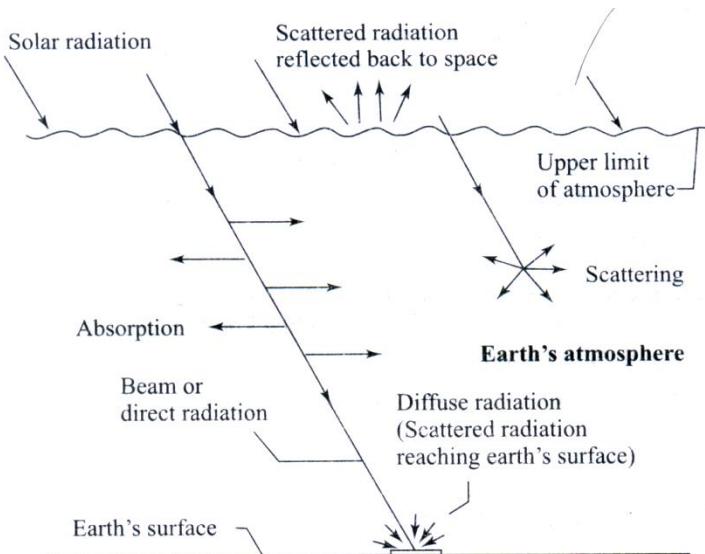
It is the rate at which energy is received from the sun on a unit area perpendicular to the ray's of the sun , at the mean distance of the earth from the sun. Based on the measurements made up to 1970 a standard value of 1353 W/m² was adopted in 1971. However based on subsequent measurements, a revised value of 1367 W/m² 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.

$$I = I'_{sc} \left\{ 1 + 0.033 \cos \frac{360n}{365} \right\}$$

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 CO₂, NO₂, CO,O₂ and CH₄) 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.

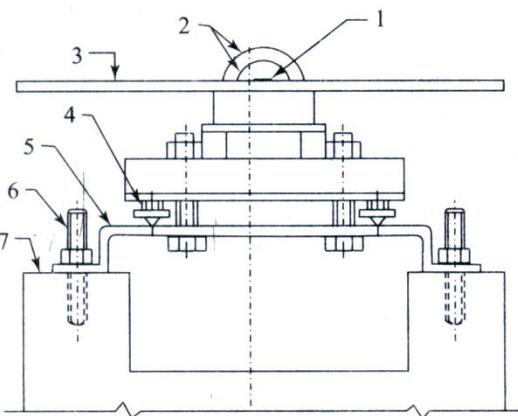
Solar radiation received at the earth's surface without change of direction i.e, in line with the sun is called *direct radiation* or *beam radiation*. The radiation received at the earth's surface from all parts of sky's hemisphere (after being subjected to scattering in the atmosphere) is called *diffuse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



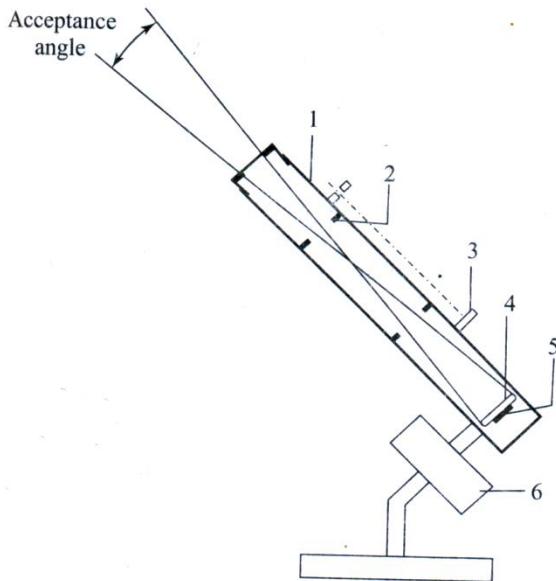
Pyranometer consists of a black surface which heats up when exposed to solar radiation. Its temperature increases until the rate of heat gain by solar radiation equals the rate of heat loss by convection, conduction and radiation. The hot junctions of thermopile are attached to the black surface, while 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 to 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 its plane is parallel to the plane of path of sun's daily movement across the sky and it shades the thermopile element and two glass 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

Definitions:

(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(y_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° on June 22 to -23.5° on December 22. On equinoxes of March 21 & Sept 22 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 immaginary 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° per hour.

(g) slope(β):

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

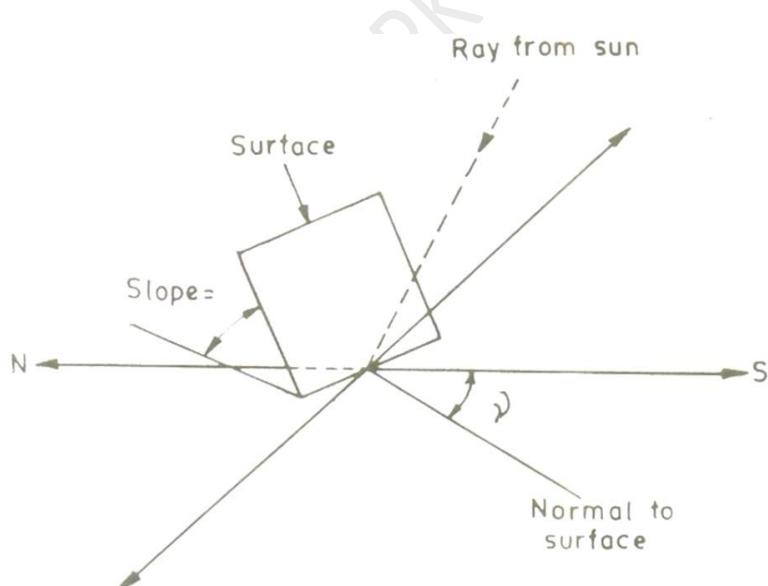
(h) surface azimuth angle(γ):

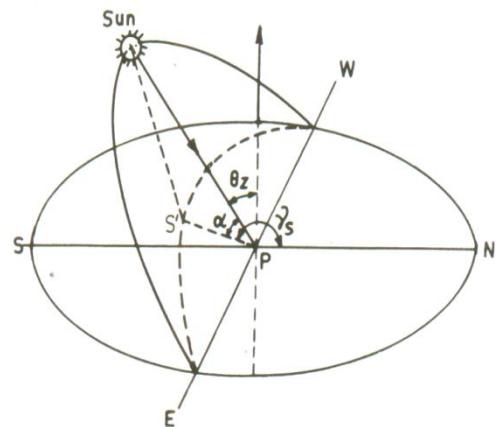
Angle between the normal to the collector and south direction is called surface azimuth angle(γ)

(i) Solar Incident angle(θ):

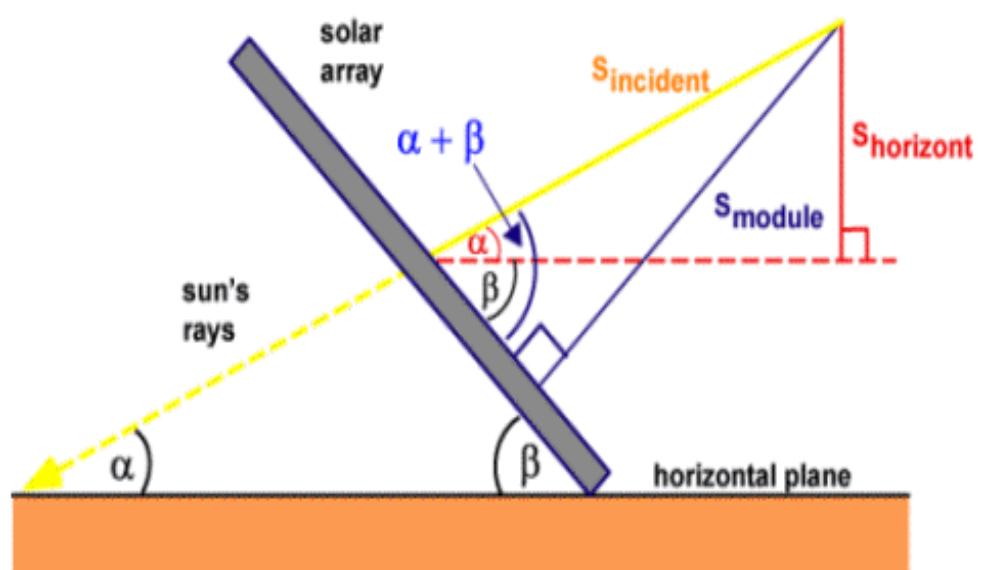
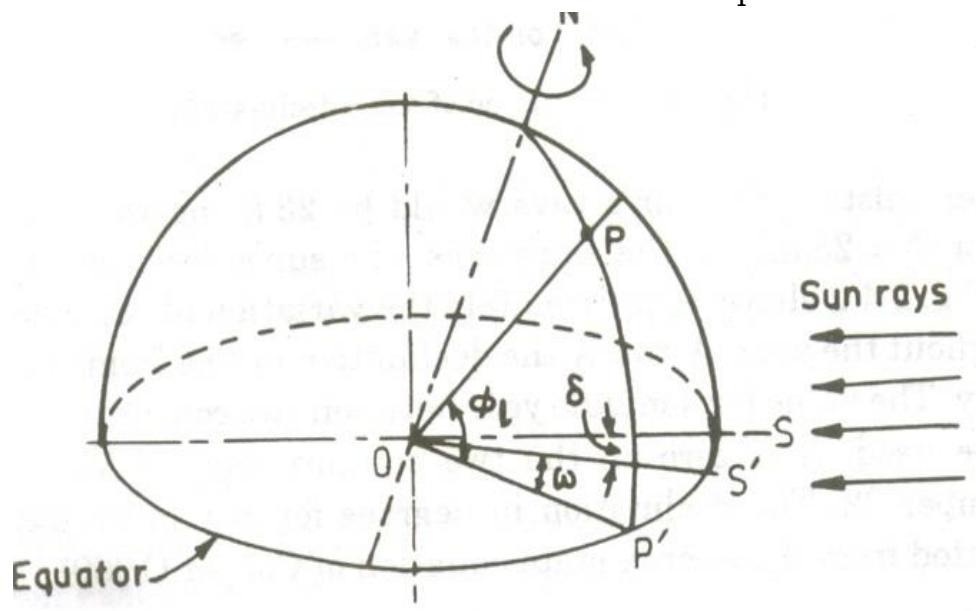
It is the angle between an incident beam radiation falling on the collector and normal to the plane surface

Figures:





he plane surface.



Relation between θ and other angles is as follows

$$\cos\theta = \sin\phi(\sin\delta \cos\beta + \cos\delta \cos\gamma \cos\omega \sin\beta) + \cos\phi(\cos\delta \cos\omega \cos\beta - \sin\delta \cos\gamma \sin\beta) + \cos\delta \sin\gamma \sin\omega \sin\beta \quad \text{Eqn(1)}$$

ϕ =Latitude(north positive)

δ =declination(north positive)

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

➤ Case1

Vertical Surface:

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

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

➤ Case2

Horizontal surfaces

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

$$\cos\theta = \sin\phi \sin\delta + \cos\delta \cos\phi \cos\omega = \sin\alpha = \cos\theta_z \quad \text{Eqn(3)}$$

➤ Case3

Surface facing south $\gamma=0$

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

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

$$= \sin\delta \sin(\phi - \beta) + \cos\delta \cos\omega \cos(\phi - \beta) \quad \text{Eqn(4)}$$

➤ Case4

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

$$\cos\theta_z = \sin\phi \cos\delta \cos\omega - \cos\phi \sin\delta \quad \text{Eqn(5)}$$

Day Length:

At the time of sunset or sunrise the zenith angle $\theta_z=90^\circ$, 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-Latitude of the location)+(Equation of time correction)

Example 1:

Determine the local solar time and declination at a location latitude $23^015'N$, longitude $77^030'E$ 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.

$$=12^h30'-4(82^030'-77^030')-1'01"$$

$$=12^h8'59"$$

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

$$\begin{aligned}\delta &= 23.45 \sin \left\{ \frac{360}{365} (284 + n) \right\} \\ &= 23.45 \sin \left\{ \frac{360}{365} (284 + 170) \right\} = 23.45 \sin 86^0 = 23.43^0\end{aligned}$$

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 $28^{\circ}35'N$. The collector is tilted at an angle of latitude plus 10° , with the horizontal and is pointing due south.

Solution:

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

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

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

$$\begin{aligned}\delta &= 23.45 \sin \left\{ \frac{360}{365} (284 + n) \right\} \\ &= 23.45 \sin \left\{ \frac{360}{365} (284 + 335) \right\} = -22^{\circ}11''\end{aligned}$$

Hour angle ω corresponding to 9.00hr= 45°

Hence,

$$\begin{aligned}\cos \theta_T &= \cos(28.58^{\circ} - 38.58^{\circ}) \cos(-22.11^{\circ}) \cos 45^{\circ} + \\ &\quad \sin(-22.11^{\circ}) \sin(28.58^{\circ} - 38.58^{\circ}) = 0.7104\end{aligned}$$

$$\theta_T = 44.72^{\circ}$$

UNIT-3**Beam Radiation:**

TILT FACTOR(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 $\gamma=0$

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

while for a horizontal surface

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

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

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

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

$(1 + \cos \beta)/2$ 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,

$$H_T = H_b R_b + \frac{H_d(1+\cos S)}{2} + \frac{(H_b+H_d)(1-\cos S)}{2} \rho$$

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 temp increases. 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 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

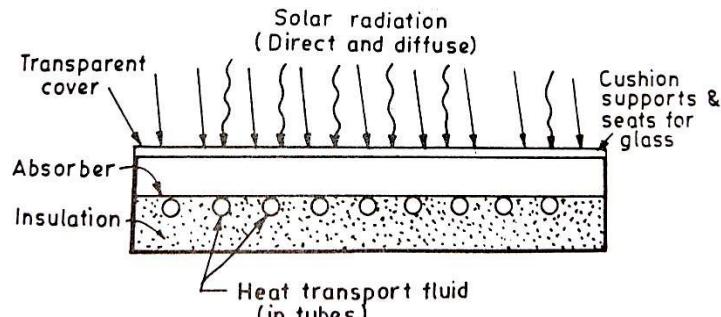


Fig. 3.3.1. Selection through typical flat-plate collector.

solar radiation into the useful energy gain and various losses.

The energy balance equation is given as

$$Q_u = A_c [HR(\tau, \alpha) - U_L(t_p - t_a)]$$

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 $^{\circ}C$, t_a is the atmospheric temp in $^{\circ}C$.

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,

$$\eta = \frac{\int Qu dt}{\int HR dt} = \frac{\text{the total useful heat gain in the collector}}{\text{the total incident radiation on the collector}}$$

Parameters affecting the performance of the FPC:

- 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) **Selective coating:** 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 $\alpha = \epsilon = 0.95$	Selective Absorber $\alpha=0.95, \epsilon = 0.12$	Selective Absorber $\alpha=0.85, \epsilon = 0.11$
T_{pm} (K)	356.1	359.3	357
U_L (W/m ² K)	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 $4\mu\text{m}$, because the incident radiation will be having a wavelength less than $4\mu\text{m}$. Similarly the coating should have minimum transmissivity for λ greater than $4\mu\text{m}$, because the radiation emitted from the absorber plate will be having a λ of greater than $4\mu\text{m}$.

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 ($\alpha=0.89, \epsilon=0.17$) nickel black on galvanized iron ($\alpha=0.868, \epsilon=0.088$).

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
$\eta \%$	40.6	43.6	41.8

Effect of No. of covers on GI absorber with selective coating ($\alpha=0.86, \epsilon = 0.11$).

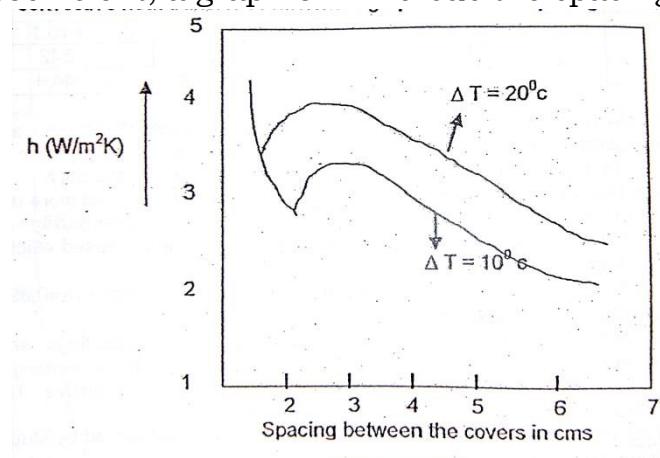
Parameter	No. of covers (1)	No. of covers (2)
$(\tau \alpha)_b$	0.7563	0.6999
$(\tau \alpha)_d$	0.6882	0.5891
$U_L (W/m^2K)$	3.61	2.51
$\eta \%$	47.0	44.9

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 $(\tau \alpha)$ 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 $(\tau \alpha)$ 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.



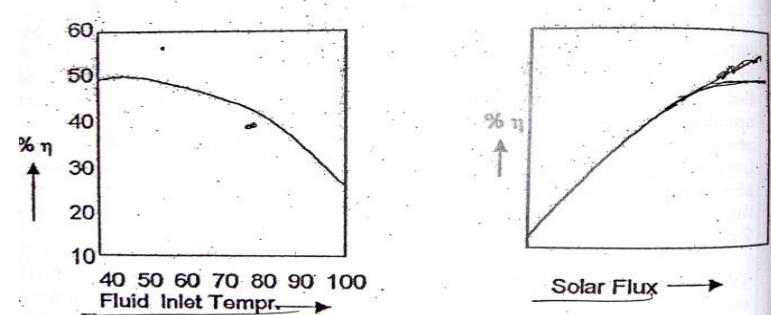
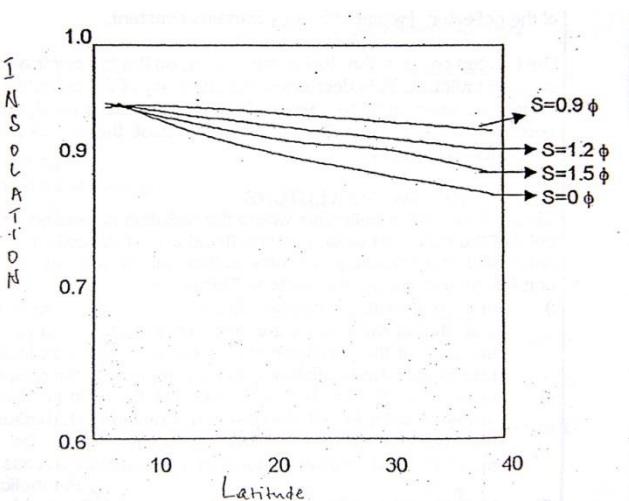
From the graph it is seen that

'h' decreases continuously upto about 2cm spacing and then increases with

the spacing, reaches a maximum continuously decreases thereafter. 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) **Tilt of the collector:** 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) **Fluid inlet temperature:** 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) **Incident solar flux:** 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) **Dust on top cover:** The dust accumulation on the top cover acts as an insulator for incident radiation. This decreases the η of the collector. In

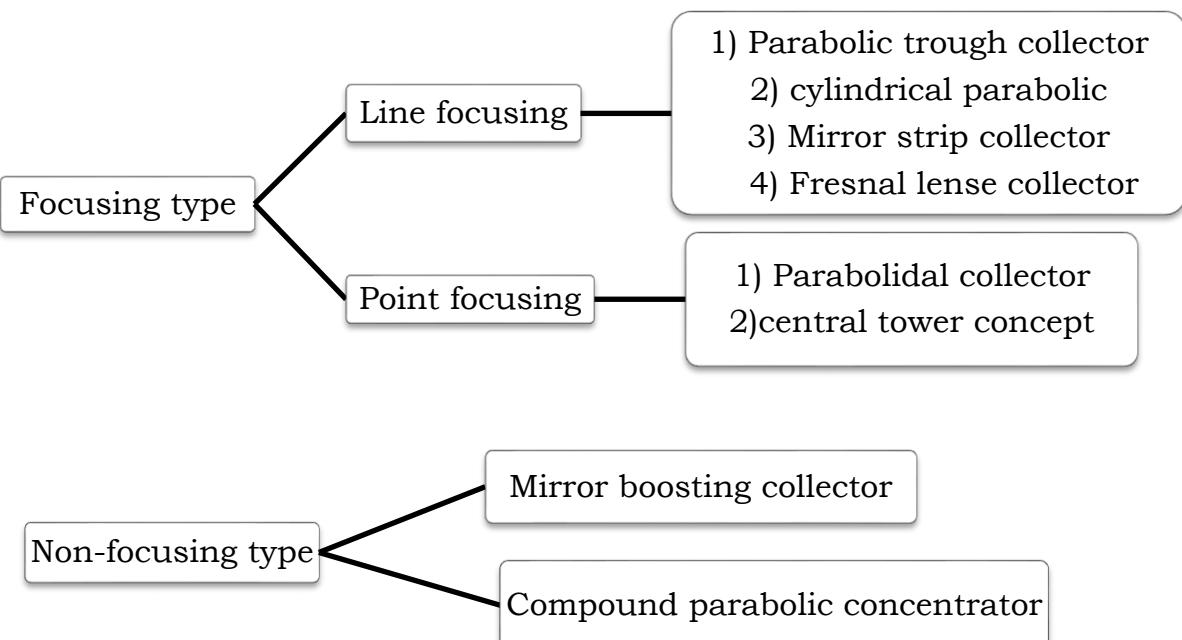


order to take care of this correction factor ranging from 0.92 to 0.99 is used. The selection of which depends on the location, the density of the dust, the collector orientation, cleaning frequency, and the season.

Concentrating collectors: 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.

Classification of concentrating collectors:



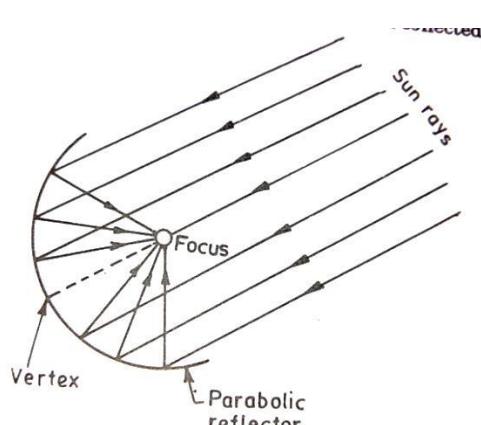


Fig. 3.7.1. Cross-section of parabolic-trough collector.

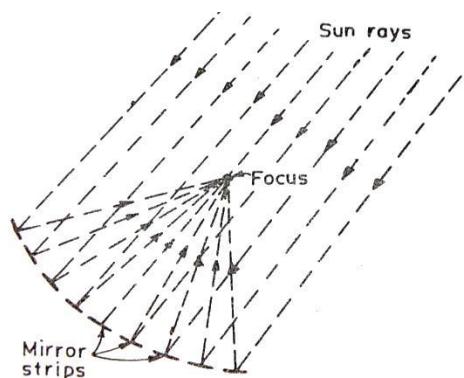
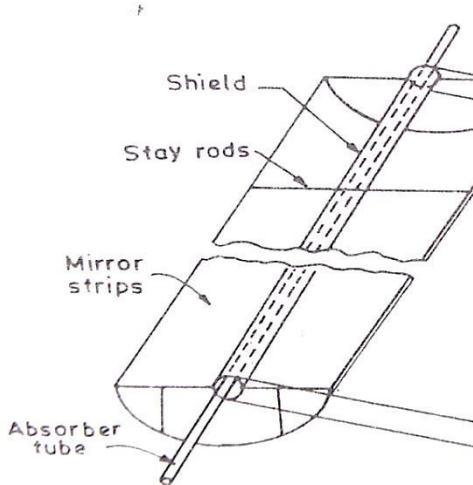


Fig. 3.7.3. Mirror-strip solar collector.

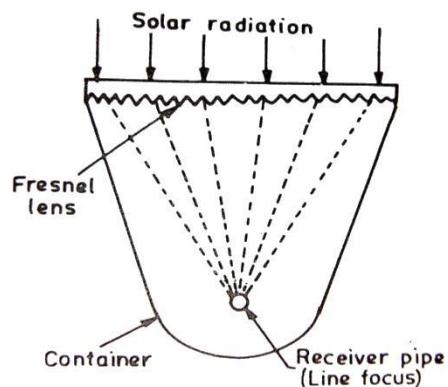


Fig. 3.7.4. Cross-section of Fresnel lens through collector.

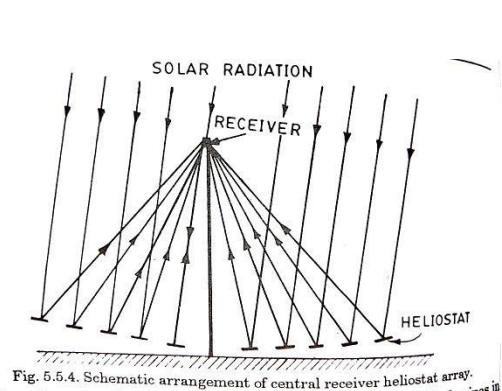


Fig. 3.7.5. Schematic arrangement of central receiver heliostat array.

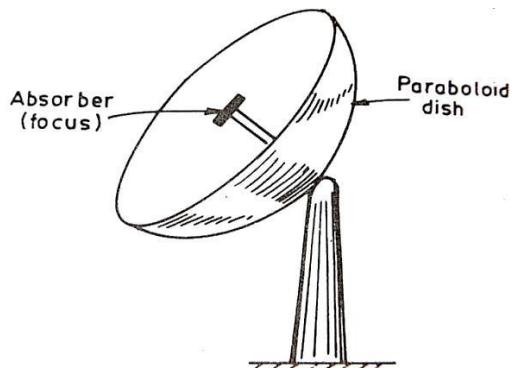


Fig. 3.7.7. Point focus solar collector (Paraboloid).

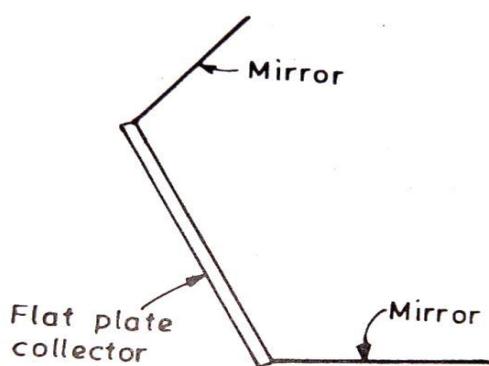


Fig. 3.7.9. Flat-plate collector augmented with mirrors.

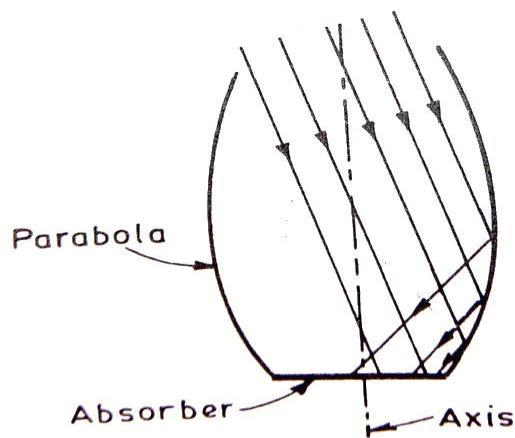


Fig. 3.7.10. Compound parabolic concentrator.

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°C.

Paraboloidal Dish Collector:

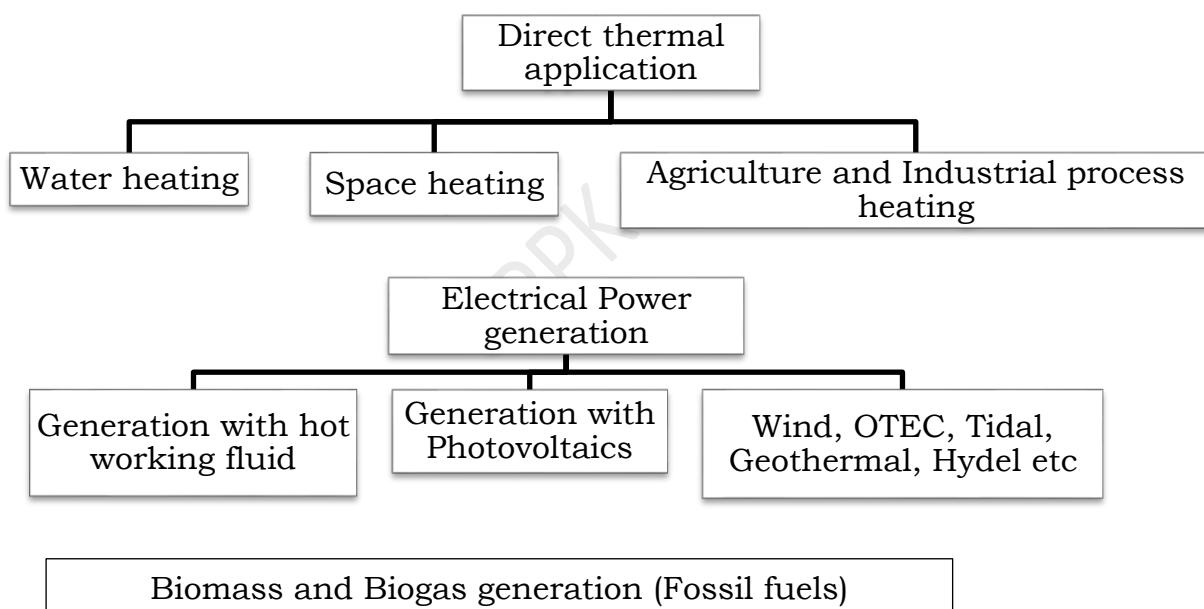
When a parabola is rotated about its optical axis a paraboloidal surface is produced. Above figure shows the details of this type of collector. Beam radiation is focused at a point in the paraboloid. This requires two axis tracking. It can have concentration ratio ranging from 10 to few thousands and can yield temperature up to 3000°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

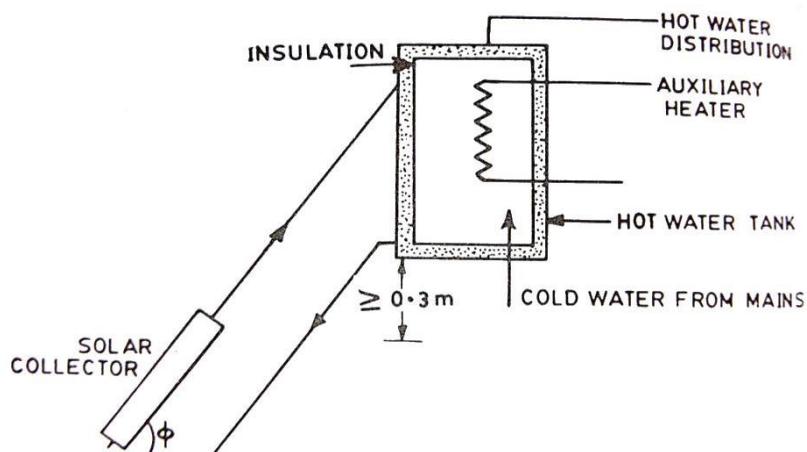
WATER HEATING SOLAR SYSTEM**NATURAL CIRCULATION SOLAR WATER HEATER (PRESSURIZED):**

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.

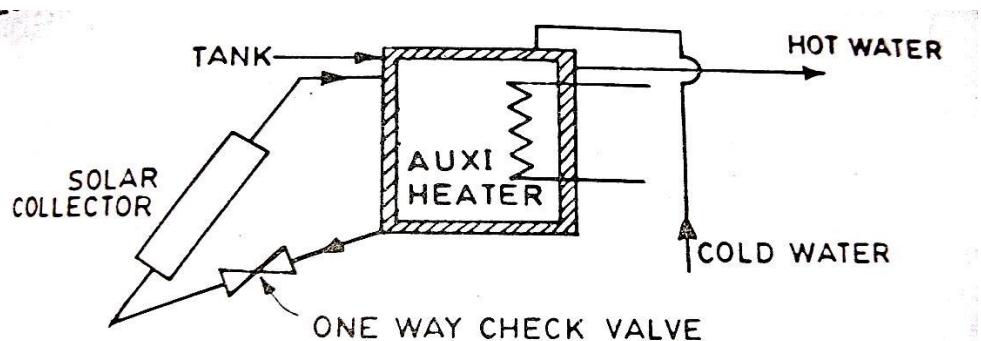
NATURAL CIRCULATION SOLAR WATER HEATER (NON-PRESSURIZED):

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.

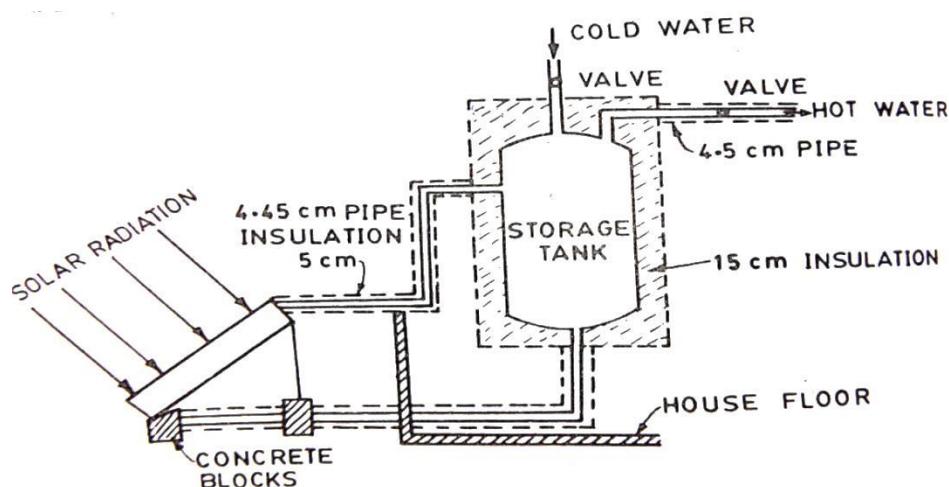


Fig. 5.2.3. A typical solar water heater.

FORCED CIRCULATION SOLAR WATER HEATER (WITHOUT ANTIFREEZE):

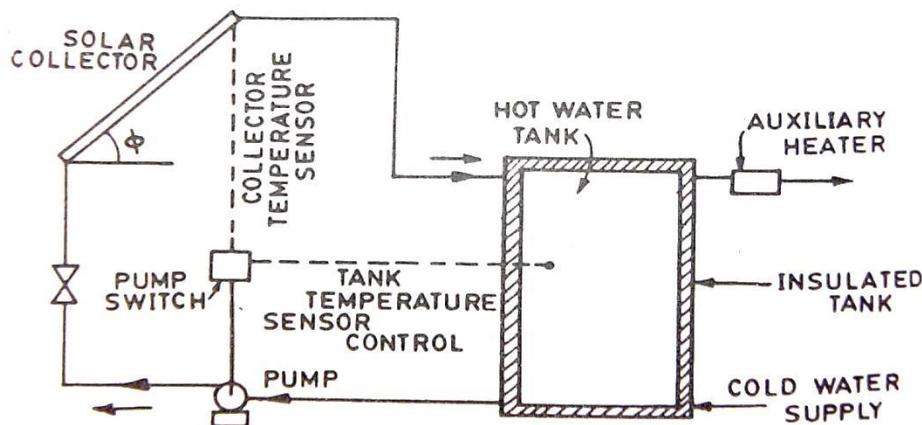


Fig. 5.2.4. Schematic of a forced circulation solar water heater.

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.

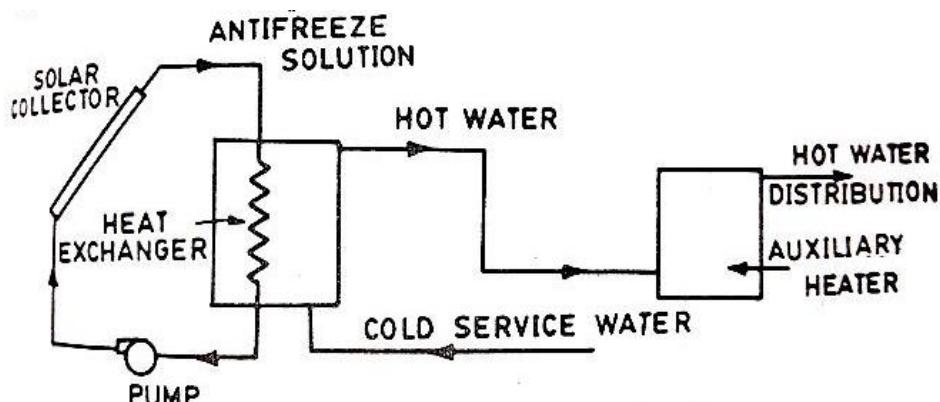
FORCED CIRCULATION SOLAR WATER HEATER (WITH ANTIFREEZE):

Fig. 5.2.5. Solar water heating system with antifreeze.

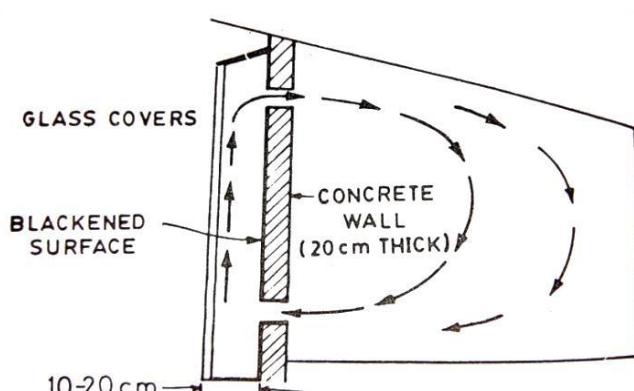
SPACE-HEATING:**SOLAR HEATING OF BUILDING:**

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.

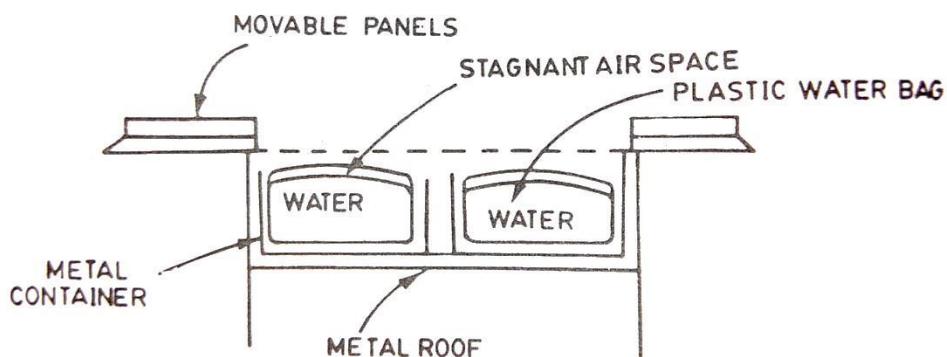
ROOF STORAGE OF SOLAR HEAT:

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.

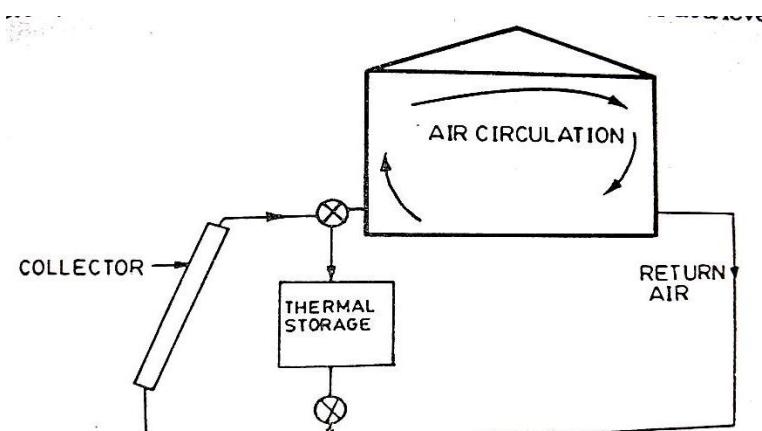
CONVECTIVE LOOP PASSIVE SOLAR HEATING:

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:

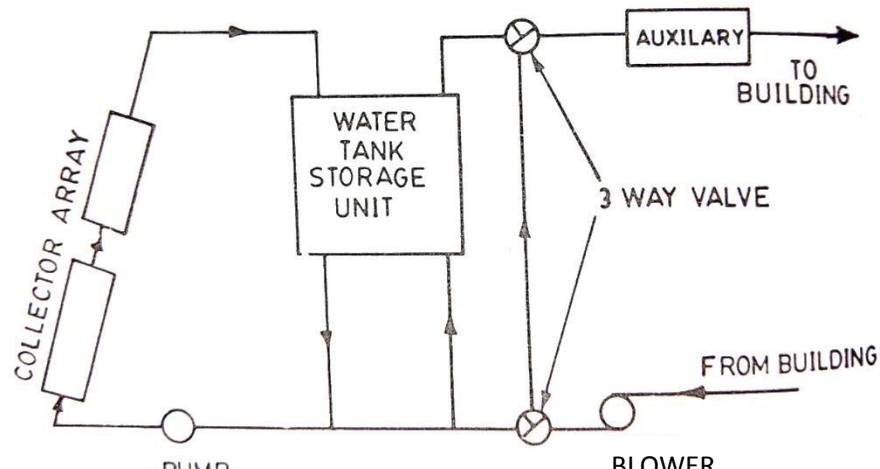


Fig. 5.3.4. Schematic of a basic hot water active system.

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):

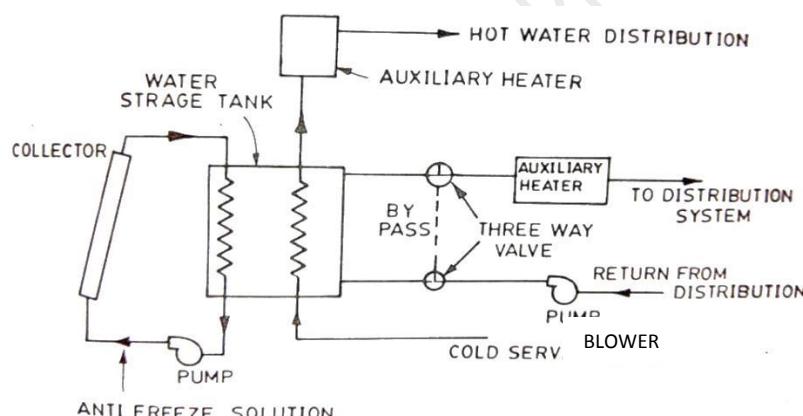


Fig. 5.3.5. Solar space heating and hot water system.

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.

BASIC HOT AIR SYSTEM:

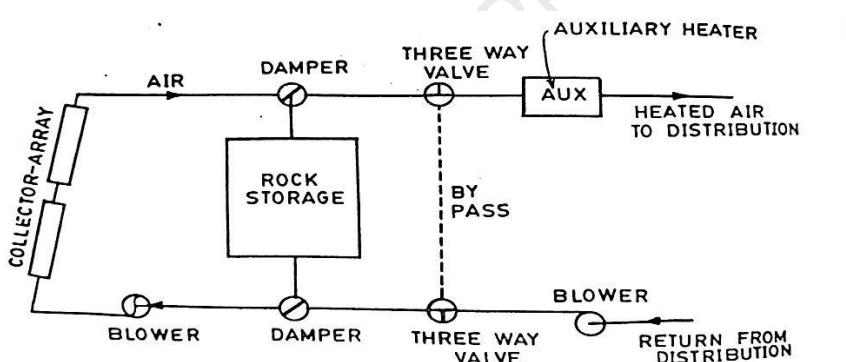


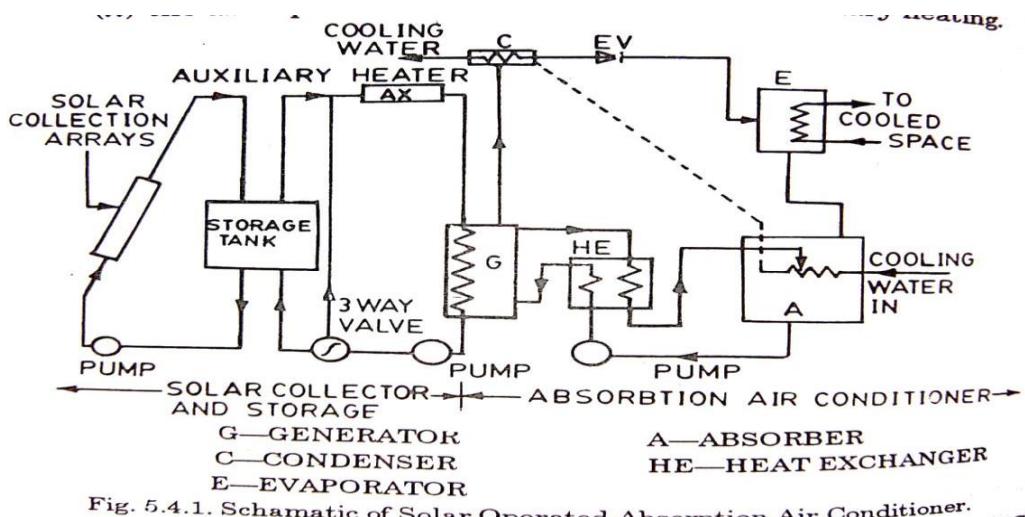
Fig. 5.3.6. Schematic diagram of a basic hot air heating system.

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.

SOLAR SPACE COOLING OF BUILDINGS:VAPOUR ABSORPTION AIR COOLING (LiBr-H₂O SYSTEM 85 to 95°C with FPC /NH₃-H₂O COOLER 120 to 130°C with concentrating collectors):



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

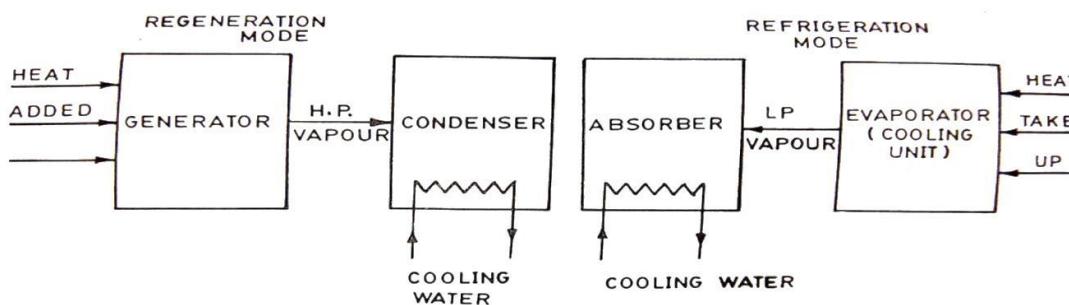
essence cooling is accomplished as the generator of the absorption cooler is supplied with heat by a fluid pumped from the collector storage system or from auxiliary. Heat is supplied to a solution of refrigerant in absorbent in the generator, where refrigerant is distilled out of the absorbent fluid. 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-H₂O 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 to date are LiBr-H₂O 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 ($\text{NH}_3\text{-H}_2\text{O}$) and ammonia-sodium thiocyanate ($\text{NH}_3\text{-NaSCN}$).

SOLAR THERMAL ELECTRIC CONVERSION:

SOLAR POND:

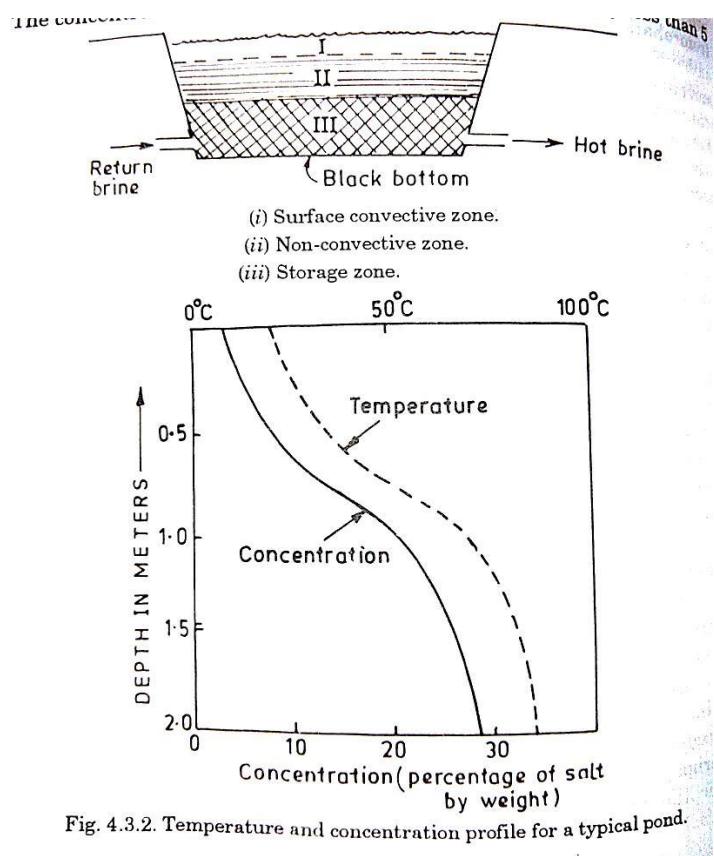


Fig. 4.3.2. Temperature and concentration profile for a typical pond.

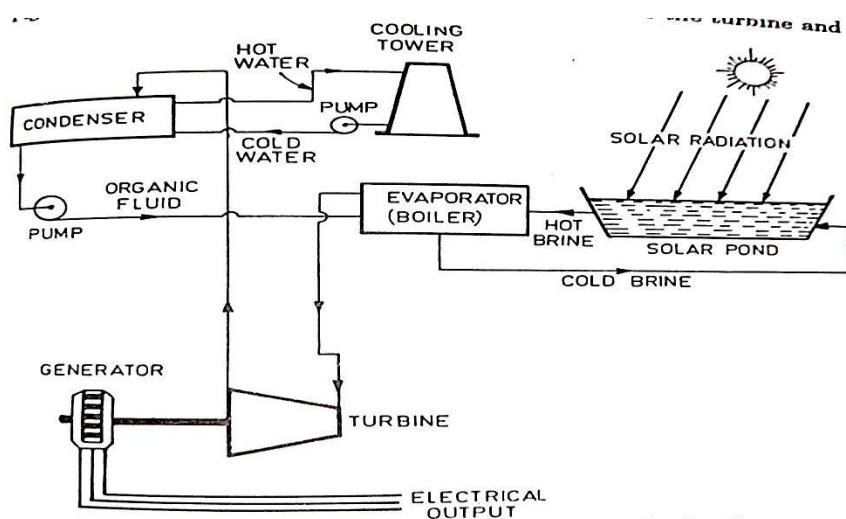


Fig. 4.3.3. Solar pond electric power plant with cooling tower.

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:

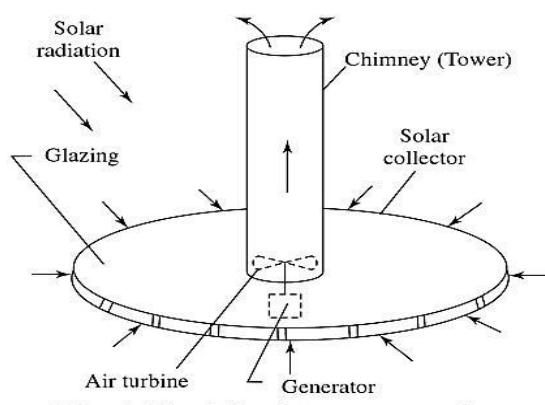


Fig. 2.20 Solar chimney power plant

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.

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

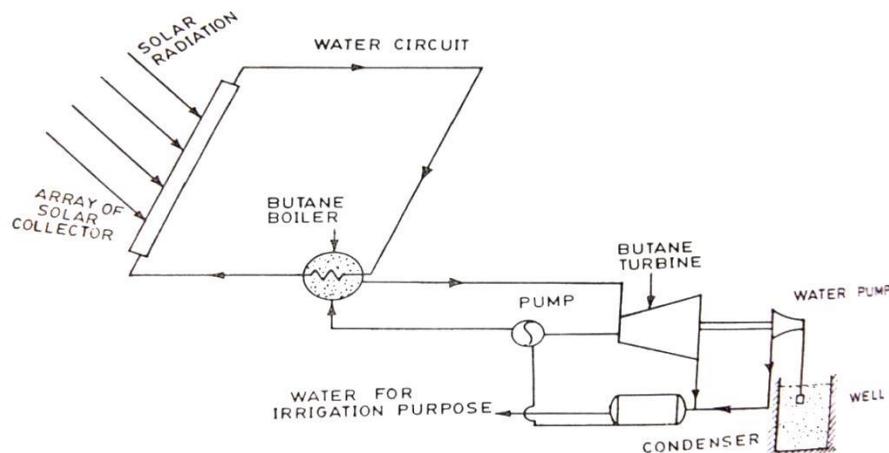


Fig. 5.5.2. Schematic of a low temperature solar power plant. nearby

The system has an 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.

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

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.

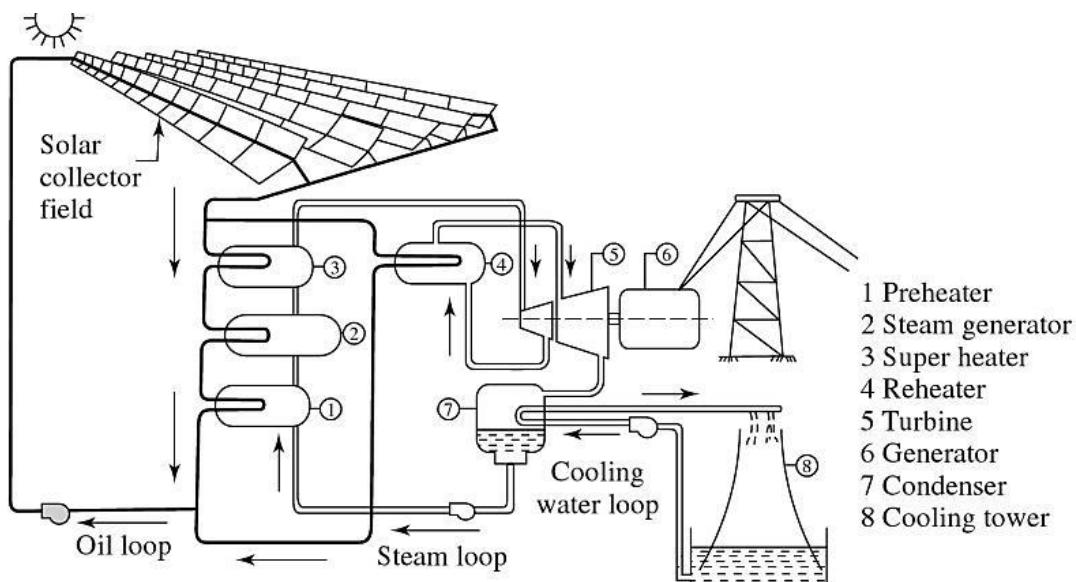


Fig. 2.21 Medium temperature power generation cycle using cylindrical parabolic concentrating collectors

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 RECEIVER 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.

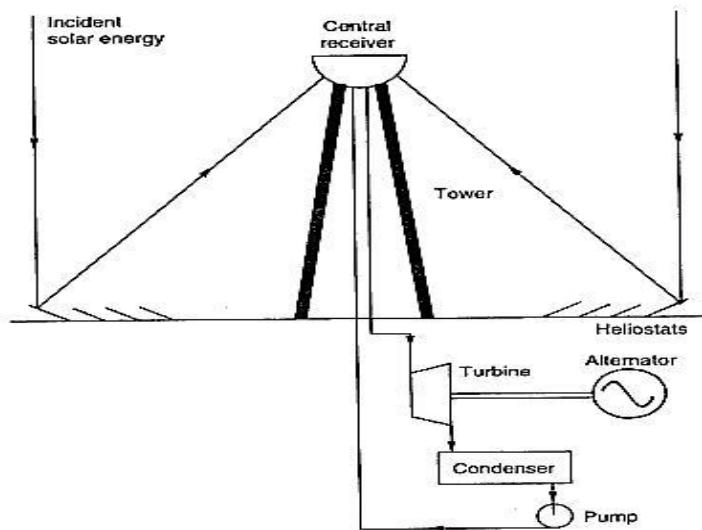


Fig. 2.16 Central Receiver Power Plant

SOLAR POWER GENERATION BY THERMAL STORAGE:

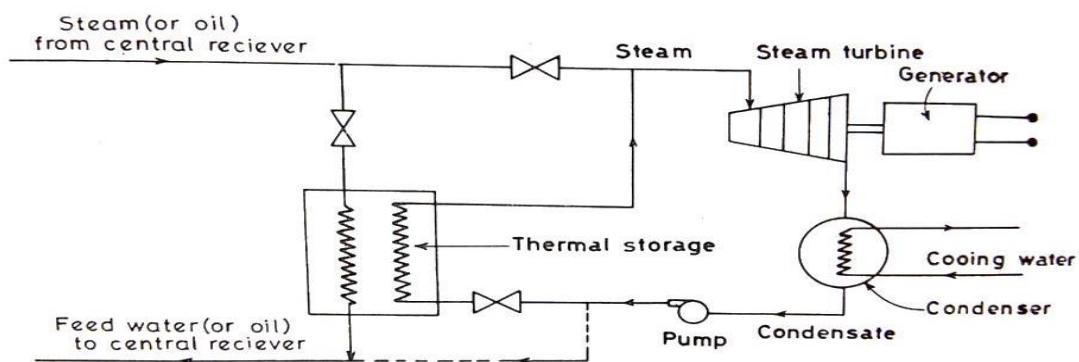


Fig. 5.5.6. Electric power generation using thermal storage.

SOLAR ELECTRIC POWER GENERATION BY SOLAR PHOTOVOLTAIC CELLS:

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.

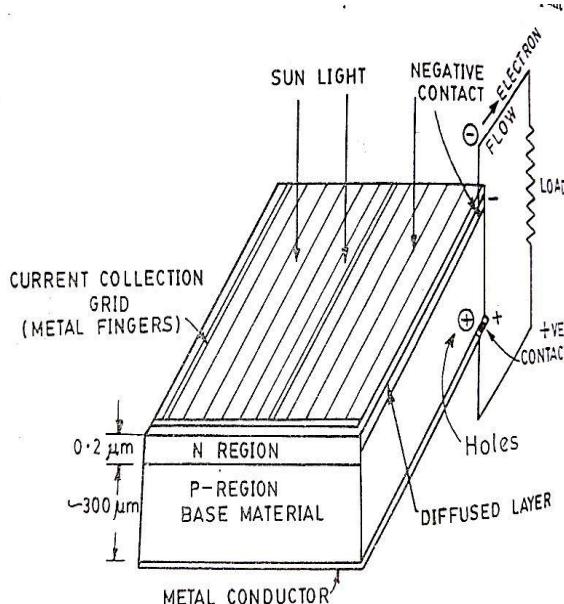


Fig. 5.6.1. Schematic view of a typical solar cell.

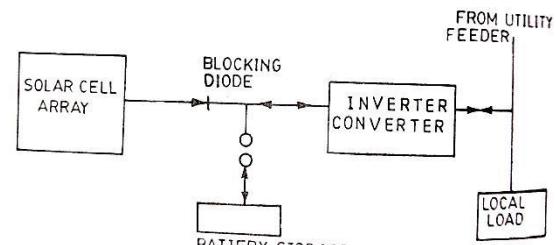


Fig. 5.6.5. Basic photovoltaic system integrated with power grid.

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.

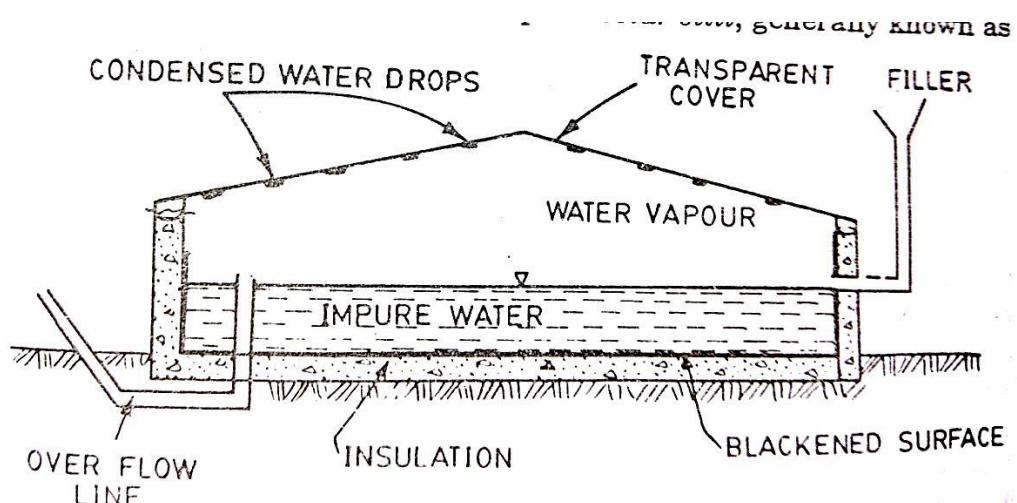
SOLAR DISTILLATION:

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 United 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 to be distilled. The depth of water is kept about 5-10 cm. It is covered with sloping 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 benzene, Pyridine, Freon-11,113, Thiopene etc.

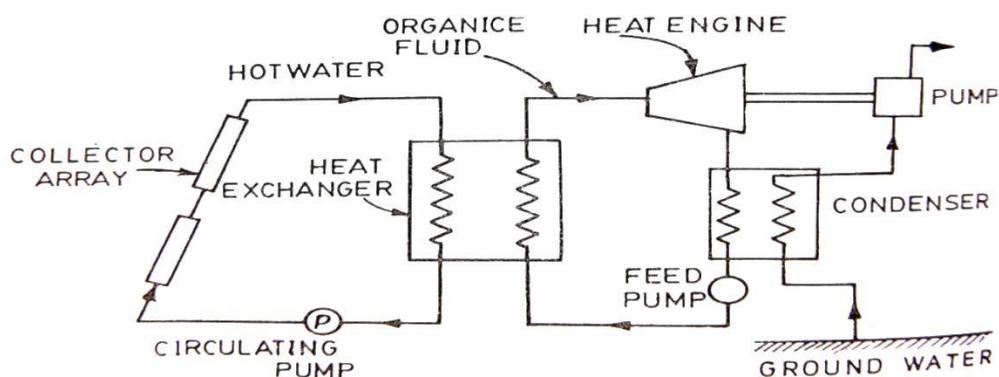


Fig. 5.9.1. Schematic of a solar pump.

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 operation 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.

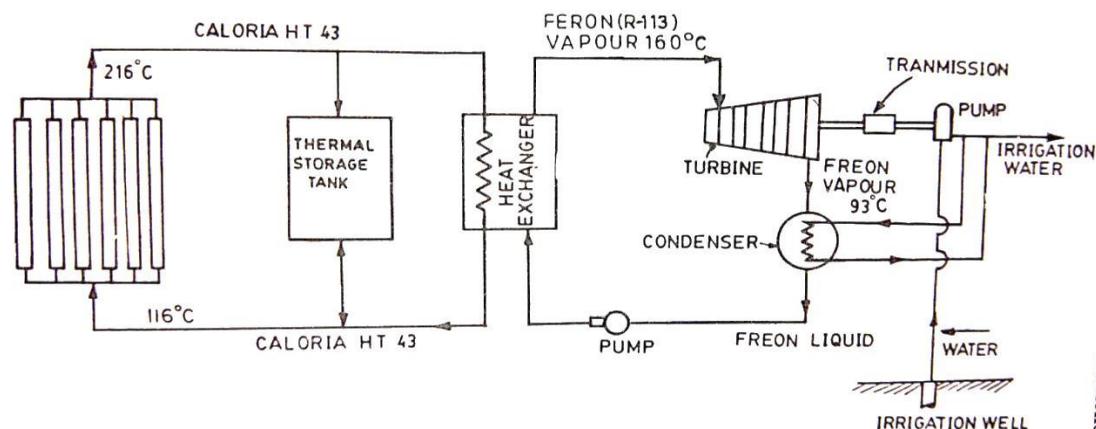


Fig. 5.9.2. A schematic of a turbine-driven pump using solar energy.

ECONOMY FOR THE SYSTEM

SOLAR FURNACE (3800°C):

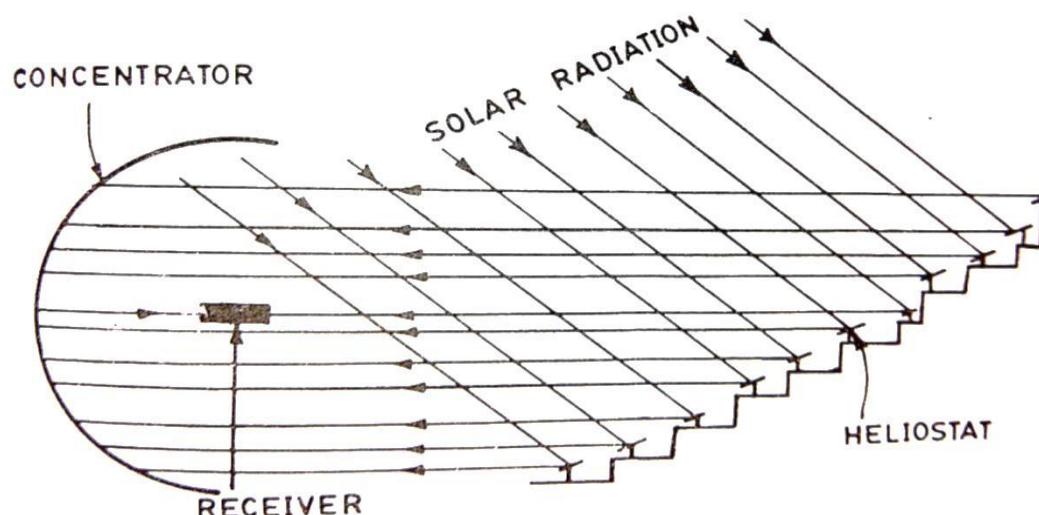


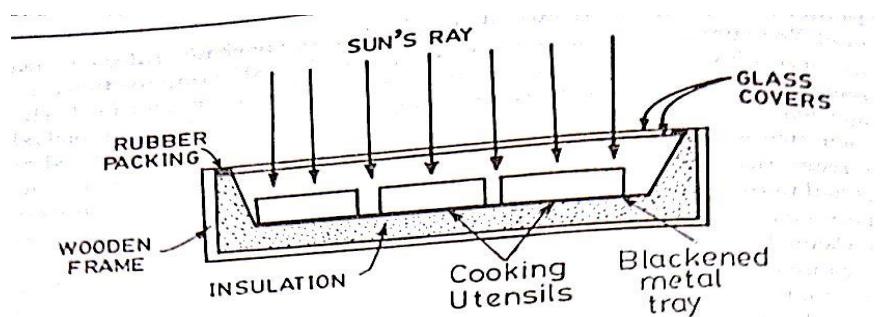
Fig. 5.10.1. Principle of Solar Furnace.

Principle of Working:

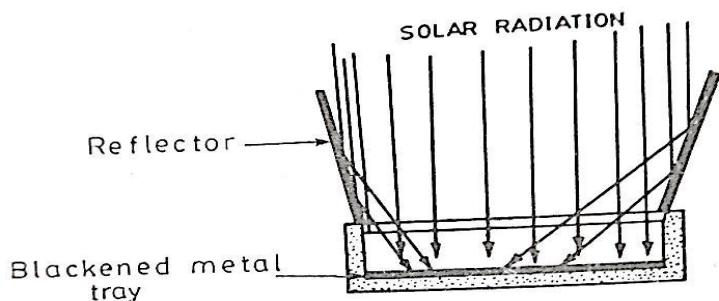
The principle of the solar furnace is outlined in Fig.5.10.1. A number of heliostates are arranged in terraces on a sloping surface so that, regardless of the sun's position, they always reflect solar radiation in the same direction onto a large paraboloid reflecting collector made up of many fixed mirrors 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:

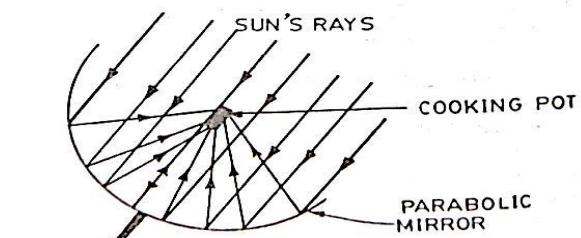
Thermal energy requirements for cooking purpose forms a major share of the total energy consumed, especially in rural areas. Variety of fuels like coal, kerosene, cooking gas, firewood, dung cakes and agricultural wastes are being used to meet the requirement. Fossil fuel is a fast depleting resource and need to be conserved, firewood for cooking causes deforestation 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):

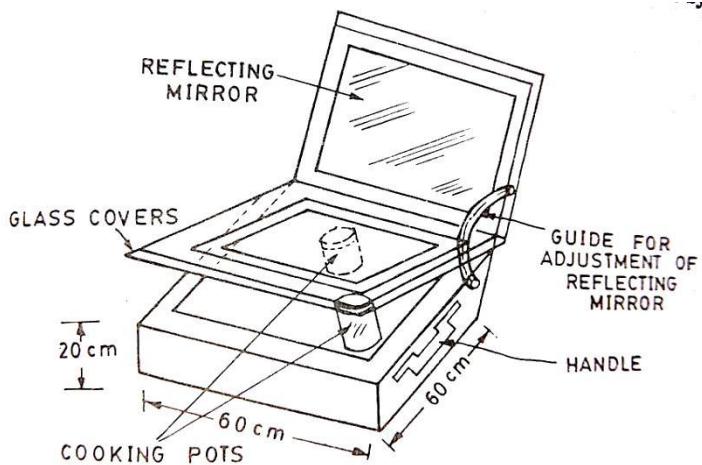


Fig. 5.11.2. Details of a box type cooker.

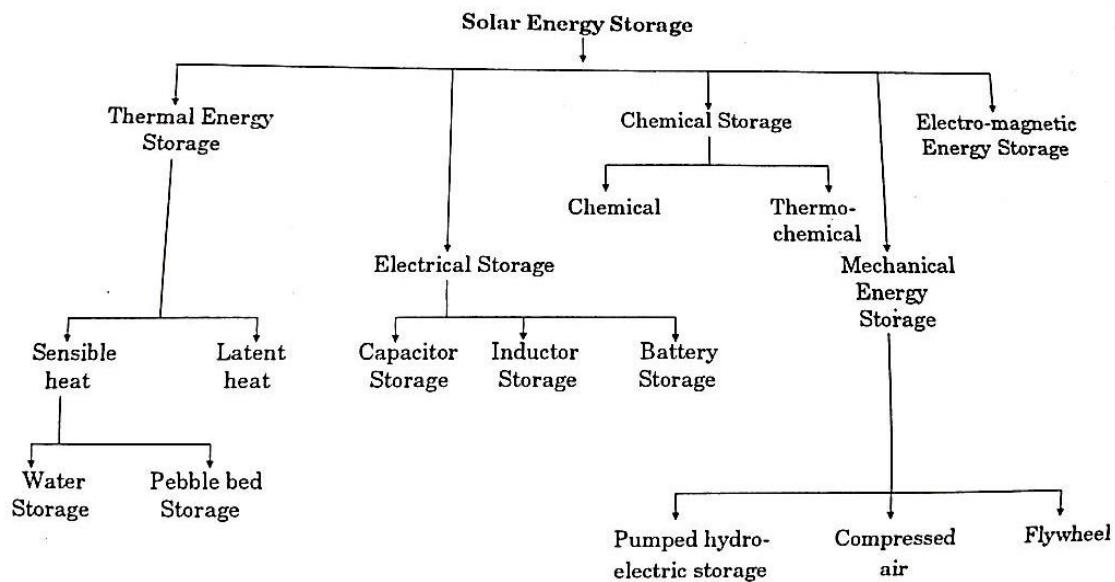
The construction of a most common, box type solar cooker is schematically shown in figure above. The external dimensions of a typical family size box type cooker are 60x60x20 cm. This cooker is simple in construction and operation. An insulated box of blackened aluminium contains the utensils with food 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°C. This is enough for cooking the boiling type food slowly in about 2-3 hours.

SOLAR ENERGY STORAGE SYSTEMS:

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.

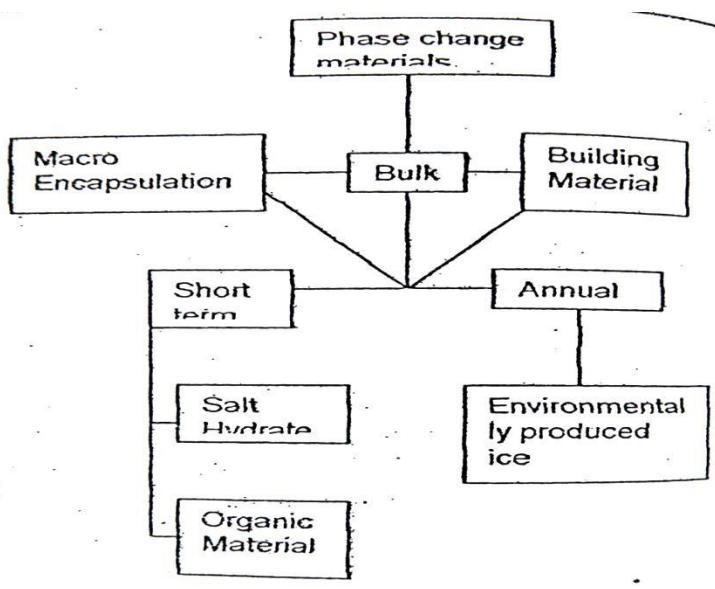
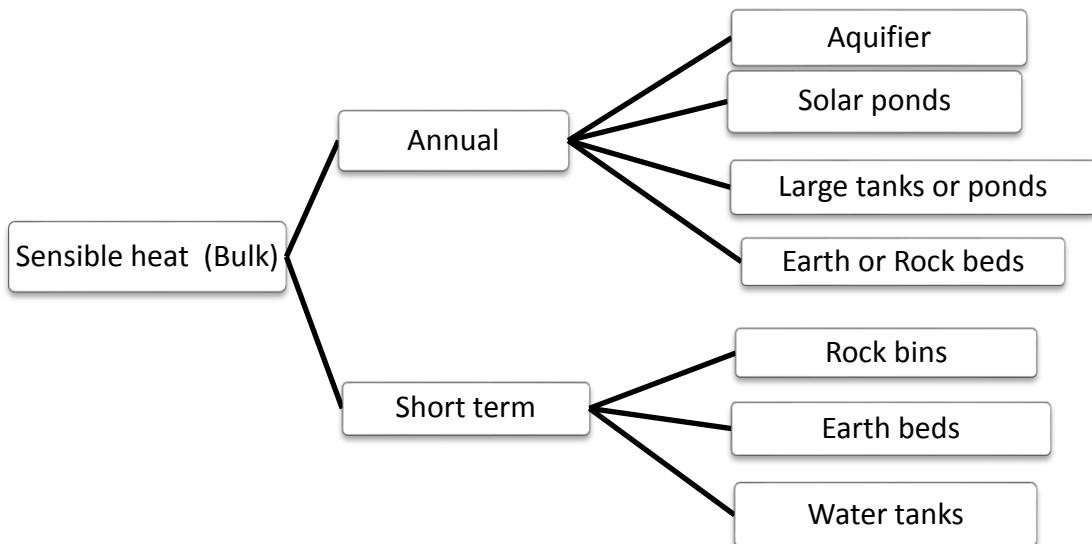


There are four main factors affecting the cost affecting the cost of solar thermal energy storage systems. They are,

- 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 - liquid)
Temperature Range	0 – 100°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

UNIT-4**Energy Balance Equation and Collector Efficiency**

The performance of solar collector is described by an energy balance that indicates the distribution of incident solar radiation into the useful energy gain and various losses. The thermal losses can be separated into three components:

(i)Conductive losses: An overall heat transfer coefficient value of less than 0.69 W/m²K is suggested to minimize back losses.

(ii)Convective losses: Sizing the air gap between the collector covers at 1.25 to 2.5 cm reduces internal convective losses to the minimum possible level. Convection losses between glass plates can also be inhibited if a honeycomb type, cellular structure is placed between the absorber and the outer window plate. Evacuation of the space between the absorber and the outer cover has been proposed to reduce internal convection and conduction, but the cost of added supports and maintenance of a vacuum are excessive,

(iii)Radiative losses: Radiative losses from the absorber can be reduced by the use of spectrally selective absorber coatings. Such coatings have a high absorptance of about 0.9 in the solar spectrum and a low emittance, usually of the order of 0.1, in the infrared spectrum in which the absorber radiates to the environment. Selective absorber coating, therefore decrease heat losses and increase collector efficiency.

Under steady conditions, the useful heat delivered by a solar collector is equal to the energy absorbed in the metal surface minus the heat losses from the surface directly and indirectly to the surroundings. This principle can be stated in the relationship:

$$Q_u = A_c [HR(\tau \times \alpha)_e - U_L(t_p - t_a)]$$

Where **Qu** is the useful energy delivered by collector, Watts or kcal/hr.

A_c is the collector area, m²

solar energy received on the upper surface of the sloping collector structure;

W/m^2 or kcal/hrm^2 .

Beam and diffuse radiations are considered separately. (τ, α) for radiation is determined from the actual angle of incidence; (τ, α) for diffuse radiation may be taken as that for beam radiation at an incidence angle of 60° . The symbol HR is used to represent the sum of H_bR_b and H_dR_d

τ is the fraction of incoming solar radiation that reaches the absorbing surface, *transmissivity* (dimensionless).

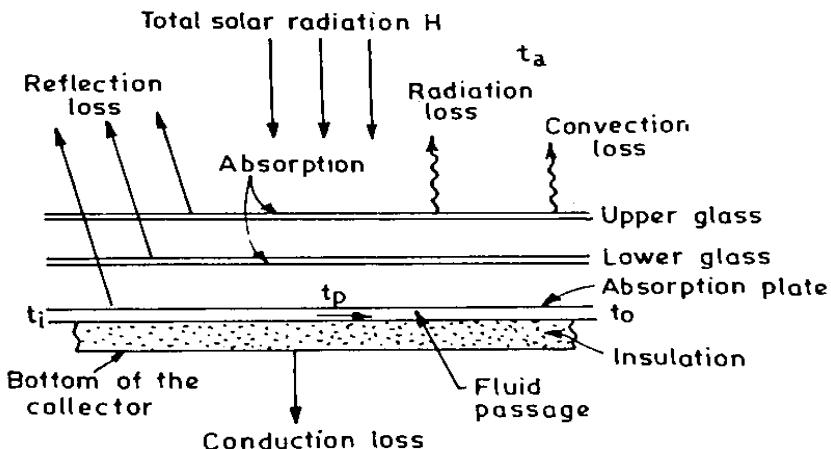
A is the fraction of solar energy reaching the surface that is absorbed, *absorptivity* (dimensionless).

$(\tau, \alpha)e$ is effective transmittance absorptance product of cover system for beam and diffuse radiation.

U_L is the overall heat loss coefficient. It is the rate of heat transferred to the surroundings per square metre of exposed collector surface per degree Celsius difference between average collector surface temperature and the surrounding air temperature, $\text{W/m}^2\text{C}$ ($\text{kcal/hr m}^2\text{C}$).

t_p is the average temperature of the upper surface of the absorber plate, $^\circ\text{C}$.

t_a is atmospheric temperature, $^\circ\text{C}$.



Absorbed Energy = $A_c \cdot HR \cdot \tau \cdot \alpha$
 Effective heat loss = $A_c U_L (t_p - t_a)$

Fig. 3.5.1. Definition sketch for Equation (3.5.1).

The *energy balance equation* on the whole collector can be written as :

$$Ac[\{HR(\tau \cdot \alpha)_b + HR(\tau \cdot \alpha)d\}] = Qu + Q_l + Q_s$$

where

Qu = rate of useful heat transfer to a working fluid in the solar heat exchanger.

Q_l = rate of energy losses from the collector to the surroundings by re-radiation, convection and by conduction through supports for the absorber plate and so on. The losses due to reflection from the covers are included in the $(\tau \cdot \alpha)$ terms; and

Q_s = rate of energy storage in the collector.

Collector efficiency η_c , is the collector performance and is defined as the ratio of the useful gain over any time period to the incident solar energy over the same time period.

$$\eta_c = \frac{\int Qu \, dT}{\int HR \, dT}$$

Thermal analysis of flat plate collector and useful heat gained by the fluid:

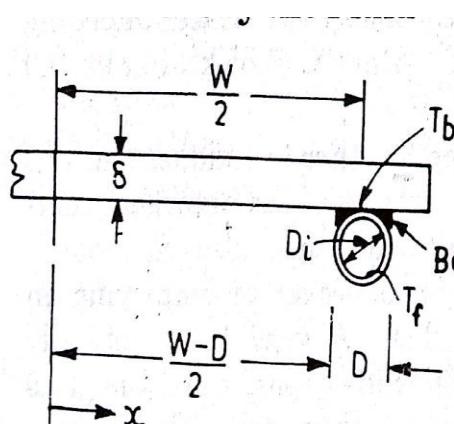


Fig. 3.6.1. Sheet and tube dimensions of a Liquid Flat Plate Collector.

Let us assume temporarily the negligible temperature gradient in the flow direction. Let W be the distance between the bond tubes (W = absorber plate length between tubes).

Let D_i and D be the inside and outside diameters of the tubes, and δ is the sheet thickness as shown in Fig. 3.6.1. Because the

sheet material is a good conductor, the temperature gradient through the sheet is negligible. Consider a section of the absorber plate with two adjacent fluid tubes. The temperature in the plate (T_p) will vary in x direction and it is assumed that the same distribution exists between any two tubes. Also assumed that sheet above the bond to be at same local base temperature T_b , i.e. above the fluid tubes, the temperature will be constant, while in between the tubes, the temperature will pass through a maximum. The region between the centre line separating the tubes and the tube base can then be considered as a classical fin problem.

The fin length is equal to $\frac{W-D}{2}$ as shown in Fig. 3.6.2, and $W/2$

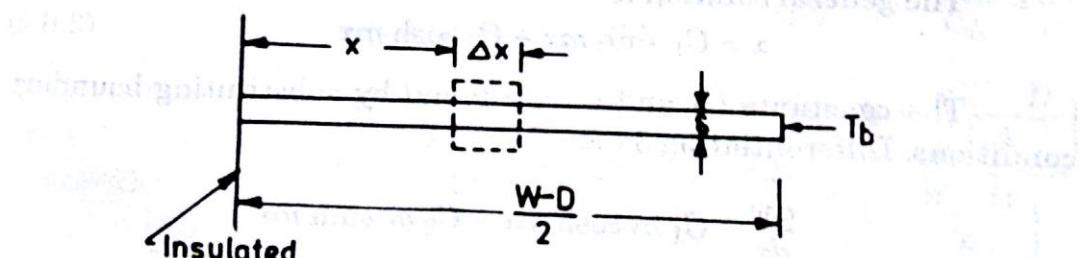
is distance from centre of collector to the centre of the tube. Considering heat transfer occurring in the x direction. For an elemental region Δx and unit length in the flow direction, energy balance yields :

$$S \Delta x - U_L \Delta x (T - T_a) + \left(-K \delta \frac{dT}{dx} \right)_x - \left(-K \delta \frac{dT}{dx} \right)_{x+\Delta x} = 0 \quad \dots(3.6.1)$$

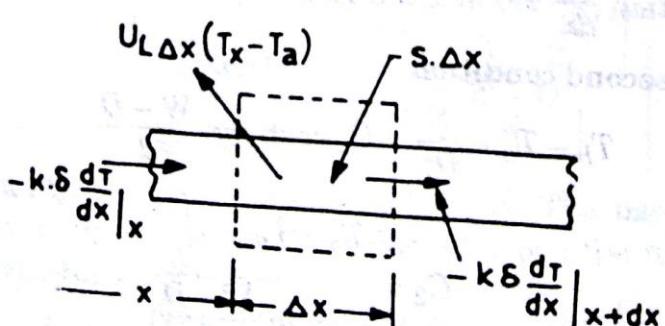
or $S \Delta x + U_L (T_a - T) \Delta x - K \delta \frac{dT}{dx} - \left[-K \delta \frac{d}{dx} (T + dt) \Delta x \right] = 0$

or $S \Delta x + U_L (T_a - T) \Delta x - K \delta \frac{dT}{dx} + K \delta \frac{dT}{dx} + K \delta \frac{d^2 T}{dx^2} \Delta x = 0$

or $S \Delta x + U_L (T_a - T) \Delta x = -K \delta \frac{d^2 T}{dx^2} \Delta x$



(a)



(b)

Fig. 3.6.2. Energy balance on fin element.

$$\text{or } S + U_L(T_a - T) = -K\delta \frac{d^2T}{dx^2}$$

$$\text{or } \frac{d^2T}{dx^2} = +\frac{U_L}{K\delta} \left(T - T_a - \frac{S}{U_L} \right) \quad \dots(3.6.2)$$

Expression 3.6.2 is of the second order differential equation, the two boundary conditions are,

$$(i) \quad \left. \frac{dT}{dx} \right|_{x=0} = 0,$$

$$(ii) \quad T \Big|_{x=\frac{W-D}{2}} = T_b$$

$$\text{Let } m^2 = \frac{U_L}{K\delta}, \text{ and } \psi = T - T_a - \frac{S}{U_L}$$

The equation 3.6.2 becomes

$$\frac{d^2\psi}{dx^2} - m^2\psi = 0 \quad \dots(3.6.3)$$

which has the boundary conditions

$$\left. \frac{dy}{dx} \right|_{x=0} = 0,$$

$$\psi \Big|_{x=\frac{W-D}{2}} = T_b - T_a - \frac{S}{U_L}$$

The general solution is

$$x = C_1 \sinh mx + C_2 \cosh mx \quad \dots(3.6.4)$$

The constants C_1 and C_2 are found by substituting boundary conditions. Differentiating 3.6.4

$$\frac{d\psi}{dx} = C_1 m \cosh mx + C_2 m \sinh mx$$

$$\text{Condition } \frac{d\psi}{dx} = 0 \text{ at } x = 0 \text{ gives } C_1 = 0$$

From second condition

$$T_b - T_a - \frac{S}{U_L} = C_2 \cosh mx \frac{W-D}{2}$$

$$C_2 = \frac{T_b - T_a - \frac{S}{U_L}}{\cosh m \frac{W-D}{2}}$$

The equation 3.6.4 becomes

$$\frac{T - T_a - S/U_L}{T_b - T_a - S/U_L} = \frac{\cosh mx}{\cosh m \left(\frac{W-D}{2} \right)} \quad \dots(3.6.5)$$

The energy conducted to the region of the tube per unit of length in the flow direction is

$$q_{fin \ base}^1 = -K \delta \frac{dT}{dx} \Big|_{x=\frac{W-D}{2}}$$

From equation (3.6.5),

$$\begin{aligned} \frac{dT}{dx} &= \left(T_b + T_a - \frac{S}{U_L} \right) \frac{m \sinh mx}{\cosh m \left(\frac{W-D}{2} \right)} \\ \therefore q_{fin \ base}^1 &= \frac{K \delta m}{U_L} [S - U_L (T_b - T_a)] \tanh \left(\frac{W-D}{2} \right) m \end{aligned} \quad \dots(3.6.6)$$

Equation 3.6.6 accounts for the energy collected to only one side of a tube, for both sides

$$\begin{aligned} q_{fin \ base} &= \frac{2K \delta m}{U_L} [S - U_L (T_b - T_a)] \tanh m \left(\frac{W-D}{2} \right) \\ &= 2 \frac{1}{m} [S - U_L (T_b - T_a)] \tanh m \left(\frac{W-D}{2} \right) \\ &\quad \left[\because m^2 = \frac{U_L}{K \delta}, \ \therefore \frac{K \delta m}{U_L} = \frac{1}{m} \right] \\ &= 2 \left(\frac{W-D}{2} \right) [S - U_L (T_b - T_a)] \frac{\tanh m \left(\frac{W-D}{2} \right)}{m \left(\frac{W-D}{2} \right)} \\ &= (W-D)(F[S - U_L (T_b - T_a)]) \end{aligned}$$

$$\text{where } F = \left\{ \frac{\tanh m \left(\frac{W-D}{2} \right)}{m \left(\frac{W-D}{2} \right)} \right\}$$

and it is usually known as the *fin efficiency*. The useful gain of the collector also includes the energy collected above the tube region. The energy gain for the tube region

$$q_{tube} = D [S - U_L (T_b - T_a)] \quad \dots(3.6.7)$$

Hence, the total energy gain of the collector tubes per unit length in the flow direction may be expressed as

$$q_u = q_{fin \ base} + q_{tube \ section}$$

$$= [(W - D)F + D][S - U_L(T_b - T_a)] \quad \dots(3.6.8)$$

Ultimately, the useful gain from the equation 3.6.7 must be transferred to the fluid. The resistance to heat flow to the tube from the plant may be consisted of three components :

- (i) the resistance due to the bonding material between the plate and the tube ;
- (ii) the resistance due to the temperature gradient in the fluid at the tube wall ;
- (iii) the resistance due to the wall thickness of the tube. Hence

$$q_u = \frac{T_b - T_f}{\frac{1}{C_b} + \frac{1}{\pi D_i h_{fi}} + \frac{1}{C_w}} \quad \dots(3.6.9)$$

where C_b = the conductance of the bond

C_w = the conductance of the tubewall

and h_{fi} = the local film heat transfer co-efficient.

The bond conductance is given as

$$C_b = \frac{K_b \cdot b}{y} \quad \dots(3.6.10)$$

where K_b = bond conductivity

b = bond length

y = bond average thickness.

The bond conductance can be very important in accurately describing collector performance. Simply wiring or clamping of the tubes to the sheet results in a significant loss of performance. It is necessary to have good metal to metal contact so that the bond resistance is less than 0.33 m °C/W.

The useful energy gain of the fluid can then be expressed in terms of the known dimensions, the physical parameters and the local fluid temperature by solving the equation 3.6.9 for T_b and substituting to obtain q_u from Eq. 3.6.8.

$$q_u = WF^1 [S - U_L(T_f - T_a)] \quad \dots(3.6.11)$$

where $F^1 = \frac{1/U_L}{W \left[\frac{1}{U_L [D + (W - D)F]} + \frac{1}{C_b} + \frac{1}{C_w} + \frac{1}{\pi D_i h_{fi}} \right]}$

$$\dots(3.6.12)$$

F^1 has been called the *collector efficiency factor*. Physical interpretation of F^1 , for most of collector geometries will be clear from equation (3.6.12). The denominator is the heat transfer resistance from the fluid to the ambient air, this is equal to $1/U_0$ say. The numerator is the heat transfer resistance from the absorber plate to the ambient air, equal to $1/U_L$, F^1 thus is the ratio of these two heat transfer coefficients.

$$F^1 = \frac{U_0}{U_L} \quad \dots(3.6.13)$$

F^1 is essentially a constant for any collector design and fluid flow rate. The heat transfer coefficient inside the tube may be assumed, $300 \text{ W/m}^2\text{C}$ (for natural circulation) or $1500 \text{ W/m}^2\text{C}$ (forced circulation)

For temperature distribution in the flow direction, consider the energy balance on a fluid element flowing through a pipe of length Δy which is receiving a uniform heat flux q_u , refer Fig. 3.6.3 so that

$$\dot{m} C_p T_f \Big|_y - \dot{m} C_p T_f \Big|_{y+\Delta y} + q_u \Delta y = 0 \quad \dots(3.6.14)$$

Dividing throughout by Δy and finding the limit as $\Delta y \rightarrow 0$; and substituting in Eq. 3.6.14 for q_u

$$\dot{m} C_p \frac{dT_f}{dy} - WF^1 [S - U_L (T_f - T_a)] = 0 \quad \dots(3.6.15)$$

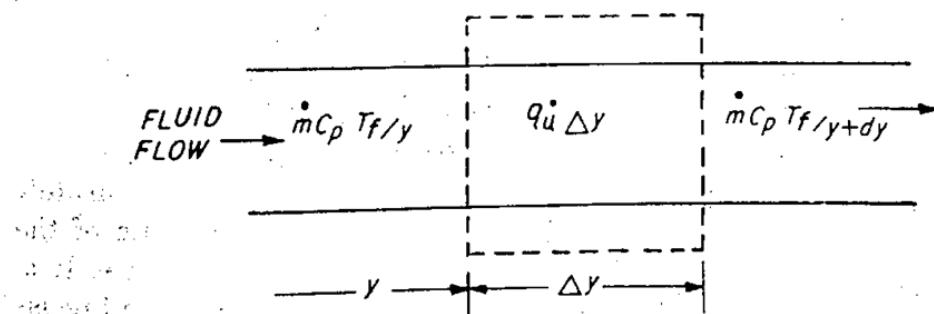


Fig. 3.6.3. Energy balance on fluid element.

If the assumption is made that F^1 and U_L are constant (and independent of y), then the solution of the differential equation for the temperature at any position (if subject to the condition that inlet fluid temperature is T_{fi}) is

$$\frac{T_f - T_a - S/U_L}{T_{fi} - T_a - S/U_L} = e^{-(U_L \cdot W F^1 y / \dot{m} C_p)} \quad \dots(3.6.16)$$

If the collector has length L in the flow direction, then the outlet fluid temperature T_{fo} is found by substituting L for y in the equation (3.6.16).

$$T_{f_o} = T_a + \left(\frac{S}{U_L} \right) - \left[\frac{S}{U_L} - (T_{f_i} - T_a) e^{-U_L F^2 A_c / \dot{m} C_p} \right] \quad \dots(3.6.17)$$

where $A_c = WL$, the area of collector.

The total useful energy collection rate Q_u may be expressed as

$$Q_u = \dot{m} C_p (T_{f_o} - T_{f_i}) \quad \dots(3.6.18)$$

Substituting for T_{f_o} , already derived, gives

$$Q_u = A_c F_R [S - U_L (T_{f_i} - T_a)] \quad \dots(3.6.19)$$

where $F_R = \frac{\dot{m} C_p}{A_c U_L} \left[1 - e^{-A_c U_L F^2 / \dot{m} C_p} \right]$... (3.6.20)

$$= \frac{G C_p}{U_L} \left[1 - e^{-U_L F^2 / G C_p} \right]$$

$\therefore Q = \dot{m}/A_c$

UNIT-5

Photovoltaic Solar Systems

What is a solar cell?

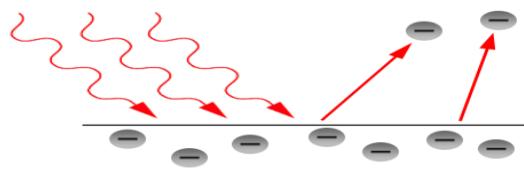
- Solid state device that converts incident solar energy directly into electrical energy

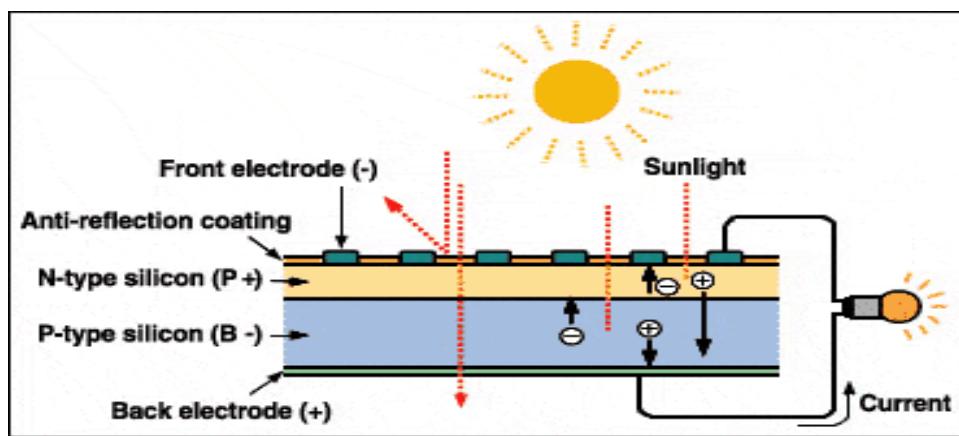
Advantages:

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

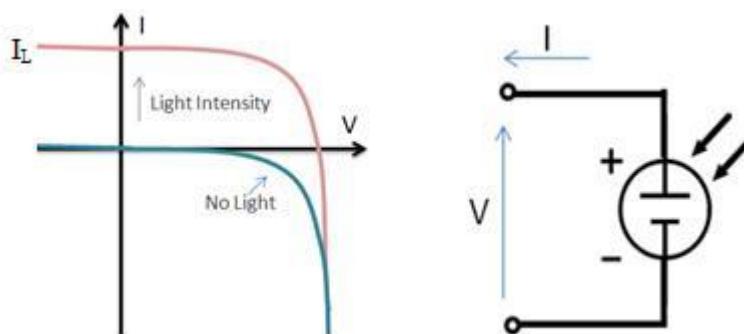




I-V characteristics of a solar cell:

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.



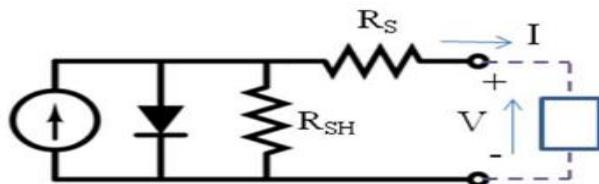
- In an ideal cell, the total current I is equal to the current I_L generated by the photoelectric effect minus the diode current I_D , according to the equation:

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

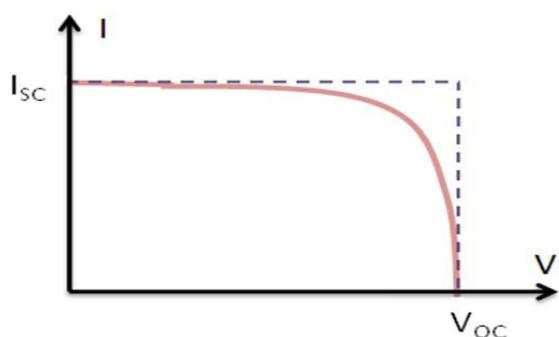
- where I_0 is the saturation current of the diode, q is the elementary charge 1.6×10^{-19} Coulombs, k is a constant of value $1.38 \times 10^{-23} \text{ J/K}$, T is the cell temperature in Kelvin, and V is the measured cell voltage that is either produced (power quadrant) or applied (voltage bias).

- 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 (Isc):

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.

$$I \text{ (at } V=0) = I_{sc}$$

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.

$$I_{sc} = I_{max} = I_l \text{ for forward-bias power quadrant}$$

Open Circuit Voltage (Voc):

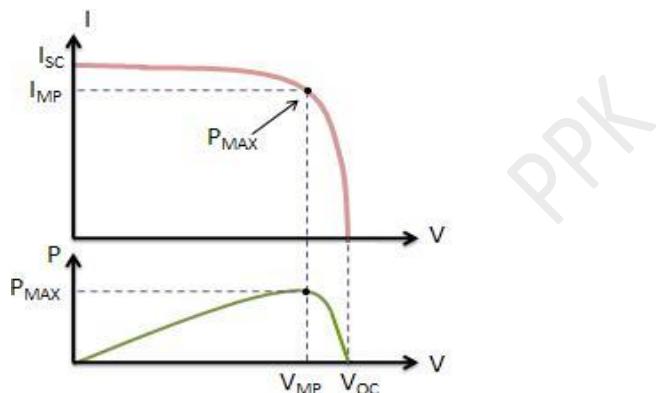
The open circuit voltage (V_{OC}) occurs when there is no current passing through the cell.

$$V \text{ (at } I=0) = V_{OC}$$

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

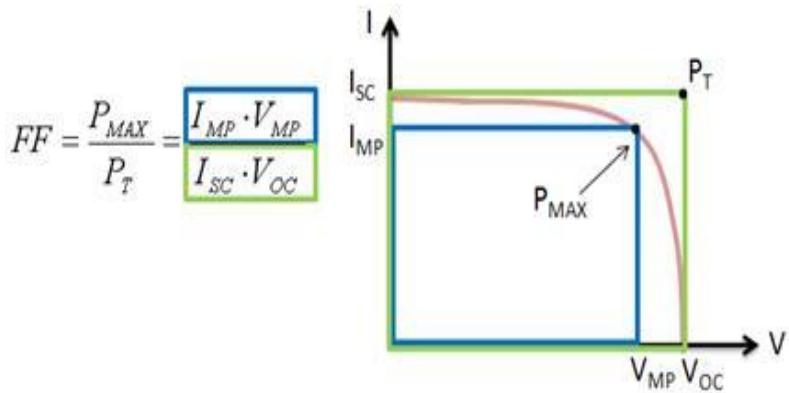
Maximum Power (P_{MAX}), Current at P_{MAX} (I_{MP}), Voltage at P_{MAX} (V_{MP}):

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.

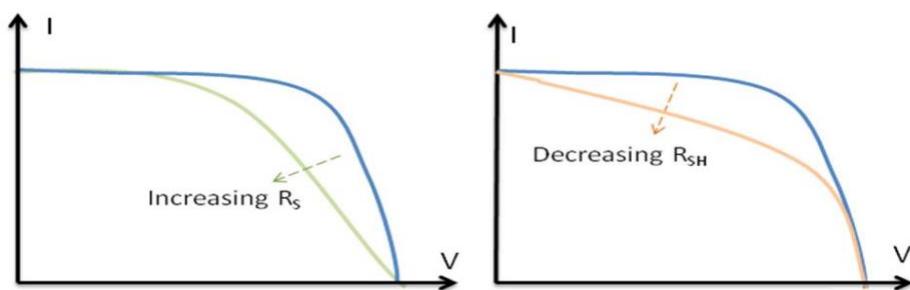
$$\eta = \frac{P_{out}}{P_{in}} \Rightarrow \eta_{MAX} = \frac{P_{MAX}}{P_{in}}$$

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

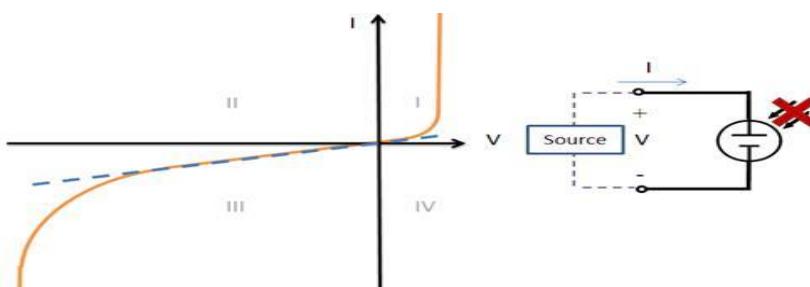
During operation, the efficiency of solar cells is reduced by the dissipation of power across internal resistances. These parasitic resistances can be modeled as a parallel shunt resistance (R_{SH}) and series resistance (R_s), as depicted in Figure previously.

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.

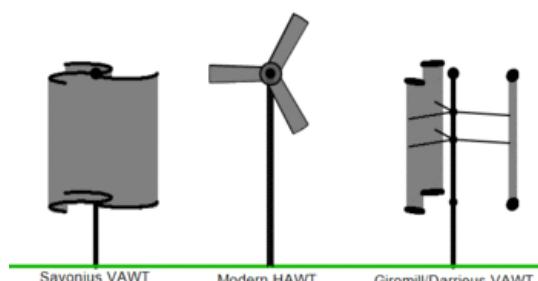
Decreasing R_{SH} and increasing R_s will decrease the fill factor (FF) and P_{MAX} as shown in Figure 6. If R_{SH} is decreased too much, V_{OC} will drop, while increasing R_s excessively can cause I_{sc} to drop instead.



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.



Wind energy:

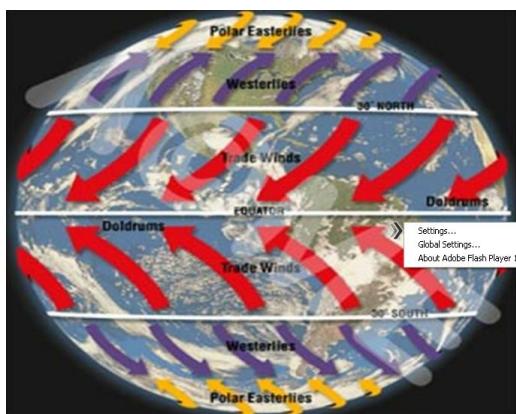
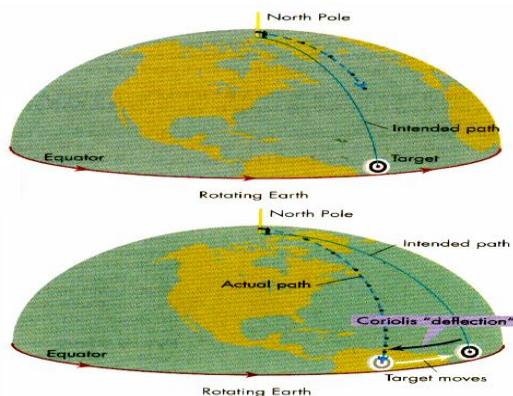


Generation of the Wind:

Planetary winds:

wind is generated by

- Differential solar heating of locations at the equator and poles
- Coriolis force due to earth's rotation
- Friction between earth's surface and the wind
- Planetary winds are caused because of the above



Local winds:

- ❖ differential heating of the land mass and nearby sea surface water creates local winds
- ❖ During day land heats up faster rapidly compared with nearby sea water. Hence there tends to be surface wind flow from the water to the land
- ❖ During night wind reverses because land surface cools faster than the water
- ❖ Second mechanism of local winds is caused by hills and mountain sides. The air above the slopes heats up during the day and cools down at night, more rapidly than the air above the low lands. This

causes heated air in the day to raise along the slopes and relatively heavy air to flow down at night.

Note: It has been estimated that 2% of solar radiation falling on the earth's face is converted into kinetic energy in the atmosphere. About 30% of this is available in the lowest 1000m from the earth's surface. This is sufficient many times than the need of a country. Direct solar radiation is predictable and dependable whereas wind is erratic, unsteady and not reliable except in some areas.

Wind turbine:

A **wind turbine** is a device that converts kinetic energy from the wind into mechanical energy. If the mechanical energy is used to produce electricity, the device may be called a **wind generator** or **wind charger**. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind pump. Developed for over a millennium, today's wind turbines are manufactured in a range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging or auxiliary power on sailing boats; while large grid-connected arrays of turbines are becoming an increasingly large source of commercial electric power.

Types of Wind turbines:

Horizontal axis

- Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind.

Vertical axis

(or VAWTs) have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable, for example when integrated into buildings.

Subtypes of VAWM:

- Darrieu's wind turbine

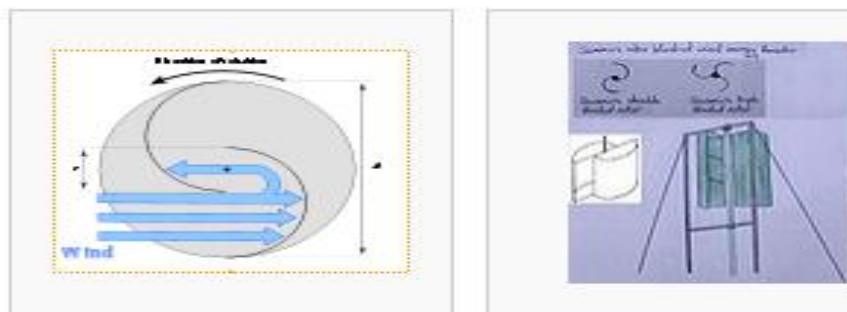
"Egbeater" turbines, or Darrieus turbines, were named after the French inventor, Georges Darrieus. They have good efficiency, but produce large torque ripple and cyclical stress on the tower, which

contributes to poor reliability. They also generally require some external power source, or an additional Savonius rotor to start turning, because the starting torque is very low. The torque ripple is reduced by using three or more blades which results in greater solidity of the rotor. Solidity is measured by blade area divided by the rotor area. Newer Darrieus type turbines are not held up by guy-wires but have an external superstructure connected to the top bearing



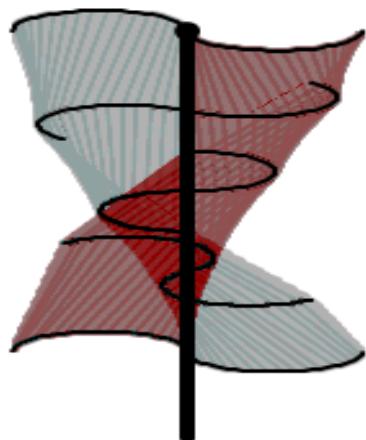
➤ Savonius Wind Turbine

These are drag-type devices with two (or more) Scoops. They are always self-starting if there are at least three scoops.



➤ Twisted Savonius

Twisted Savonius is a modified savonius, with long helical scoops to give a smooth torque, this is mostly used as roof wind turbine or on some boats.



Subtypes of Horizontal axis wind mills:

Single blade rotor

- Rotor must move more rapidly to capture same amount of wind
- Gearbox ratio reduced
- Added weight of counterbalance negates some benefits of lighter design
- Higher speed means more noise, visual, and wildlife impacts
- Blades easier to install because entire rotor can be assembled on ground
- Captures 10% less energy than two blade design
- Ultimately provide no cost savings

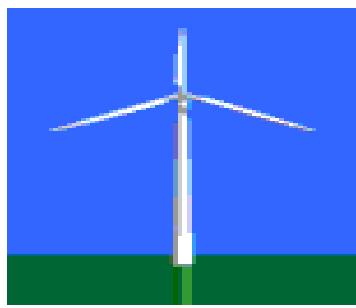


Two bladed rotor:

- Advantages & disadvantages similar to one blade
- Need teetering hub and or shock absorbers because of gyroscopic imbalances
- Capture 5% less energy than three blade designs



Three bladed rotor:

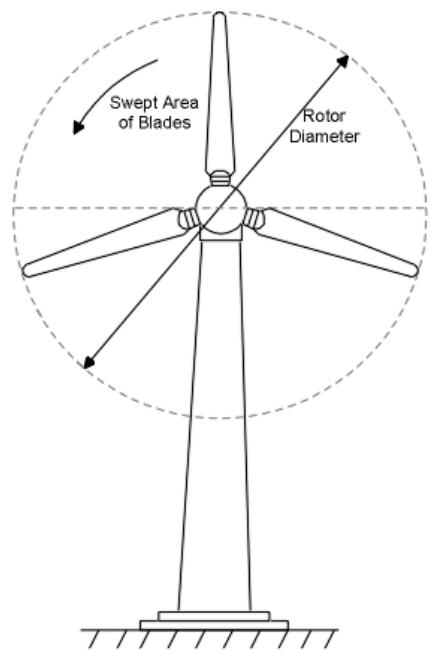


- Balance of gyroscopic forces
- Slower rotation
 - increases gearbox & transmission costs
 - More aesthetic, less noise, fewer bird strikes

Calculation of Wind Power:

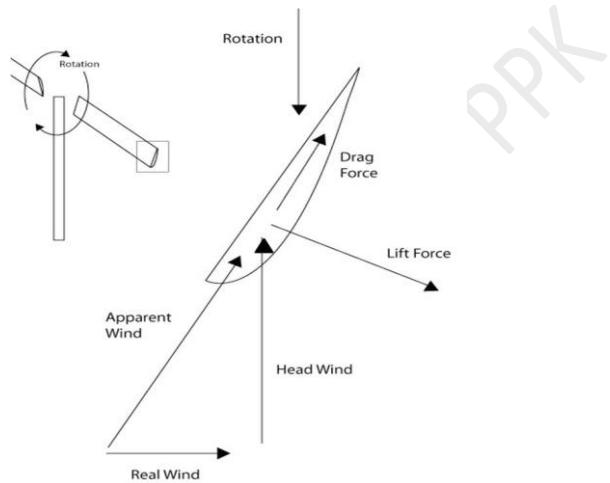
$$\text{Power in the Wind} = \frac{1}{2} \rho A V^3$$

- Effective swept area, A
- Effective wind speed, V
- Effective air density, ρ



- Swept Area: $A = \pi R^2$ Area of the circle swept by the rotor (m^2).

Lift/Drag Forces Experienced by Turbine Blades



TIP-SPEED RATIO (TSR):

Tip-speed ratio is the ratio of the speed of the rotating blade tip to the speed of the free stream wind. There is an optimum angle of attack which creates the highest lift to drag ratio. Because angle of attack is dependent on wind speed, there is an optimum tip-speed ratio

$$\text{TSR} = \frac{\Omega R}{V}$$

Where,

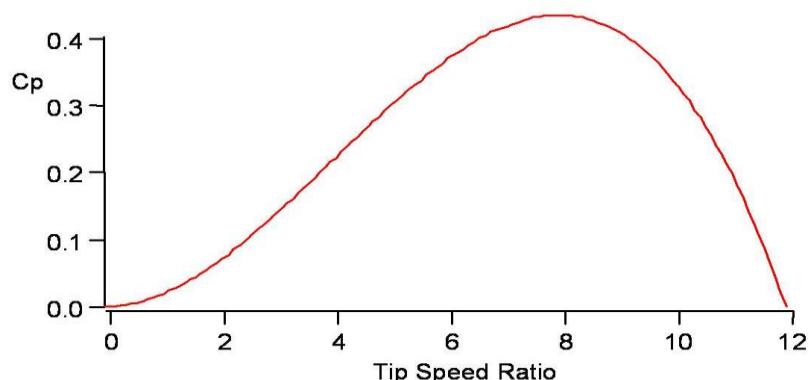
Ω = rotational speed in radians / sec

R = Rotor Radius

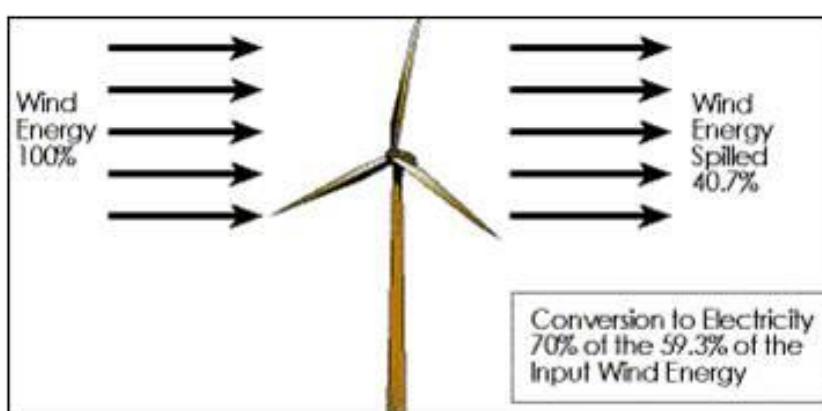
V = Wind "Free Stream" Velocity

Performance Over Range of Tip Speed Ratios:

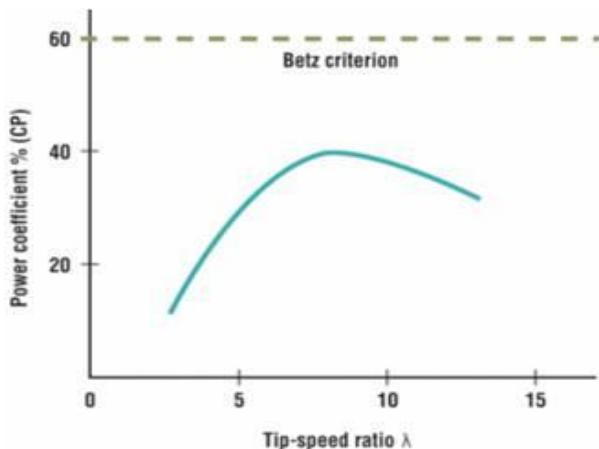
- Power Coefficient Varies with Tip Speed Ratio ,Characterized by C_p vs Tip Speed Ratio Curve



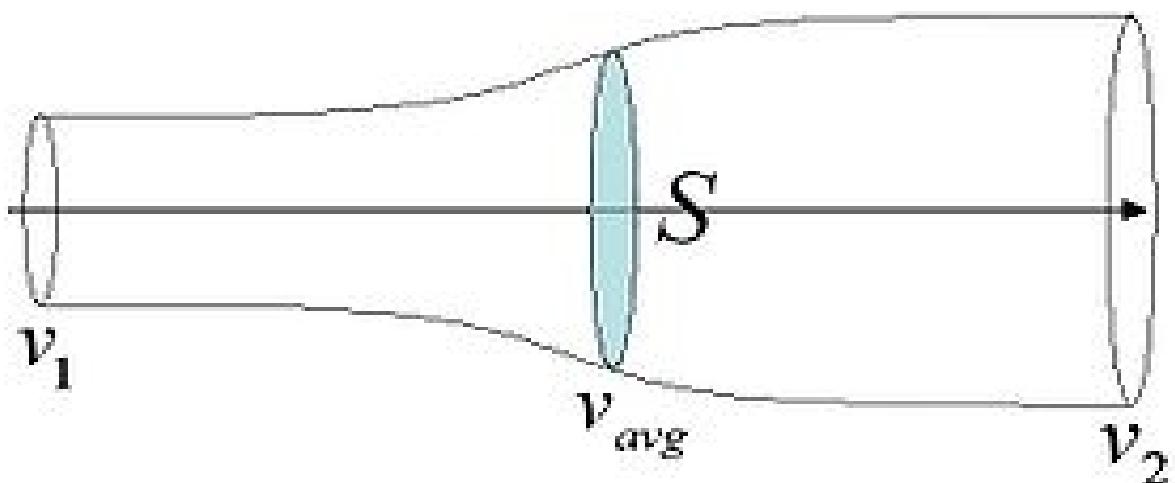
Betz Limit:



All wind power cannot be captured by rotor or air would be completely still behind rotor and not allow more wind to pass through.Theoretical limit of rotor efficiency is 59%.Most modern wind turbines are in the 35 – 45% range.



Proof:



It shows the maximum possible energy — known as the **Betz limit** — that may be derived by means of an infinitely thin rotor from a fluid flowing at a certain speed.

In order to calculate the maximum theoretical efficiency of a thin rotor (of, for example, a windmill) one imagines it to be replaced by a disc that withdraws energy from the fluid passing through it. At a certain distance behind this disc the fluid that has passed through flows with a reduced velocity.

Assumptions:

The rotor does not possess a hub, this is an ideal rotor, with an infinite number of blades which have no drag. Any resulting drag would only lower this idealized value.

2. The flow into and out of the rotor is axial. This is a control volume analysis, and to construct a solution the control volume must contain all flow going in and out, failure to account for that flow would violate the conservation equations.
3. This is incompressible flow. The density remains constant, and there is no heat transfer from the rotor to the flow or vice versa.
4. The rotor is also massless. No account is taken of angular momentum imparted to either the rotor or the air flow behind the rotor, i.e., no account is taken of any wake effect.

PPK

Application of conservation of mass (continuity equation):

Applying conservation of mass to this control volume, the [mass flow rate](#) (the mass of fluid flowing per unit time) is given by:

$$\dot{m} = \rho \cdot A_1 \cdot v_1 = \rho \cdot S \cdot v = \rho \cdot A_2 \cdot v_2$$

where v_1 is the speed in front of the rotor and v_2 is the speed downstream of the rotor, and v is the speed at the fluid power device. ρ the fluid density, and the area of the turbine is given by S . The force exerted on the wind by the rotor may be written as

$$\begin{aligned} F &= m \cdot a \\ &= m \cdot \frac{dv}{dt} \\ &= \dot{m} \cdot \Delta v \\ &= \rho \cdot S \cdot v \cdot (v_1 - v_2) \end{aligned}$$

Power and work

The [work done](#) by the force may be written incrementally as

$$dE = F \cdot dx$$

and the power (rate of work done) of the wind is

$$P = \frac{dE}{dt} = F \cdot \frac{dx}{dt} = F \cdot v$$

Now substituting the force F computed above into the power equation will yield the power extracted from the wind:

$$P = \rho \cdot S \cdot v^2 \cdot (v_1 - v_2)$$

However, power can be computed another way, by using the kinetic energy. Applying the conservation of energy equation to the control volume yields

$$\begin{aligned} P &= \frac{\Delta E}{\Delta t} \\ &= \frac{1}{2} \cdot \dot{m} \cdot (v_1^2 - v_2^2) \end{aligned}$$

Looking back at the continuity equation, a substitution for the mass flow rate yields the following

$$P = \frac{1}{2} \cdot \rho \cdot S \cdot v \cdot (v_1^2 - v_2^2)$$

Both of these expressions for power are completely valid, one was derived by examining the incremental work done and the other by the conservation of energy. Equating these two expressions yields

$$P = \frac{1}{2} \cdot \rho \cdot S \cdot v \cdot (v_1^2 - v_2^2) = \rho \cdot S \cdot v^2 \cdot (v_1 - v_2)$$

Examining the two equated expressions yields an interesting result, mainly

$$\frac{1}{2} \cdot (v_1^2 - v_2^2) = \frac{1}{2} \cdot (v_1 - v_2) \cdot (v_1 + v_2) = v \cdot (v_1 - v_2)$$

or

$$v = \frac{1}{2} \cdot (v_1 + v_2)$$

Therefore, the wind velocity at the rotor may be taken as the average of the upstream and downstream velocities. This is often the most argued against portion of Betz' law, but as it can be seen from the above derivation, it is indeed correct.

Betz' law and coefficient of performance

Returning to the previous expression for power based on kinetic energy:

$$\begin{aligned}\dot{E} &= \frac{1}{2} \cdot \dot{m} \cdot (v_1^2 - v_2^2) \\ &= \frac{1}{2} \cdot \rho \cdot S \cdot v \cdot (v_1^2 - v_2^2) \\ &= \frac{1}{4} \cdot \rho \cdot S \cdot (v_1 + v_2) \cdot (v_1^2 - v_2^2) \\ &= \frac{1}{4} \cdot \rho \cdot S \cdot v_1^3 \cdot \left(1 - \left(\frac{v_2}{v_1}\right)^2 + \left(\frac{v_2}{v_1}\right) - \left(\frac{v_2}{v_1}\right)^3\right).\end{aligned}$$

By differentiating (through careful application of the chain rule) \dot{E} with respect to $\frac{v_2}{v_1}$ for

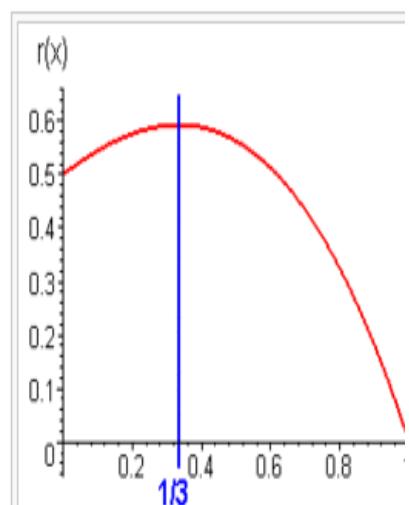
a given fluid speed v_1 and a given area S one finds the maximum or minimum value for \dot{E} . The result is that \dot{E} reaches maximum value when $\frac{v_2}{v_1} = \frac{1}{3}$.

Substituting this value results in:

$$P_{\max} = \frac{16}{27} \cdot \frac{1}{2} \cdot \rho \cdot S \cdot v_1^3$$

The work rate obtainable from a cylinder of fluid with cross sectional area S and velocity v_1 is:

$$P = \frac{1}{2} \cdot \rho \cdot S \cdot v_1^3 \cdot C_p$$



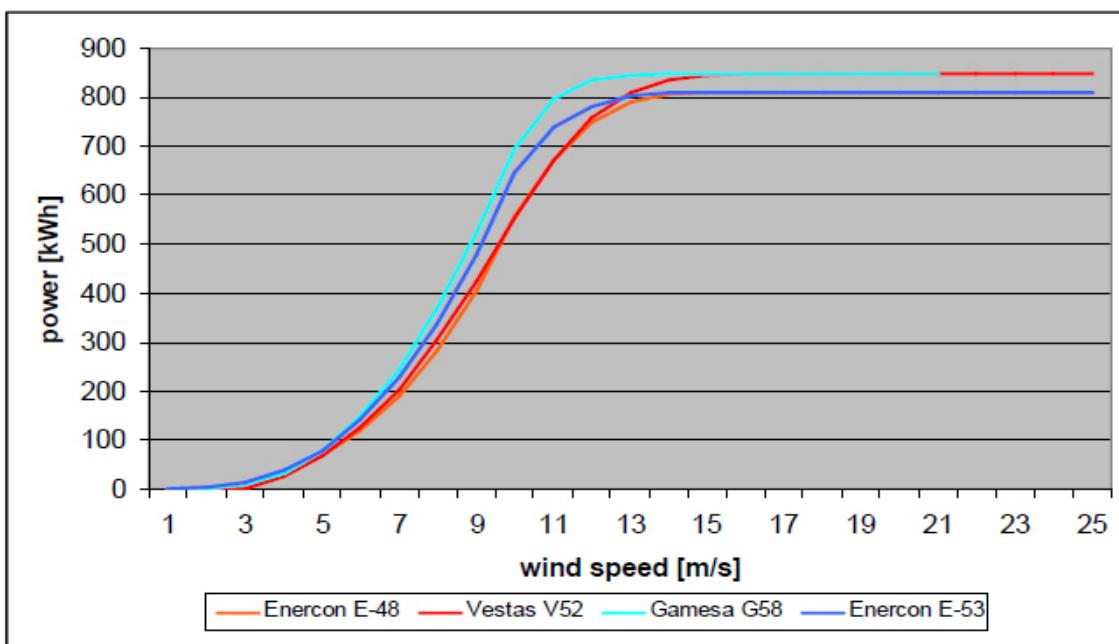
The "power coefficient" C_p ($= P / P_{\text{wind}}$) has a maximum value of: $C_{p,\max} = 16/27 = 0.593$ (or 59.3%; however, coefficients of performance are usually expressed as a decimal, not a percentage).

Wind power curve:

The Power curve of a wind turbine is an important parameter, describing the relation between the wind speed on site and the respective electrical energy output. Power curves and c_t -values (a parameter for the calculation of the wake effect) of the turbines under consideration are applied for the energy calculation. Power curves which had been measured by independent institutions are of higher quality than calculated ones. Due to the fluctuations of both the characteristics of the wind turbine components, and the measuring conditions power curves of different measurements differing slightly between each other.

Several manufacturers are thus providing power curves which are calculated from the results of several measured ones; the performance of these calculated power curves might be contractually guaranteed by the manufacturers.

During the calculation of the energy yield, the power curves, given for the standard conditions of air density = 1.225 kg/m^3 are adapted to the air density of each individual turbine location at hub height, with the transformed power curves for the average air density. The air density can be calculated for each individual wind turbine according to the site conditions, height above sea level plus the hub height of the turbines (e.g. 57 m / 60 m) and an annual average temperature level. As verification, the calculated adaptations for air density at the turbine sites should be compared to information provided by nearby meteorological stations. Figure next shows the power curves of several wind turbines at an air density of $\rho = 1,225 \text{ kg / m}^3$.



Forces on blades and thrust on turbines:

There are two types of forces that act on the blades

1. Circumferential force acting in the direction of wheel rotation that provides torque.
2. Axial force acting in the wind stream that provides axial thrust that must be counteracted by the proper mechanical design

The circumferential force, or torque T can be obtained from,

$$T = \frac{P}{\omega} = \frac{P}{\pi D N}$$

Where

P =Torque in Newton

ω =angular velocity in m/s

D =diameter of the turbine wheel

$$D = \sqrt{\frac{4}{\pi} A \cdot m}$$

N = wheel revolution per unit time

$$\text{real efficiency } \eta = \frac{P}{P_{\text{total}}}$$

$$P = \eta P_{\text{total}}$$

For a turbine operating at power P , the expression for torque becomes

$$T = \eta \frac{\rho A}{2g_c} \frac{V_i^3}{\pi D N}$$

$$T = \eta \frac{1}{2g_c} \frac{\rho \pi}{4} \frac{D^2}{\pi D N} V_i^3 = \eta \frac{1}{8g_c} \frac{\rho D V_i^3}{N}$$

At maximum efficiency i.e, 59.3%, Torque has maximum value given by,

$$T_{\max} = \frac{2}{27g_c} \frac{\rho D V_i^3}{N}$$

Axial Thrust given by,

$$F_x = \frac{1}{2g_c} \rho A (V_i^2 - v_e^2)$$

$$= \frac{\pi}{8g_c} \rho D^2 (V_i^2 - v_e^2)$$

On substituting $v_e = 1/3 V_i$

$$F_{x \max} = \frac{4}{9g_c} \rho A V_i^2$$

$$= \frac{\pi}{9g_c} \rho D^2 V_i^2$$

- ❖ It can be seen that axial forces are proportional to the square of the diameter of turbine wheel, this limits the turbine wheel diameter of large size.

Wind Energy – India

In the early 1980s, the Indian government established the Ministry of Non-Conventional Energy Sources (MNES) to encourage diversification of the country's energy supply, and satisfy the increasing energy demand of a rapidly growing economy. In 2006, this ministry was renamed the Ministry of New and Renewable Energy (MNRE).

Renewable energy is growing rapidly in India. With an installed capacity of 13.2 GW, renewable energy sources (excluding large hydro) currently account for 9% of India's overall power generation capacity. By 2012, the Indian government is planning to add an extra 14 GW of renewable sources.

In its 10th Five Year Plan, the Indian government had set itself a target of adding 3.5 GW of renewable energy sources to the generation mix. In reality, however, nearly double that figure was achieved. In this period, more than 5.4 GW of wind energy was added to the generation mix, as well as 1.3 GW from other RE sources. The total power in 2008-2012 was increased to 14 GW, 10.5 GW of which to be new wind generation capacity.

The Indian Ministry of New and Renewable Energy (MNRE) estimates that there is a potential of around 90,000 MW for the country, including 48,561 MW of wind power, 14,294 MW of small hydro power and 26,367 MW of biomass. In addition, the potential for solar energy is estimated for most

parts of the country at around 20 MW per square kilometer of open, shadow free area covered with 657 GW of installed capacity.

The total potential for wind power in India was first estimated by the Centre for Wind Energy Technology (C-WET) at around 45 GW, and was recently increased to 48.5 GW. This figure was also adopted by the government as the official estimate.

The C-WET study was based on a comprehensive wind mapping exercise initiated by MNRE, which established a country-wide network of 1050 wind monitoring and wind mapping stations in 25 Indian States. This effort made it possible to assess the national wind potential and identify suitable areas for harnessing wind power for commercial use, and 216 suitable sites have been identified.

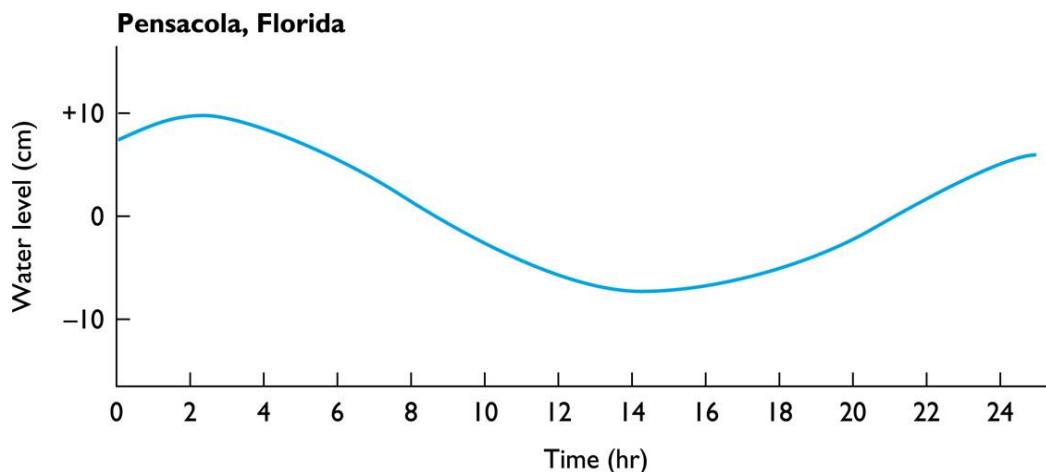
However, the wind measurements were carried out at lower hub heights and did not take into account technological innovation and improvements and repowering of old turbines to replace them with bigger ones At heights of 55-65 meters, the Indian Wind Turbine Manufacturers Association (IWTMA) estimates that the potential for wind development in India is around 65-70 GW. The World Institute for Sustainable Energy, India (WISE) considers that with larger turbines, greater land availability and expanded resource exploration, the potential could be as big as 100 GW.

UNIT-6

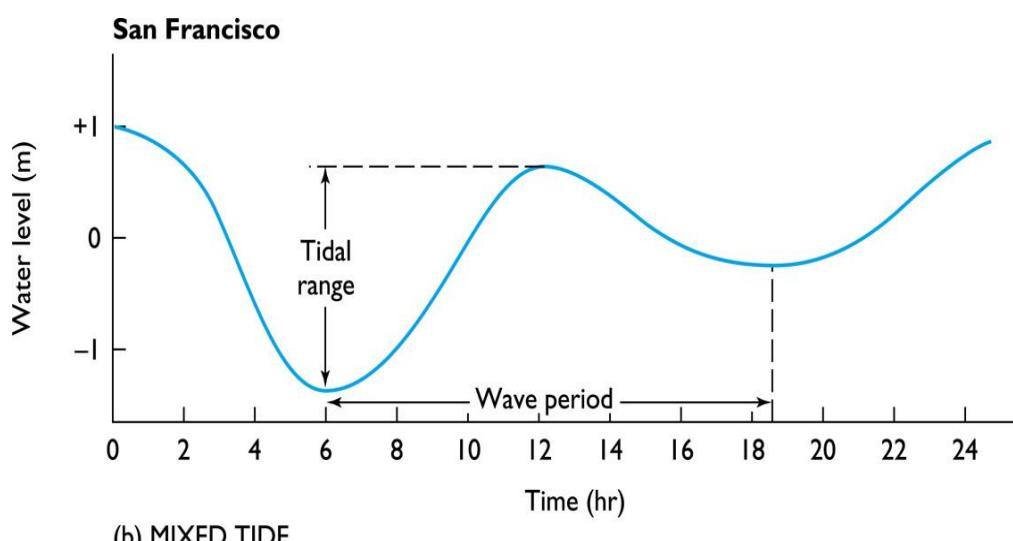
TIDAL POWER

Tides have a wave form, but differ from other waves because they are caused by the interactions between the ocean, Sun and Moon.

- Crest of the wave form is high tide and trough is low tide.
- The vertical difference between high tide and low tide is the tidal range.
- Tidal period is the time between consecutive high or low tides and varies between 12 hrs 25 min to 24 hrs 50 min.
- There are three basic types of daily tides defined by their period and regularity: Diurnal tides, Semidiurnal tides, and Mixed tides.



(a) DIURNAL TIDE

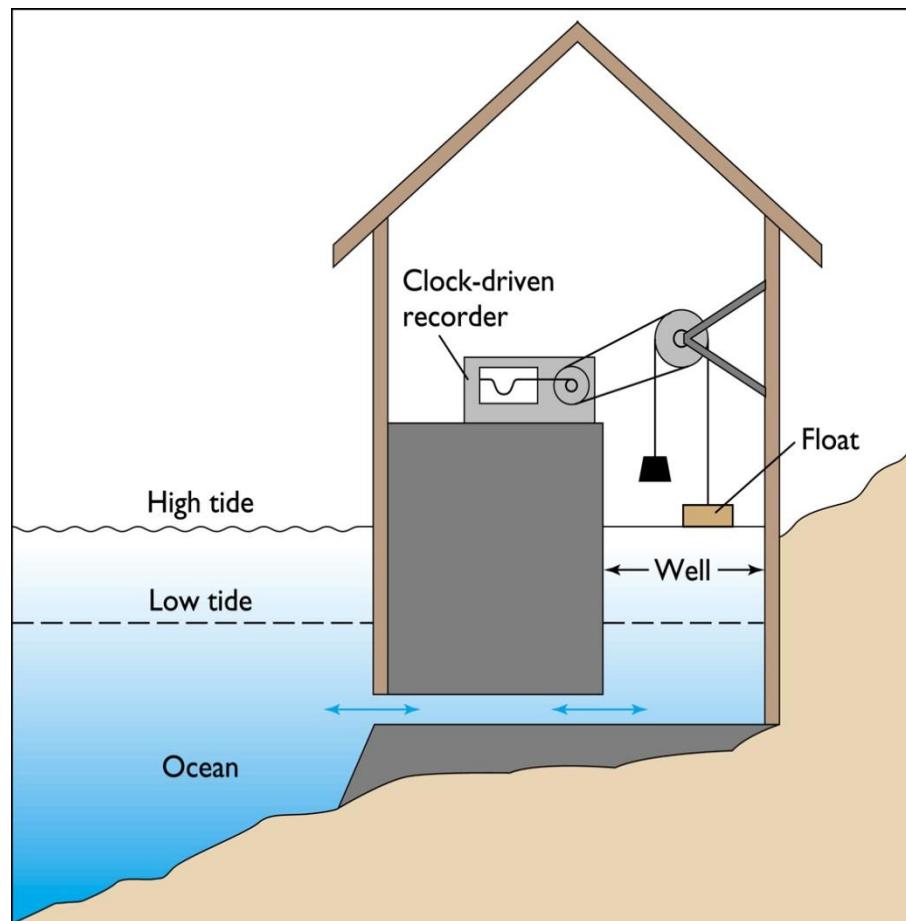


(b) MIXED TIDE

Note:

1. Over a month the daily tidal ranges vary systematically with the cycle of the Moon.
2. Tidal range is also altered by the shape of a basin and sea floor configuration.

Following figure shows a tide gauging station

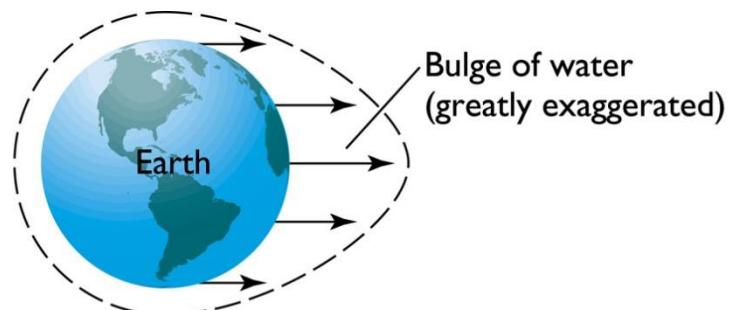


(a) TIDE-GAUGE STATION

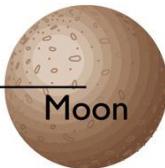
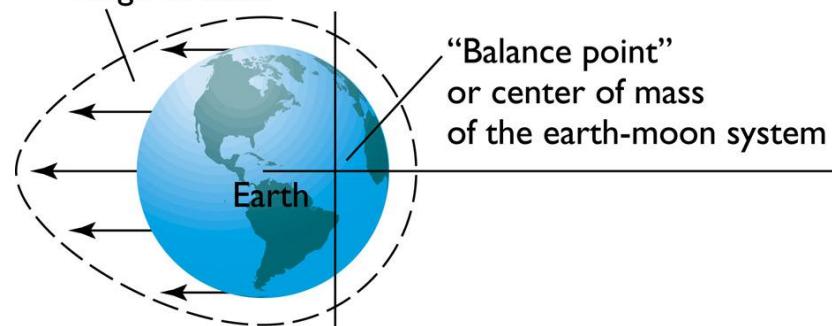
Tides result from gravitational attraction and centrifugal effect.

- Gravity varies directly with mass, but inversely with distance.
- Although much smaller, the Moon exerts twice the gravitational attraction and tide-generating force as the Sun because the Moon is closer.
- Gravitational attraction pulls the ocean towards the Moon and Sun, creating two gravitational tidal bulges in the ocean (high tides).
- Centrifugal effect is the push outward from the center of rotation.

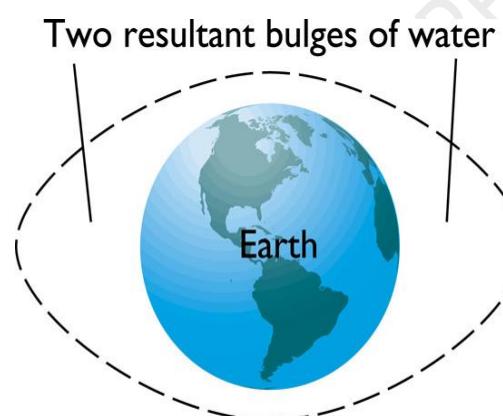
Following figures show how the gravitational forces and centrifugal forces create tides.



- (a) **GRAVITATIONAL FORCE**
Bulge of water



(b) CENTRIFUGAL FORCE

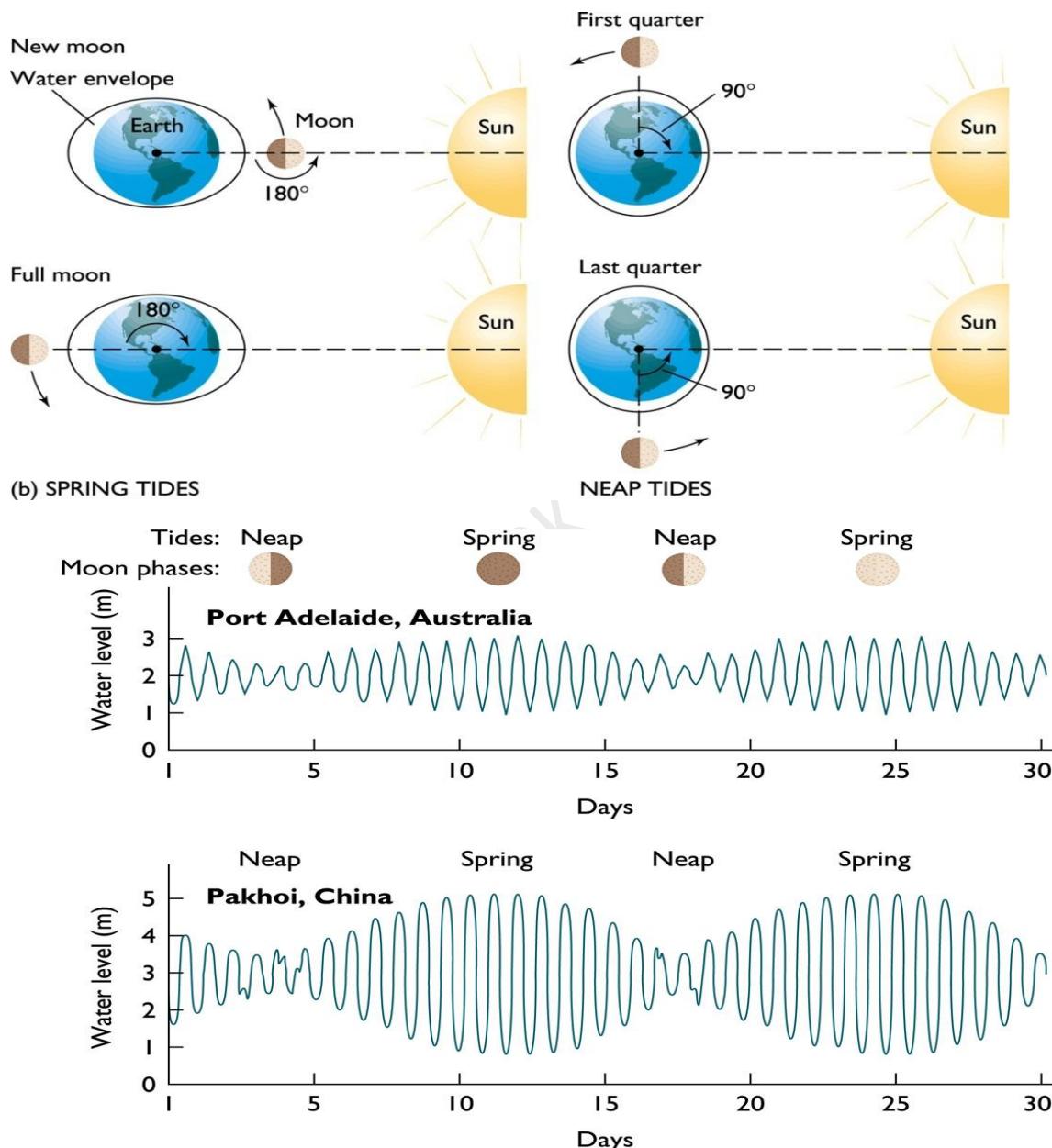


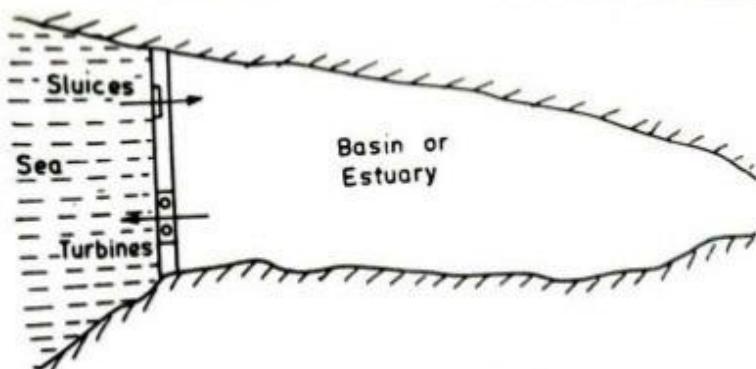
(c) GRAVITATIONAL AND CENTRIFUGAL FORCE

- Latitude of the tidal bulges is determined by the declination, the angle between Earth's axis and the lunar and solar orbital plane.
- Spring tides occur when Earth, Moon and Sun are aligned in a straight line and the tidal bulges display constructive interference, producing very high, high tides and very low, low tides.
- Spring tides coincide with the new and full moon.

- Neap tides occur when the Earth, Moon and Sun are aligned forming a right angle and tidal bulges displaying destructive interference, producing low high tides and high low tides.
- Neap tides coincide with the first and last quarter moon.

Earth on its axis and the Moon in its orbit both revolve eastward and these causes the tides to occur 50 minutes later each day.



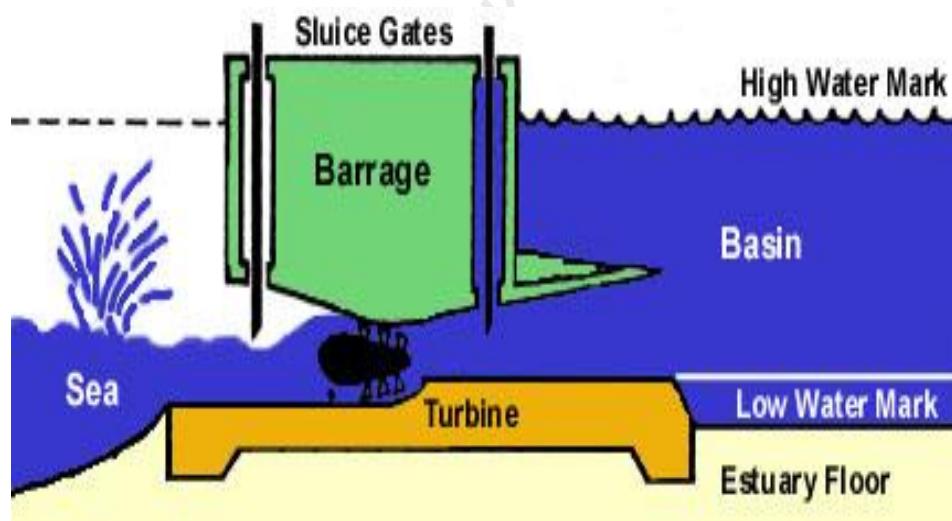


(a) Tidal plant operation (plan).

Tidal Power Stations

Single Basin Tidal System:

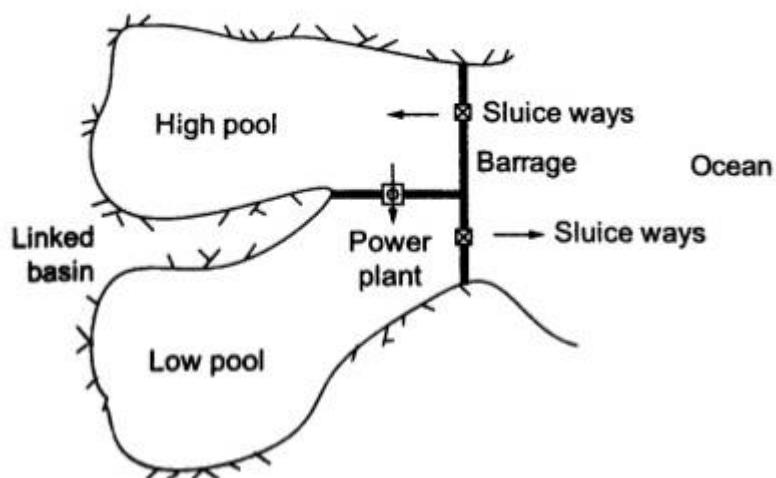
- The simplest generating system for tidal plants, known as an ebb generating system, involves a dam, known as a barrage across an estuary.
- Sluice gates on the barrage allow the tidal basin to fill on the incoming high tides and to exit through the turbine system on the outgoing tide (known as the ebb tide).



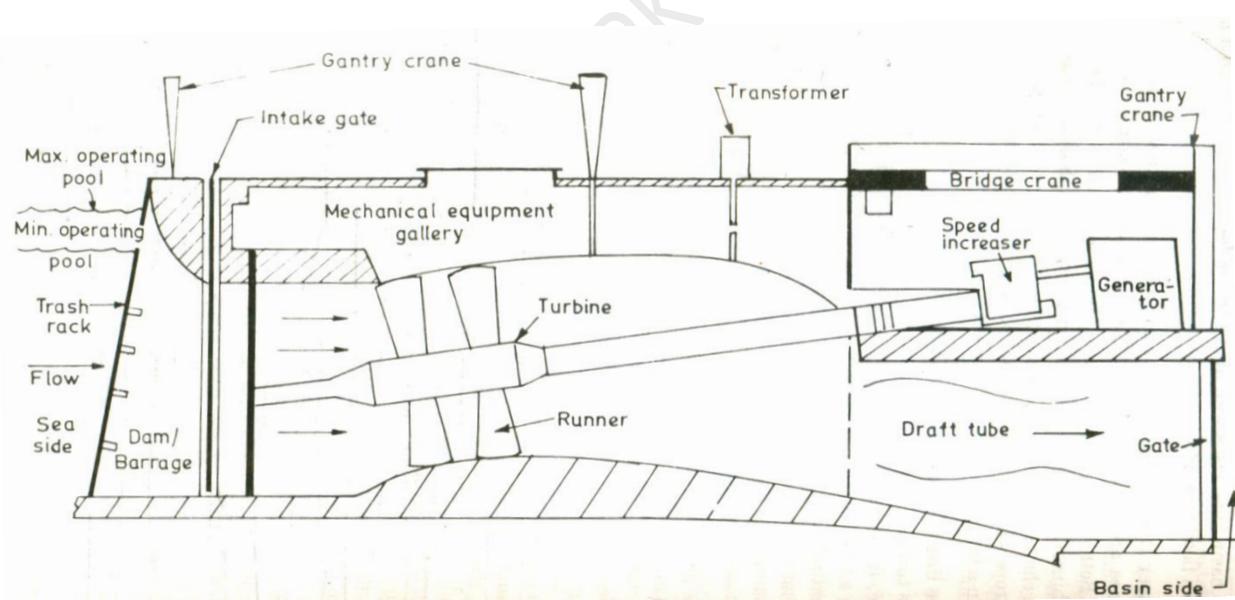
- Alternatively, flood-generating systems, which generate power from the incoming tide are possible, but are less favored than ebb generating systems.

Double basin Tidal System: another form of energy barrage configuration is that of the dual basin type. With two basins, one is filled at high tide and the other is emptied at low tide. Turbines are placed between the basins. Two-basin schemes offer advantages over normal schemes in that generation time can be adjusted with high flexibility and it is also possible to generate almost continuously. In normal estuarine situations, however,

two-basin schemes are very expensive to construct due to the cost of the extra length of barrage. There are some favorable geographies, however, which are well suited to this type of scheme.



Components of a tidal power station:



- (i) Power House
- (ii) The Dam or Barrage
- (iii) Sluice ways from basin to sea and vice versa

DAM (Barrage):

The barrages store water behind them. The barrages should provide channels for the turbines, gates and locks. The tidal power barrages

should be of shorter length. The length should be less than resonant length of tidal waves. The tidal barrages require sites where a sufficiently high tidal range is available. The barrages require flat bottom.

POWER HOUSE:

Large size turbines are needed to because of small head available.Hence power house will also be large structure. The types of turbines used are

(i)Bulb type:

In systems with a bulb turbine, water flows around the turbine, making access for maintenance difficult, as the water must be prevented from flowing past the turbine.

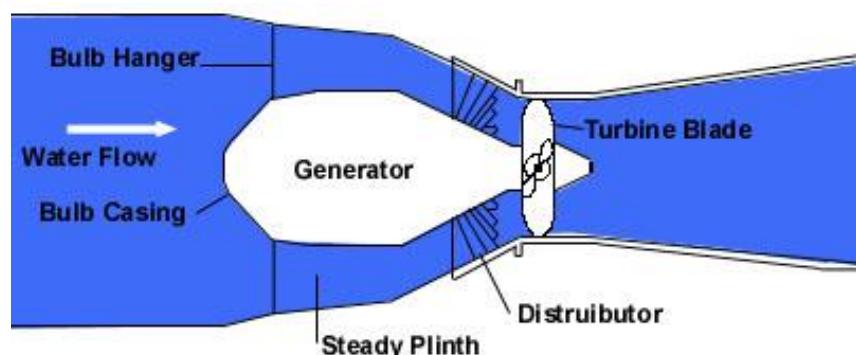
(ii) Rim type:

Rim turbines reduce these problems as the generator is mounted in the barrage, at right angles to the turbine blades. Unfortunately, it is difficult to regulate the performance of these turbines and it is unsuitable for use in pumping.

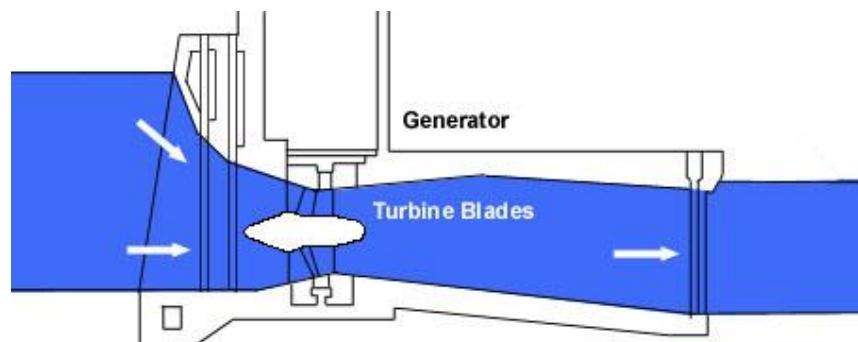
(iii)Tubular type:

Tubular turbines have been proposed for use some UK projects. In this configuration, the blades are connected to a long shaft and orientated at an angle so that the generator is sitting on top of the barrage.

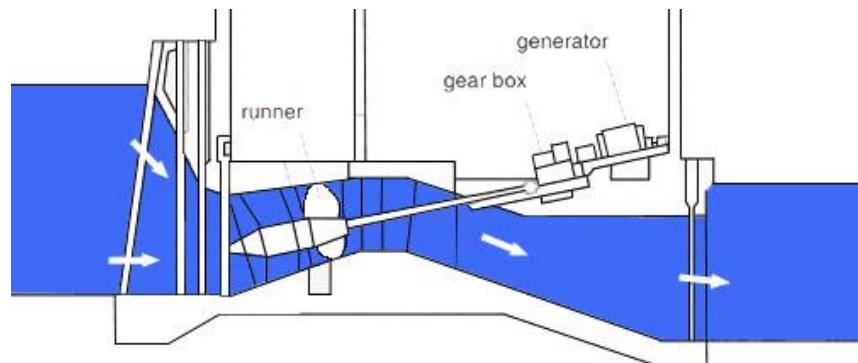
Following are the figures.



Bulb type turbine



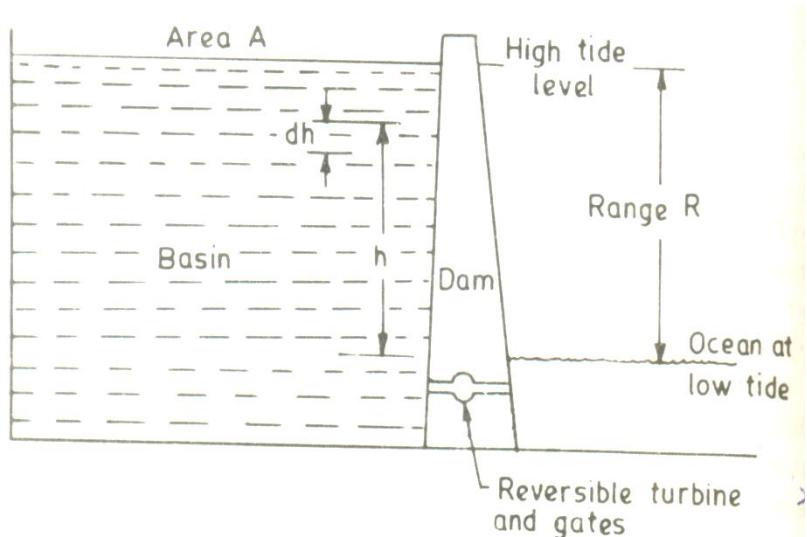
Rim type turbine



Tubular type turbine

Estimation of tidal power:

Single basin system:



We can write

$$dw = dm \cdot g \cdot h$$

$$dm = -\rho A dh$$

$$dw = -\rho A dh g h$$

Where

W=work done by water in joules

g=gravitational constant

m=mass flowing through the turbine, Kg

h=head. m

ρ =water density,Kg/m³

A=basin surface area in m²

The total amount of work during a full emptying or filling is given by

$$\begin{aligned} W &= \int_R^0 dw = -g\rho A \int_R^0 h dh \\ &= \frac{1}{2} g\rho A R^2 \end{aligned}$$

The power is rate of doing work. The time taken for producing power once is tidal period. Tidal wave has period equal to 6h, 12.5min i.e, 22350seconds.

$$\begin{aligned} P_{av} &= \frac{W}{Time} = \frac{\frac{1}{2}}{22350} g\rho A R^2 \\ &= \frac{1}{44700} g\rho A R^2 \end{aligned}$$

Assuming an average water density as 1025Kg/m³, The average power per unit basin area is given by,

$$\begin{aligned} \frac{P_{av}}{A} &= \frac{1}{44700} \times 9.81 \times 1025 \times R^2 \\ &= 0.225R^2 \text{ watts/m}^2 \end{aligned}$$

Example problem:

A Tidal power plant of the simple single basin type has a basin area of $30 \times 10^6 \text{ m}^2$. The tide has a range of 12m. The turbine however stops operating when the head falls below three meters. Calculate the energy generated in one filling(or emptying) process, in KW hours if the generator efficiency is 0.73.

Solution

The total theoretical Work $W = \int_R^r dw$

Here $R=12\text{m}$

R =the head below turbine stops operating=3m

$$\begin{aligned} W &= \int_R^r -g\rho Ah dh = -g\rho A \int_R^r h dh \\ &= \frac{1}{2} g\rho A(R^2 - r^2) \end{aligned}$$

Thus the average power

$$\begin{aligned} P_{av} &= \frac{W}{\text{time}} \\ &= \frac{\frac{1}{2} g\rho A(R^2 - r^2)}{44700} \end{aligned}$$

The average power generated

$$\begin{aligned} &= \frac{1}{44700} \times 9.81 \times 1025 \times 30 \times 10^6 \times (12^2 - 3^2) \text{Watts} \\ &= \frac{1}{44700} \times 9.81 \times 1025 \times 30 \times 10^6 \times 135 \text{ watts} \\ &= 911.25 \times 10^6 \text{ watts} = \frac{911.25}{1000} \times 3600 \times 10^6 \text{kWh} \\ &= 3280.5 \times 10^6 \text{kWh} \end{aligned}$$

Considering turbine generator efficiency, the energy generated

$$= 3280.5 \times 10^6 \times 0.73 = 2395 \times 10^6 \text{kWh}$$

Ocean Power:**What is OTEC?**

- OTEC, or Ocean Thermal Energy Conversion, is an energy technology that converts solar radiation to electric power.
- OTEC systems use the ocean's natural thermal gradient—the fact that the ocean's layers of water have different temperatures—to drive a power-producing cycle.
- As long as the temperature between the warm surface water and the cold deep water differs by about 20°C (36°F), an OTEC system can produce a significant amount of power with a maximum Carnot Efficiency of about 6.7%

Lambert's Law

Solar Energy absorption by the water takes place according to Lambert's Law of absorption, which states that each layer of equal thickness absorbs the same fraction of light that passes through it.

$$\frac{-dI_{(x)}}{dx} = kI$$

$$I_{(x)} = I_0 e^{-kx}$$

Where I_0 and $I_{(x)}$ are intensities of radiation at the surface($x=0$) and at a distance x below the surface. K is the extinction coefficient and it has the value 0.05m^{-1} for very clear fresh water, 0.27 for turbid fresh water and 0.5m^{-1} for very salty water.

Consequences of Lambert's Law

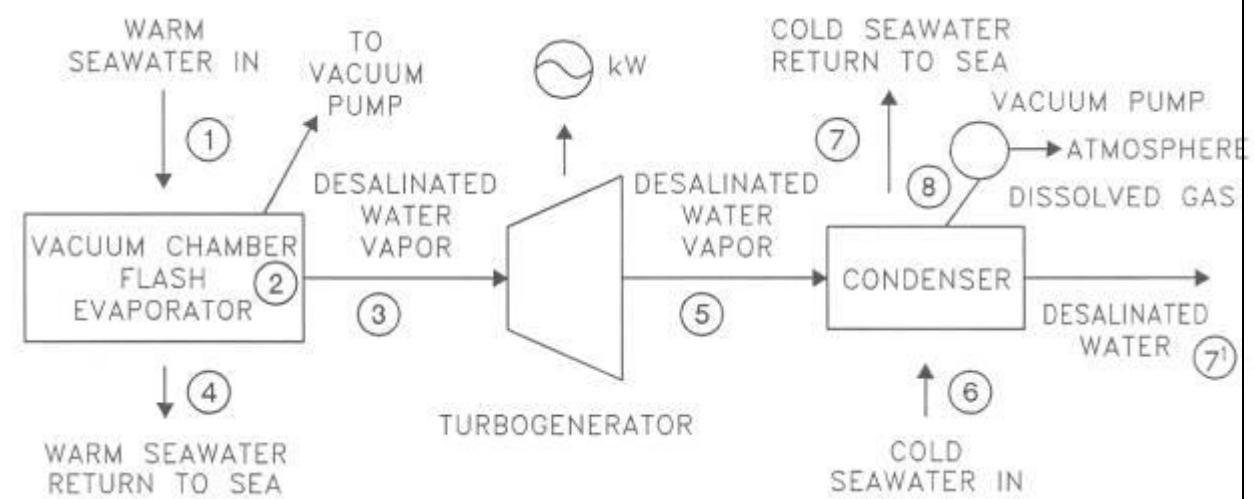
- Intensity decreases exponentially with depth and depending upon K value almost all the absorption takes place very close to the surface water. Maximum temperature occur just below the top surface of water.
- Deep water remains cool
- There will not be thermal convection currents between the warmer, lighter surface water and cool heavier water at the depth
- ❖ In the tropics, the ocean surface temperature often exceeds 25°C while 1Km below temperature is not higher than 10°C

- ❖ A heat engine can be made to work between these two temperatures and power can be obtained

OTEC POWER PLANTS

Open-Cycle(Claude Cycle):

Open-cycle OTEC uses the tropical oceans' warm surface water to make electricity. When warm seawater is placed in a low-pressure container, it boils. The expanding steam drives a low-pressure turbine attached to an electrical generator. The steam, which has left its salt behind in the low-pressure container, is almost pure fresh water. It is condensed back into a liquid by exposure to cold temperatures from deep-ocean water.

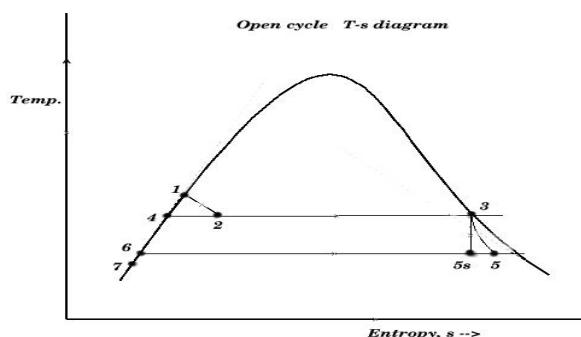


Open cycle thermodynamic analysis:

In this scheme, warm surface water at around 27°C (81°F) enters an evaporator at pressure slightly below the saturation pressure causing it to vaporize.

$$H_1 = H_f$$

Where H_f is enthalpy of liquid water at the inlet temperature, T_1 .



This water undergoes volume boiling as opposed to pool boiling in conventional boilers where the heating surface is in contact. Thus the water partially flashes to steam with two-phase equilibrium prevailing. Suppose that the pressure inside the evaporator is maintained at the saturation pressure, T_2 .

$$H_2 = H_1 = H_f + x_2 H_{fg}$$

Here, x_2 is the fraction of water by mass that vaporizes. The warm water mass flow rate per unit turbine mass flow rate is $1/x_2$.

The low pressure in the evaporator is maintained by a vacuum pump that also removes the dissolved non-condensable gases from the evaporator. The evaporator now contains a mixture of water and steam of very low vapor quality (steam content). The steam is separated from the water as saturated vapor. The remaining water is saturated and is discharged to the ocean in the open cycle. The steam is a low pressure/high specific volume working fluid. It expands in a special low pressure turbine

$$H_3 = H_g$$

Here, H_g corresponds to T_2 .

For an ideal isentropic (reversible adiabatic) turbine,

$$S_{5s} = S_3 = S_f + x_{5s} S_{gf}$$

The above equation corresponds to the temperature at the exhaust of the turbine, T_5 . x_{5s} is the mass fraction of vapor at state 5.

The enthalpy at T_5 is,

$$H_{5s} = H_f + x_{5s} H_{fg}$$

This enthalpy is lower. The adiabatic reversible turbine work = $H_3 - H_{5s}$.

Actual turbine work $W_T = (H_3 - H_{5s}) \times \text{polytropic efficiency}$

$$H_5 = H_3 - \text{actual work}$$

The condenser temperature and pressure are lower. Since the turbine exhaust is to be discharged back into the ocean, a direct contact condenser is used to mix the exhaust with cold water, which results in a near-saturated water. That water is now discharged back to the ocean.

$H_6 = H_f$, at T_5 . T_7 is the temperature of the exhaust mixed with cold sea water, as the vapour content now is negligible

$$H_7 \approx H_f \text{ at } T_7$$

The temperature differences between stages include that between warm surface water and working steam, that between exhaust steam and cooling water, and that between cooling water reaching the condenser and deep water. These represent external irreversibility that reduce the overall temperature difference.

The cold water flow rate *per unit* turbine mass flow rate,

$$m_c = \frac{\dot{H}_5 - H_6}{H_6 - H_7}$$

Turbine mass flow rate,

$$\dot{M}_T = \frac{\text{turbine work required}}{W_T}$$

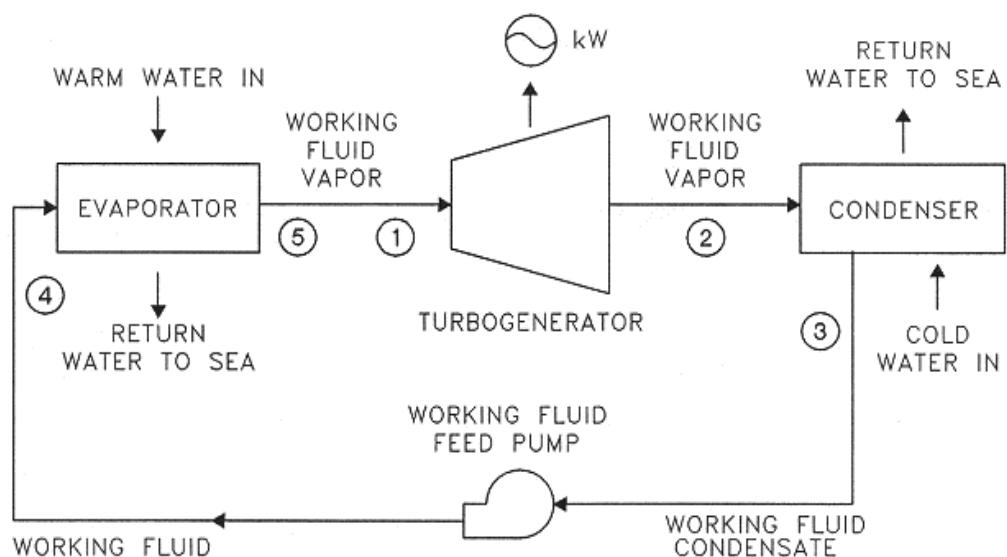
Warm water mass flow rate,

$$\dot{M}_w = M_T \dot{m}_w$$

Cold water mass flow rate

$$\dot{M}_c = M_T \dot{m}_C$$

Closed-Cycle (Rankine)



Closed-cycle systems use fluid with a low-boiling point, such as ammonia, to rotate a turbine to generate electricity. Here's how it works. Warm surface seawater is pumped through a heat exchanger where the low-boiling-point fluid is vaporized. The expanding vapor turns the turbo-generator. Then, cold, deep seawater—pumped through a second heat exchanger—condenses the vapor back into a liquid, which is then recycled through the system.

Thermodynamic analysis

In this cycle, Q_H is the heat transferred in the evaporator from the warm sea water to the working fluid. The working fluid exits the evaporator as a gas near its dew point.

The high-pressure, high-temperature gas then is expanded in the turbine to yield turbine work, W_T . The working fluid is slightly superheated at the turbine exit and the turbine typically has an efficiency of 90% based on reversible, adiabatic expansion.

From the turbine exit, the working fluid enters the condenser where it rejects heat, $-Q_C$, to the cold sea water. The condensate is then compressed to the highest pressure in the cycle, requiring condensate pump work, W_C . Thus, the Anderson closed cycle is a Rankine-type cycle similar to the conventional power plant steam cycle except that in the Anderson cycle the working fluid is never superheated more than a few degrees Celsius. Owing to viscous effects, working fluid pressure drops in both the evaporator and the condenser. This pressure drop, which depends on the types of heat exchangers used, must be considered in final design calculations but is ignored here to simplify the analysis. Thus, the parasitic condensate pump work, W_C , computed here will be lower than if the heat exchanger pressure drop was included. The major additional parasitic energy requirements in the OTEC plant are the cold water pump work, W_{CT} , and the warm water pump work, W_{HT} . Denoting all other parasitic energy requirements by W_A , the net work from the OTEC plant, W_{NP} is

$$W_{NP} = W_T + W_C + W_{CT} + W_{HT} + W_A$$

The thermodynamic cycle undergone by the working fluid can be analyzed without detailed consideration of the parasitic energy requirements. From the first law of thermodynamics, the energy balance for the working fluid as the system is

where $W_N = W_T + W_C$ is the net work for the thermodynamic cycle.

$$W_N = Q_H + Q_C$$

For the idealized case in which there is no working fluid pressure drop in the heat exchangers, and so that the net thermodynamic cycle work becomes,

$$Q_H = \int_H T_H ds$$

and

$$Q_C = \int_C T_C ds$$

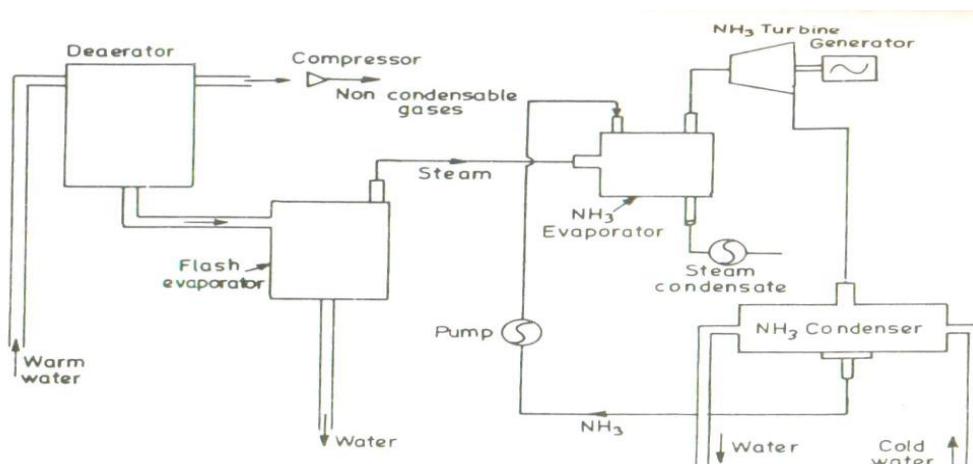
so that the net thermodynamic cycle work becomes

$$W_N = \int_H T_H ds + \int_C T_C ds$$

Sub cooled liquid enters the evaporator. Due to the heat exchange with warm sea water, evaporation takes place and usually superheated vapor leaves the evaporator. This vapor drives the turbine and the 2-phase mixture enters the condenser. Usually, the subcooled liquid leaves the condenser and finally, this liquid is pumped to the evaporator completing a cycle

Hybrid System:

Hybrid systems combine the features of both the closed-cycle and open-cycle systems. In a hybrid system, warm seawater enters a vacuum chamber where it is flash-evaporated into steam, similar to the open-cycle evaporation process. The steam vaporizes a low-boiling-point fluid (in a closed-cycle loop) that drives a turbine to produces electricity.



Advantages:

- **Low Environmental Impact**

The distinctive feature of OTEC energy systems is that the end products include not only energy in the form of electricity, but several other synergistic products.

- **Fresh Water**

The first by-product is fresh water. A small 1 MW OTEC is capable of producing some 4,500 cubic meters of fresh water per day, enough to supply a population of 20,000 with fresh water.

- **Food**

A further by-product is nutrient rich cold water from the deep ocean. The cold "waste" water from the OTEC is utilised in two ways. Primarily the cold water is discharged into large contained ponds, near shore or on land, where the water can be used for multi-species mariculture (shellfish and shrimp) producing harvest yields which far surpass naturally occurring cold water upwelling zones, just like agriculture on land.

- **Minerals**

OTEC may one day provide a means to mine ocean water for 57 trace elements. Most economic analyses have suggested that mining the ocean for dissolved substances would be unprofitable because so much energy is required to pump the large volume of water needed and because of the expense involved in separating the minerals from seawater. But with OTEC plants already pumping the water, the only remaining economic challenge is to reduce the cost of the extraction process.

UNIT-7**Biomass and Biogas****Introduction:**

The energy obtained from organic matter, derived from biological organisms (Plants and animals) is known as biomass energy. Animals feed on plants, and plants grow through the photosynthesis process using solar energy. Thus, photosynthesis process is primarily responsible for the generation of biomass energy. A small portion of the solar radiation is captured and stored in the plants during photosynthesis process. Therefore, it is an indirect form of solar into biomass energy is estimated to be 0.5 – 1.0%. To use biomass energy, the initial biomass may be transformed by chemical or biological processes to produce intermediate bio-fuels such as methane, producer gas, ethanol and charcoal etc. On combustion it reacts with oxygen to release heat, but the elements of the material remain available for recycling in natural ecological or agricultural processes. Thus, the use of industrial bio-fuels, when linked carefully to natural ecological cycle, may be non-polluting and sustainable. It is estimated that the biomass, which is 90% in trees, is equivalent to the proven current extractable fossil fuels reserves in the world. The dry matter mass of biological material cycling in biosphere is about 250×10^9 tons/y. The associated energy bound in photosynthesis is 2×10^{21} J/y (0.7×10^{14} W of power).

Biomass mainly in the form of wood, is mankind's oldest form of energy. It has traditionally been used both in domestic as well as industrial activities, basically by direct combustion. As industrial activities increased, the growing demand for energy depleted the biomass natural reserves. The development of new, more concentrated and more convenient sources of energy has led to its replacement to a large extent by other sources. Though biomass energy share in primary energy supply for the industrialized countries is not more than 3%, a number of developing countries still use a substantial amount of it, mostly in the form of non-commercial energy.

Main advantages of biomass energy are:

- i. It is a renewable source.
- ii. The energy storage is an in-built feature of it.
- iii. It is an indigenous source requiring little or no foreign exchange.
- iv. The pollutant emissions from combustion of biomass are usually lower than those from fossil fuels.

- v. Commercial use of biomass may avoid or reduce the problems of waste disposal in other industries, particularly municipal solid waste in urban centers.
 - vi. The nitrogen rich bio-digested slurry and sludge from biogas plant serves as a very good soil conditioner and improves the fertility of the soil.
- Main disadvantages are:
- i. It is a dispersed and land intensive source.
 - ii. It is often of low energy density.
 - iii. It is also labour intensive, and the cost of collecting large quantities for commercial application is significant.

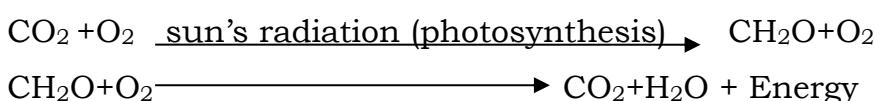
Most current commercial applications of biomass energy use material that has been collected for other reasons, such as timber and food processing residues and urban waste.

Biomass: It is the organic matter consisting of plant animal matter. Any matter which is biodegradable is known as biomass or organic matter. Generation of energy from biomass is referred to as 'Photo chemical' harnessing of solar radiation since to generate biomass; solar radiation is a must as seen from the following equation



Energy from the biomass is generated in three different forms namely) Direct burning, ii) Liquefaction, iii) Gas generation.

Direct burning: When biomass is directly burnt, energy is generated as given by the following expression,



Thus when photosynthesis reaction is reversed energy is liberated.

Liquefaction: Biomass is liquefied either by thermo-chemical method or biochemical method to generate alcohols like methyl and ethyl alcohol. These are mixed with petrol and used in IC Engines as fuels.

Bio gas: Biomass is converted to biogas by the process of digestion or fermentation in the presence of micro-organisms. This biogas mainly contains methane which is a good combustible gas.

Biogas consists of 50-55% of methane, 30-35% of CO₂ and remaining waste gases like H₂, N₂, H₂S etc. since it contains a hydrocarbon gas it is a very good fuel and hence can be used in IC engines. It is a slow burning gas with calorific

value of 5000-5500 Kcal/kg. the raw material used to generate this are algae, crop residue, garbage, kitchen waste, paper waste, waste from sugar cane refinery, water hyacinth etc. apart from the above mentioned raw materials excreta of cattle, piggery waste and poultry droppings are also used as raw materials.

Biogas is generated by fermentation or digestion of organic matter in the presence of aerobic and anaerobic micro-organisms. Fermentation is the process of breaking down the complex organic structure of the biomass to simple structures by the action of micro-organisms either in the presence of O₂ or in the absence of O₂. The container in which the digestion takes place is known as the digester.

Advantages

- The initial investment is low for the construction of biogas plant.
- The technology is very suitable for rural areas.
- Biogas is locally generated and can be easily distributed for domestic use.
- Biogas reduces the rural poor from dependence on traditional fuel sources, which lead to deforestation.
- The use of biogas in village helps in improving the sanitary condition and checks environmental pollution.
- The by-products like nitrogen rich manure can be used with advantage.
- Biogas reduces the drudgery of women and lowers incidence of eye and lung diseases.

The digestion takes place in the following steps

- i) Enzymatic hydrolysis ii) Acid formation iii) Methane formation.
- ii) **Enzymatic hydrolysis:** In this step the complex organic matter like starch, protein, fat, carbohydrates etc are broken down to simple structures using anaerobic micro-organisms.
- ii) **Acid formation:** In this step the simple structures formed in the enzymatic hydrolysis step are further reacted by anaerobic and facultative micro-organisms (which thrive in both the presence and absence of oxygen) to generate acids.
- iii) **Methane formation:** In this step the organic acids formed are further converted to methane and CO₂ by anaerobic micro-organisms (anaerobes).

Factors affecting Biogas generation:

- 1) PH value
- 2) Temperature
- 3) Total solid content
- 4) Load rating
- 5) Seeding
- 6) Uniform feeding
- 7) Dia to depth ratio
- 8) Carbon to nitrogen ratio
- 9) Nutrient
- 10) Mixing
- 11) Retention time
- 12) Type of feedstock
- 13) Toxicity
- 14) Pressure

1) PH value: It is an index of hydrogen ion concentration in the mixture which also predicts acidity or alkalinity of the mixture. For effective gas generation the required PH value is 6.5 to 7.6. If this value decreases to 4-6, the mixture becomes acidic and if the value becomes 9-10 then it becomes alkaline. Both for acidic and alkaline conditions the methane forming bacteria becomes inactive and the gas generation is reduced. Thus for effective gas generation the required PH value is 6.5-7.5.

2) Temperature: The effect of temp on gas generation is as shown in graph. The two curves represent two types of bacteria which are sensitive to two different temp levels. Mesophilic type of bacteria will effectively generate gas at a temp of about 35° C . Thermophilic type of bacteria will generate gas effectively at a temp of about 55° C . As the temperature

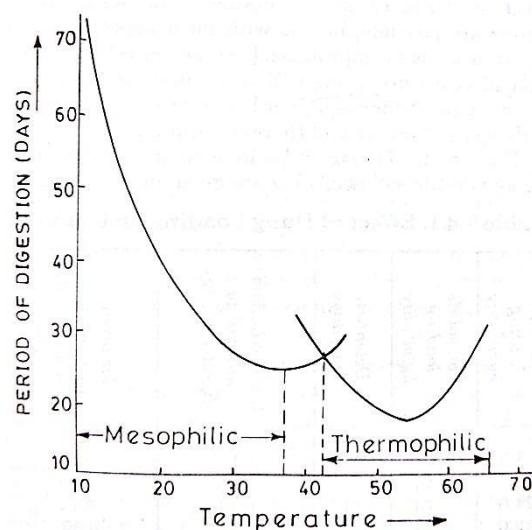


Fig. 7.5.1. Effect of temperature on digestion.

decreases or increases from the above values the period of gas generation will be increased. Since it is easy to maintain a temp of 35° C, it is advisable to select mesophilic type of bacteria for digestion.

- 3) **Total solid content:** The raw material added to the digester contains both solid and liquid in the ratio of 20:80 by weight. From the experience it is found that the gas generation is improved by maintaining the solid content of the mixture at about 8 to 10% by weight. This is done by adding water to the mixture.
- 4) **Loading rate:** It is the addition of the raw material to the digester/day/unit volume. The effective load rating is found to be 0.5 to 1.6 kg of solid material/day/m³.
- 5) **Seeding:** During digestion the methane forming bacteria are consumed rapidly and their number will decrease affecting the gas generation. In order to maintain the quantity of methane forming bacteria, digested slurry from the previous batch is added to the digestor. The digested slurry is rich in methane forming bacteria and the process is known as seeding.
- 6) **Uniform feeding:** this is one of the prerequisites of good digestion. The digester must be fed at the same time every day with a balanced feed of the same quality and quantity.
- 7) **Dia to depth ratio:** from the experiments it is seen that the gas generation is improved by maintaining a dia to depth ratio of 0.66 to 1. This provides uniform temp distribution throughout the digester resulting in increased gas generation.
- 8) **Carbon to nitrogen ratio:** The bacteria in the digester utilize carbon for energy generation (as food) while nitrogen is used for cell building. Hence a carbon to nitrogen ratio of 30:1 is maintained for effective gas generation. If the ratio is not maintained the availability of carbon and nitrogen will vary resulting in reduced gas generation.
- 9) **Nutrients:** The nutrients required by the bacteria for food digestion are hydrogen, nitrogen, oxygen, carbon, phosphorous and sulphur. Of these nitrogen and phosphorous have to be provided externally while the others are contained in the raw material itself. Nitrogen is provided by adding 'leguminous plants' (plants with seeds enclosed in casings, eg: Maize) which

are rich in nitrogen content. Phosphorous is provided by adding ‘night soil’ (soil mixed with excreta of animals and humans) to the digester.

10) Mixing: Since bacteria in the digester have very limited reach to their food it is necessary that the slurry is properly mixed and the bacteria get their food supply. It is found that the slight mixing improves the digestion and a violent mixing retards the digestion.

11) Retention time: It is the time period required for the gas generation. It completely depends on the type of the raw materials used. Eg: Night soil requires 30 days, pig dump and poultry droppings require 20 days while cow dung and other kitchen waste requires 50 days of retention time.

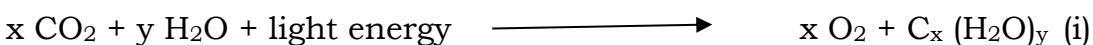
12) Type of feed stock: The usual feed stock used are cow dung, human excreta, poultry dropping, pig dump, kitchen waste etc. To obtain an efficient digestion these feed stocks are in some proportions, Predigested and finally chopping will be helpful for fibrous type of raw materials.

13) Toxicity: If the digester is left with the digested slurry it results in toxicity which in turn reduces the gas generation. Hence the digested slurry should be removed after the gas is generated.

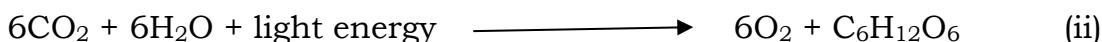
14) Pressure: It is found that the gas generation is increased with the decrease in the pressure of the digester.

Photosynthesis Process:

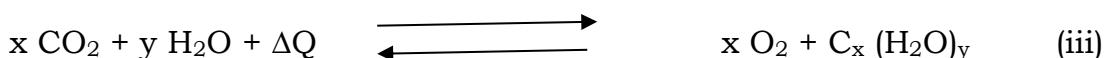
Solar radiation incident on green plants and other photosynthetic organisms performs two basic functions: (i) temperature control for chemical reactions to proceed, and (ii) Photosynthesis process. The fundamental conversion process in green plants is photosynthesis, which is the process of combining CO_2 from the atmosphere with water plus light energy to produce oxygen and carbohydrates (sugars, starches, celluloses and hemicelluloses). They are the ultimate source of most of our foods and other necessities of daily life such as clothes (in the form of cotton), furniture (in the form of wood), etc.



The generalized symbol $\text{C}_x (\text{H}_2\text{O})_y$ is used to indicate the carbohydrates. The products of this reaction are about 5ev per C atom higher in energy than the initial material. Photosynthesis is a complex process. It involves several successive stages, but the overall basic reaction is the formation of hexose (glucose, fructose, etc.) as represented by:



More complex hydrocarbons (sucrose, starch, cellulose, etc.) are formed by a chain of these simple structures. The reverse of this process is called respiration, in which CO_2 , H_2O and energy are produced using carbohydrate and oxygen. In green plants, both photosynthesis and respiration occur during the day and only respiration at night. This is shown in figure below. There is a net overall gain of energy in the process, as the rate of energy loss in respiration is much less as compared to rate of energy gain during photosynthesis process. The process also results in net gain of oxygen and fixation of carbon in the form of biomass. The net energy absorbed from solar radiation during photosynthesis can be measured from its combustion.



ΔQ is enthalpy change of the combustion process, equal to the energy absorbed from photons of solar radiation, less the energy of respiration during growth. The value of ΔQ is 4.8eV per carbon atom, 470kJ per mole of carbon or 16 MJ/kg of dry carbohydrate material. It is to be noted that the combustion requires the temperature of approximately 400°C , whereas respiration occurs at 20°C through catalytic enzyme reactions.

The uptake of CO_2 by a plant leaf is a function of many factors, especially temperature, CO_2 concentration and the intensity and wavelength distribution of light. Solar radiation incident on a leaf is reflected, transmitted and absorbed. Part of the absorbed radiation (<5%) provides the energy stored in the photosynthesis and produces oxygen and carbohydrate; the remainder is absorbed in the plant as sensible heat raising its temperature, or as latent heat for water evaporation. Absorption is usually most marked in the blue and red regions.

Biochemical reactions in anaerobic digestion:

There are four key biological and chemical stages of anaerobic digestion:

Hydrolysis

Acido genesis

Aceto genesis

Methano genesis.

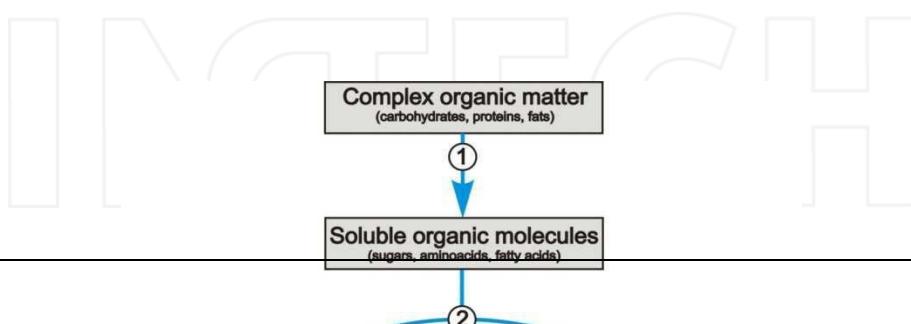


Fig.7.2. Anaerobic pathway of complex organic matter degradation

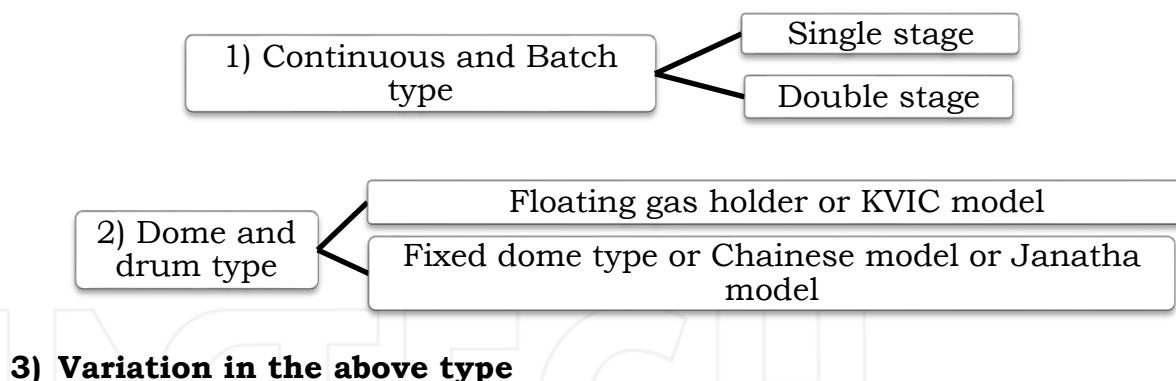
In most cases biomass is made up of large organic compounds. In order for the microorganisms in anaerobic digesters to access the chemical energy potential of the organic material, the organic matter macromolecular chains must first be broken down into their smaller constituent parts. These constituent parts or monomers such as sugars are readily available to microorganisms for further processing. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis. Therefore hydrolysis of high molecular weight molecules is the necessary first step in an aerobic digestion. It may be enhanced by mechanical, thermal or chemical pretreatment of the waste. Hydrolysis step can be merely biological (using hydrolytic microorganisms) or combined: bio-chemical (using extra cellular enzymes), chemical (using catalytic reactions) as well as physical (using thermal energy and pressure) in nature.

Acetates and hydrogen produced in the first stages can be used directly by methanogens. Other molecules such as volatile fatty acids (VFA's) with a chain length that is greater than acetate must first be catabolised into compounds that can be directly utilized by methanogens. The biological process of acidogenesis is where there is further breakdown of the remaining components by acidogenic (fermentative) bacteria. Here VFA's are generated along with ammonia, carbon dioxide and hydrogen sulphide as well as other by-products.

The third stage anaerobic digestion is acetogenesis. Here simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid (or it's salts) as well as carbon dioxide and hydrogen.

The final stage of anaerobic digestion is the biological process of methanogenesis. Here methanogenic archaea utilize the intermediate products of the preceding stages and convert the min to methane, carbondioxide and water. It is these components that makes up the majority of the biogas released from the system. Methanogenesis is—beside other factors-sensitive to both high and low pH values and performs well between pH 6.5 and pH 8. The remaining, non-digestible organic and mineralmaterial, which the microbes cannot feed upon, along with any dead bacterial residues constitutes the solid digestate.

Classification of the biogas plants:



3) Variation in the above type

Single stage continuous plant:

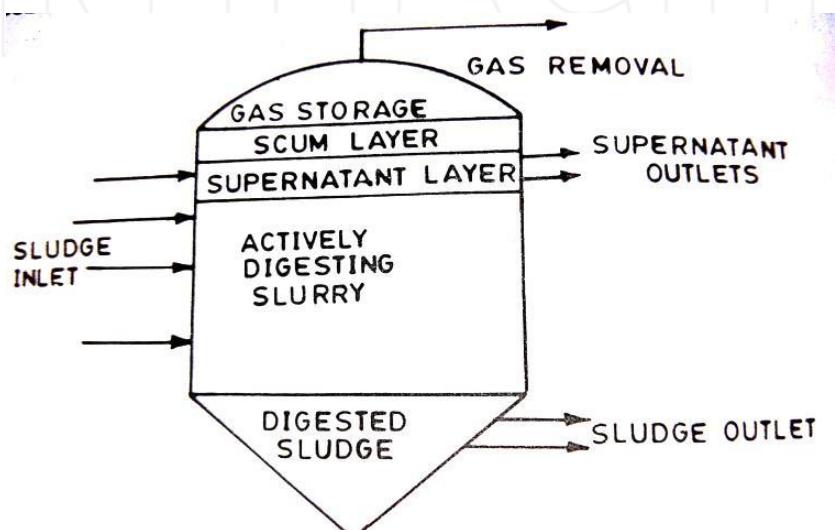


Fig. 7.6.1. Schematic of single process conventional digester.

The entire process of conversion of complex organic compounds into biogas in completed in a single chamber. This chamber is regularly fed with the raw materials while the spent residue keeps moving out. Serious problems are encountered with agricultural residues when fermented in a single stage continuous process.

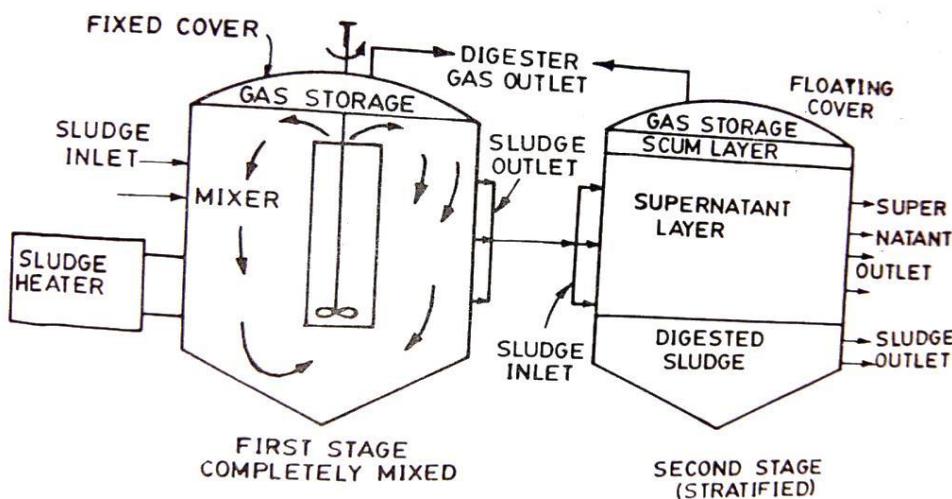
Two stage continuous plant: (i) Acid & ii) Methane forming:

Fig. 7.6.2. Schematic of two-stage digestion process.

The acidogenic stage and methanogenic stage are physically separated into two chambers. Thus the first stage of acid production is carried out in a separate chamber and only the diluted acids are fed into the second chamber where bio-methanation takes place and the biogas can be collected from the second chamber. Considering the problems encountered in fermenting fibrous plant waste materials the two stage process may offer higher potential of success. However, appropriate technology suiting to rural India is needed to be developed based on the bauble stage process.

The main features of continuous plant are that:

- 1) It will produce gas continuously;
- 2) It requires small digestion chambers;
- 3) It needs lesser period for digestion;
- 4) It has fewer problems compared to batch type and it is easier in operation.

a) **Indian Digester (Floating drum type/Khadi Villege Industries Commission Plant (KVIC)):**

This mainly consists of a digester or pit for fermentation and a floating drum for the collection of gas. Digester is 3.5-6.5 m in depth and 1.2 to 1.6 m in diameter. There is a partition wall in the center, which divides the digester vertically and submerges in the slurry when it is full. The digester is connected to the inlet and outlet by two pipes. Through the inlet, the dung is mixed with water (4:5) and loaded into the digester. The fermented material will flow out through outlet pipe. The outlet is generally connected to a compost pit. The gas generation takes place slowly and in two stages. In the first stage, the complex, organic substances contained in the waste are acted upon by a certain kind of bacteria, called acid formers and broken up into small-chain simple acids. In the second stage, these acids are acted upon by another kind of bacteria, called methane formers and produce methane and carbon dioxide.

Gas holder:

The gas holder is a drum constructed of mild steel sheets. This is cylindrical in shape with concave top. The top is supported radially with angular iron stripes. The holder fits into the digester like a stopper. It sinks into the slurry due to its own weight and rests upon the ring constructed for this purpose. When gas is generated the holder rises and floats freely on the surface of slurry. A central guide pipe is provided to prevent the holder from tilting. The holder also acts as a seal for the gas. The gas pressure varies between 7 and 9 cm of water column. Under shallow water table conditions, the adopted diameter of digester is more and depth is reduced. The cost of drum is about 40% of total cost of plant. It requires periodical maintenance. The unit cost of KVIC model with a capacity of 2 m³/day costs approximately Rs. 14, 000/-.

Janata type biogas plant (Chinese):

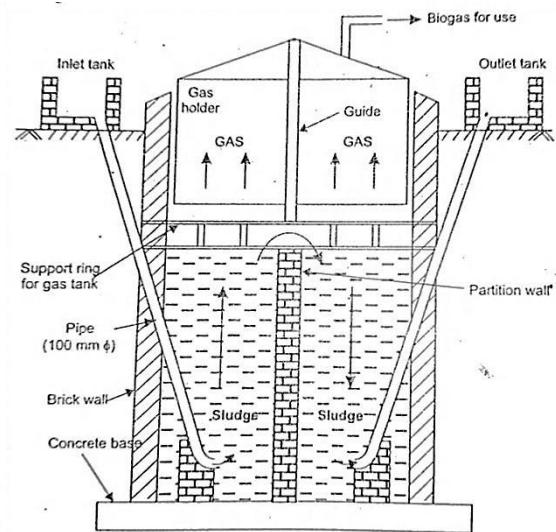


Fig. 8-6. Indian Design Digestor

The design of this plant is of Chinese origin but it has been introduced under the name "Janata biogas plant" by Gobar Gas Research Station, Ajitmal in view of its reduced cost. This is a plant where no steel is used, there is no moving part in it and maintenance cost is low. The plant can be constructed by village mason taking some pre-explained precautions and using all the indigenously available building materials. Good quality of bricks and cement should be used to avoid the afterward structural problems like cracking of the dome and leakage of gas. This model have a higher capacity when compared with KVIC model, hence it can be used as a community biogas plant. This design has longer life than KVIC models. Substrates other than cattle dung such as municipal waste and plant residues can also be used in janata type plants. The plant consists of an underground well sort of digester made of bricks and cement having a dome shaped roof which remains below the ground level is shown in figure. At almost middle of the digester, there are two rectangular openings facing each other and coming up to a little above the ground level, act as an inlet and outlet of the plant. Dome shaped roof is fitted with a pipe at its top which is the gas outlet of the plant. The principle of gas production is same as that of KVIC model. The biogas is collected in the restricted space of the fixed dome; hence the pressure of gas is much higher, which is around 90 cm of water column.

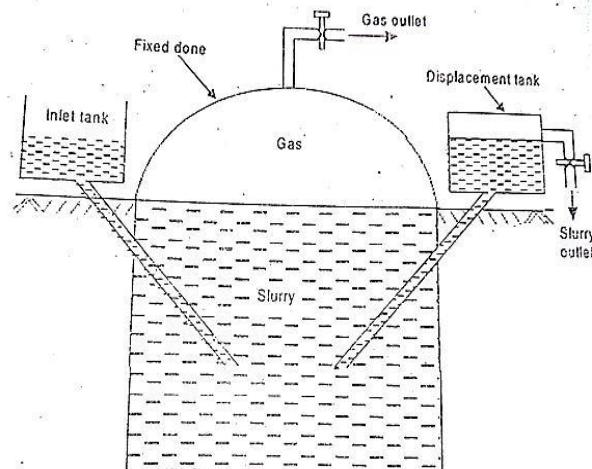
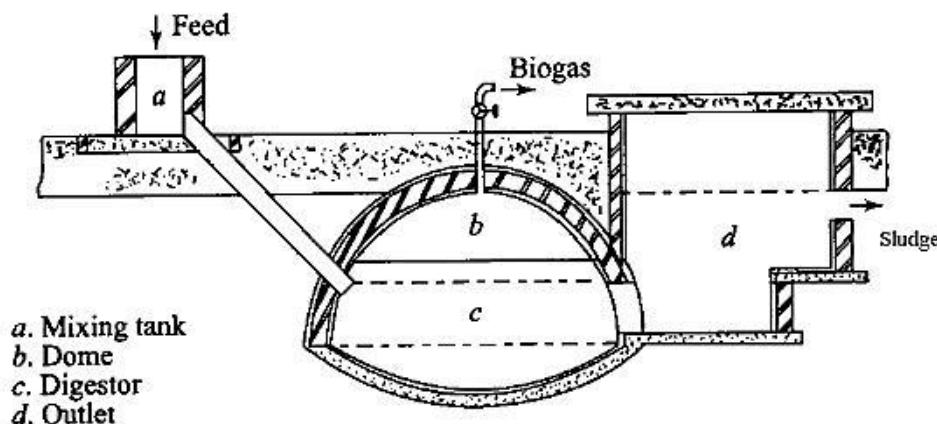


Fig. 8-7. Chinese design biogas plant

Deenbandhu biogas plant:



Deenbandhu model was developed in 1984, by Action for Food Production (AFPRO), a voluntary organization based in New Delhi. Schematic diagram of a Deenabandhu biogas plant entire biogas programme of India as it reduced the cost of the plant half of that of KVIC model and brought biogas technology within the reach of even the poorer sections of the population. The cost reduction has been achieved by minimizing the surface area through joining the segments of two spheres of different diameters at their bases. The cost of a Deenbandhu plant having a capacity of 2 m³/day is about Rs.8000/. The Deenbandhu biogas plant has a hemispherical fixed-dome type of gas holder, unlike the floating dome of the KVIC-design is shown. The dome is made from pre-fabricated Ferro cement or reinforced concrete and attached to the digester, which has a curved bottom. The slurry is fed from a mixing tank through an inlet pipe connected to the digester. After fermentation, the biogas collects in the space under the dome. It is taken out for use through a pipe connected to the top of the dome, while the sludge, which is a by-product, comes out through an opening in the side of the digester. About 90% of the biogas plants in India are of the Deenbandhu type.

Problems Related to Bio-gas Plants:

Some problems are natural and some are created by the persons biogas plants owners but all are controllable.

1. Handling of effluent slurry is major problem if the person is not having sufficient open space or compost pits to get the slurry dry. Use of press filters and transportation is expensive and out of reach of poor farmers. For a domestic plant, 200 litres capacity oil drums can be used to carry this effluent

to the fields but this will require some human-animal labour or consumption of diesel if a auto vehicle is used.

2. The gas forming-methanogenic bacteria are very sensitive towards the temperature compared to those of non-methanogenic. During winter as the temperature falls, there is decrease in the activity of methanogenic bacteria and subsequently fall in gas production rate. Many methods have been suggested to overcome this temperature problem as described earlier, e.g.,

- a) Use of solar heated hot water to make a slurry of influent but the temperature of water should not exceed 60°C otherwise the mesophilic bacteria will die.
- b) Circulation of hot water obtained either from solar heater or I.C. engine heat exchanger, through pipes inside the digester.
- c) Green house effect also give good results but it is costlier and after few years the polythene sheet used in it becomes opaque.
- d) Addition of various nutrients for bacteria.
- e) Converting the biogas plant by straw bags during night hours.

3. Due to lack of proper training to the bio-gas plant owners for the operation of plant, a lot of problems arises. It has been noticed that many persons increase the loading rate and some also do not try to mix the cattle dung with water, keeping in mind more gas production. Due to this, the flow of slurry from inlet towards outlet is very slow or even stops. This may cause accumulation of volatile fatty acids and drop in Ph and then failure of digester. Also it is not possible to stir the digester content of high solid concentration.

4. Some persons add urea-fertilizer in large quantities due to which toxicity of ammonia nitrogen may cause a decrease in gas production.

5. pH and volatile fatty acids play an important role in anaerobic digestion and should remain under optimum range otherwise this may cause upsetting of digester and even its failure. pH can be checked from time to time by the use of cheap and easily available pH paper but volatile fatty acids can only be determined in a laboratory having its testing facilities. For controlling pH in optimum range, it tends to fall below 7.0, lime has been suggested, as it is easily available cheap material and does not harm the activity of bacteria.

6. Leakage of gas from gas holder especially in case of Janta type biogas plants is a major and very common problem. When there is quite enough gas in a gas holder, the leakage should be checked by using water and the points marked and then get repaired. During repairing there should be no gas inside the gas holder and the stop cock remains open till repaired points get dry. Quality of constructing material such as cement is important.

Advantages of Biogas:

1. Biogas is an energy carrier which can be used for several energy applications (eg. electricity generation, heat production, combine heat and power production, transport fuel, injection to the natural gas grid).

2. Biogas can contribute to several sectors:

i) Environment

(eg. Fight against Climate change)

ii) Energy

(eg. Energy security, local source)

iii) Agriculture

(eg. Sustainable cultivation and animal breeding)

iv) Society

(eg. Employment enhancement, rural development)

3. Some Environmental benefits of biogas:

i) Reduced emissions of greenhouse gases, direct and indirect (eg. CO₂, CH₄ and nitrous oxide -N₂O).

ii) Water and Waste management (Reduced consumption of resources and increased recycling, reduced water environment pollution from leaching of nutrients, environmental friendly solution to the waste disposal problem).

iii) Reduced odour and flies nuisances.

iv) Soil and landscape

4. Emissions reduction of greenhouse gases (eg. CO₂, CH₄ and nitrous oxide -N₂O).

Direct:

The combustion of biogas also releases CO₂. Compared to fossil fuels, the carbon in biogas was recently up taken from the atmosphere, by photosynthetic activity of the plants (closed carbon cycle) .

- Biogas production by AD reduces also emissions of methane (CH₄) and nitrous oxide (N₂O) from storage and utilization of animal manure as fertilizer. It is worth mentioning that although biogas is a potential low

- carbon energy source, this depends on the way biogas is produced. In the case that biogas comes from residues, waste or from energy crops grown on abandoned agricultural land this offers sustained GHG advantages.
- Emissions reduction of greenhouse gases (eg. CO₂, CH₄ and nitrous oxide -N₂O). Indirect:
- Utilisation of biogas substitute fossil fuel (such as lignite, hard coal, crude oil and natural gas) and thus reduces emissions (externalities).

5. Water and Waste management

- Compared to other biofuels, biogas needs the lowest amount of process water. This aspect is very important since many regions of the world face huge water problems
- One of the main advantages of biogas production is the ability to transform waste material into a valuable resource, by using it as feedstock for AD.
- Biogas technologies contribute to reduce the volume of wastes and the costs for waste disposal (transportation, disposal).

6. Health issues, odour and flies

Utilisation of digestate as fertilizer improves veterinary safety, when compared to untreated manure and slurries.
AD reduces odours (positive change in the composition of odours as well). Digestate is almost odourless and the remaining disappear shortly after application as fertilizer on the fields (ammonia odours).

7. Employment

8. Rural development

9. Local economy and Energy Market development

Application of bio-gas in engines:

Biogas in Diesel Engine applications:

Biogas generally has a high self-ignition temperature hence; it cannot be directly used in a CI engine. So it is useful in dual fuel engines. The dual fuel engine is a modified diesel engine in which usually a gaseous fuel called the primary fuel is inducted with air into the engine cylinder. This fuel and air mixture does not auto ignite due to high octane number. A small amount of diesel, usually called pilot fuel is injected for promoting combustion. The primary fuel in dual fuelling system is homogeneously mixed with air that leads to very low level of smoke. Dual fuel engine can use a wide variety of primary and pilot fuels. The pilot fuels are generally of high cetane fuel. Biogas can also be used in dual fuel mode with vegetable oils as pilot fuels in diesel engines. Introduction of biogas normally leads to deterioration in performance and emission characteristics. The performance of engine depends on the amount of biogas and the pilot fuel used. Measures like addition of hydrogen, LPG, removal of CO₂ etc. have shown significant improvements in the

performance of biogas dual fuel engines. The ignition delay of the pilot fuel generally increases with the introduction of biogas and this will lead to advance the injection timing. Injectors opening pressure and rate of injection also are found to play important role in the case of biogas fuelled engine, where vegetables oil is used as a pilot fuel. The CO₂percentage in biogas acts as diluents to slow down the combustion process in Homogenous charged compression ignition (HCCI) engines. However, it also affects ignition. Thus a fuel with low self-ignition temperature could be used along with biogas to help its ignition. This kind of engine has shown a superior performance as compared to a dual fuel mode of operation.

Biogas in Dual Fuel Engine applications:

In this case, the normal diesel fuel injection system still supplies a certain amount of diesel fuel. The engine however sucks and compresses a mixture of air and biogas fuel which has been prepared in external mixing device. The mixture is then ignited by and together with the diesel fuel sprayed in. The amount of diesel fuel needed for sufficient ignition is between 10% and 20% of the amount needed for operation on diesel fuel alone. Operation of the engine at partial load requires reduction of the biogas supply by means of a gas control valve. A simultaneous reduction of airflow would reduce power and efficiency because of reduction of compression pressure and main effective pressure. So, the air/fuel ratio is changed by different amounts of injected biogas. All other parameters and elements of diesel engine remain unchanged.

Biogas As Alternate Fuel In Diesel Engines: A Literature Review
Modification of diesel engine into dual fuel engine Advantages-Operation on diesel fuel alone is possible when biogas is not available.-Any contribution of biogas from 0% to 85% can substitute a corresponding part of diesel fuel while performance remains as in 100% diesel fuel operation.- Because of existence of a governor at most diesel engines automatic control of speed/power can be done by changing the amount of diesel fuel injection while the biogas flow remains uncontrolled. Diesel fuel substitutions by biogas are less substantial in this case.

Limitations:

- The dual fuel engine cannot operate without the supply of diesel fuel for ignition.
- The fuel injection jets may overheat when the diesel fuel flow is reduced to 10% or 15% of its' normal flow. Larger dual fuel engines circulate extra diesel fuel through the injector for cooling.
- To what extent the fuel injection nozzle can be affected is however a question of its' specific design, material and the thermal load of the engine, and hence differs from case to case.
-

A check of the injector nozzle after 500 hours of operation in dual fuel is recommended.

Biogas in HCCI Engine applications:

The Homogeneous Charge Compression Ignition (HCCI) concept is a potential for achieving a high thermal efficiency and low Nitrogen Oxide (NO) emission. The HCCI engine with 50 % biogas as a primary fuel and 50% diesel as pilot fuel gives a maximum NO of 20 ppm is a major advantage over biogas diesel dual fuel mode. In biogas diesel dual fuel mode the presence of CO₂ in biogas lowers the thermal efficiency however, in biogas diesel HCCI (BDHCCI) mode CO₂ reduces high heat release rate. The break mean effective pressure (BMEP) in BDHCCI mode is in the range of 2.5 bar to 4 bar. The smoke and Hydro Carbon (HC) level were also low when the biogas is used as a primary fuel for BDHCCI mode. For HCCI operation the inducted charge temperature is required to be maintained at 80-135°C, which can be obtained from the exhaust heat. Thus biogas with HCCI engine gives high efficiency and low emission.

PPK

Unit-8

HYDROGEN ENERGY

Introduction:

Hydrogen as an energy carrier can play an important role as an alternative to conventional fuels, provided its technical problems of production, storage & transportation can be resolved satisfactorily & the cost could be brought down to acceptable limits.

- ❖ One of the most attractive features of H₂ as an energy carrier is that it can be produced from water which is abundantly available in nature.
- ❖ H₂ has the highest energy content per unit mass of any chemical fuel & can be substituted for hydrocarbons in a broad range of applications, often with the increased combustion efficiency. Its burning process is non-polluting & it can be used in the fuel cells to produce both electricity & useful heat.

Use of H₂ as an energy source involves 5 basic issues:

- 1] production, 2] Storage & Transportation, 3] Utilization, 4] Safety & Management, 5] Economy

Use of hydrogen:

Hydrogen is mainly used for the conversion of heavy petroleum fractions into lighter ones via the process of hydro cracking and other petroleum fractions (dehydrocyclization and the aromatization process). It is also required for cleaning fossil fuels via hydrodesulphurization.

Hydrogen is mainly used for the production of ammonia via Haber process. In this case, the hydrogen is produced in situ. Ammonia is the major component of most fertilizers.

Earlier it was common to vent the surplus hydrogen off, nowadays the process systems are balanced with hydrogen pinch to collect hydrogen for further use.

Hydrogen may be used in fuel cells for local electricity generation, making it possible for hydrogen to be used as a transportation fuel for an electric vehicle.

Hydrogen is also produced as a by-product of industrial chlorine production by electrolysis. Although requiring expensive technologies, hydrogen can be cooled, compressed and purified for use in other processes on site or sold to a customer via pipeline, cylinders or trucks. The discovery and development of less expensive methods of production of bulk hydrogen is relevant to the establishment of a hydrogen economy

PROPERTIES OF HYDROGEN:

- Hydrogen at ordinary temperature & pressure is a light gas with a density only 1/14th that of air & 1/9th that of a natural gas under the same conditions.
- By cooling to the extremely low temperature of 253°C at atmospheric pressure, the gas is condensed to a liquid with a specific gravity of 0.07, roughly 1/10th of that of gasoline.
- The standard heating value of H₂ gas is 12.1 MJ/m³ with an average of 38.3 MJ/m³ for natural gas.
- The heating value of H₂ is 120 MJ/Kg or 8400 MJ/m³; the corresponding value for gasoline {or approximately for jet fuel} is 44 MJ/Kg or 32,000 MJ/m³. Hence, for producing a specific amount of energy, liquid H₂ is superior [or jet fuel] on a weight basis but inferior on a volume basis.
- Despite its stability, hydrogen forms many bonds and is present in many different compounds.

- Three naturally occurring isotopes of hydrogen exist: protium, deuterium, and tritium, each with different properties due to the difference in the number of neutrons in the nucleus.
- The flame speed of H₂ burning in air is much greater than for natural gas, & the energy required to initiate combustion is less.
- One consequence of the low ignition energy is that flameless combustion on a catalytic surface is possible with H₂ at much lower temperature than flame burning.

Mixture of H₂ & air are combustible over an exceptionally wide range of compositions; thus, the flammability limits at ordinary temperature extended from 4 to 74 % by volume of H₂ in air, that means, Hydrogen is the lightest element and will explode at concentrations ranging from 4-75 percent by volume in the presence of sunlight, a flame, or a spark. This wide range has an important bearing on the use of H₂ fuel in I.C. Engines.

SOURCES OF HYDROGEN:

- ✓ Natural gas contains hydrogen (about 95% of natural gas is **methane**, CH₄), as does biomass (cellulose) and hydrocarbons, like coal. An equally diverse array of primary energy sources, such as wind, solar, geothermal, nuclear and hydropower, can be used to extract hydrogen from water.
- ✓ H₂ made from coal is of questionable importance as a fuel of gas even it Is relatively inexpensive but on the other hand, it would not be as conviently transported or utilized in transmission & combustion system.

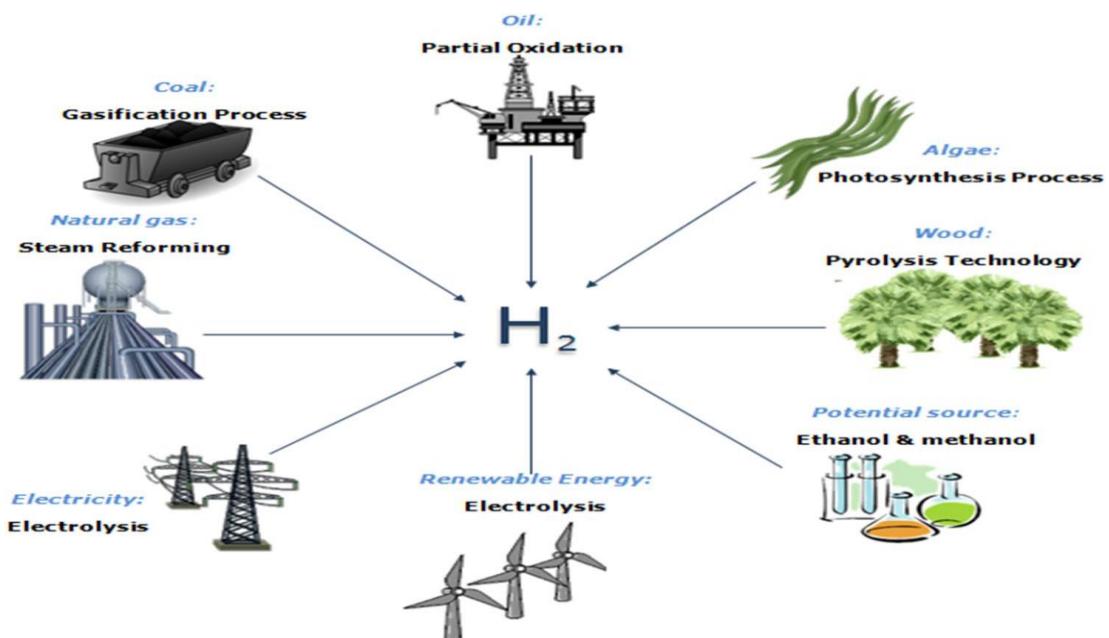
Sources and Commercial Preparation:

While hydrogen is only about one part per million in the atmosphere, it is the most abundant element in the universe. It is believed that hydrogen makes up about three quarters of the mass of the universe, or over 90% of the molecules. It is found in the sun and in other stars, where it is the major fuel in the fusion reactions (see nucleosynthesis) from which stars derive their energy.

Hydrogen is prepared commercially by catalytic reaction of steam with hydrocarbons, by the reaction of steam with hot coke (carbon), by the electrolysis of water, and by the reaction of mineral acids on metals. Millions of cubic feet of hydrogen gas are produced daily in the United States alone.

Hydrogen can be produced from a wide variety of primary sources. These include:

- **Coal** - hydrogen can be produced from the gasification of coal.
- **Oil** - hydrogen can be produced from steam reforming or partial oxidation of fossil oils.
- **Gas** - hydrogen can be produced as a by-product from reforming natural gas or biogas with steam.
- **Power** - hydrogen can be produced from water electrolysis using any power source including nuclear, wind and solar power.
- **Wood/Biomass** - hydrogen can be produced by decomposing biomass under controlled conditions.
- **Algae** - hydrogen can be produced via methods that utilise photosynthesis.
- **Alcohols** - hydrogen can be produced from gas or biomass-derived alcohols such as ethanol and methanol.



HYDROGEN PRODUCTION:

- H₂ made from coal can probably only be justified as a fuel for special applications where the unique characteristics of H₂ can be put to advantage, such as its weight or its non-polluting characteristics.
- Small quantities of H₂ are commercially produced today by the electrolysis of water-usually in situations where electric power is cheap, or reliable unattended operations are required.
- Electrolysis is the only presently available technology by which H₂ can be made from non-fossil energy [nuclear, solar, geothermal or wind].

The methods of producing H₂ may be classified according to the immediate source of addition of energy to decomposes, thus electrical energy [in electrolysis], heat energy [in thermo chemical methods], fossil fuels & solar energy.

Electrolysis or the electrolytic production of hydrogen:

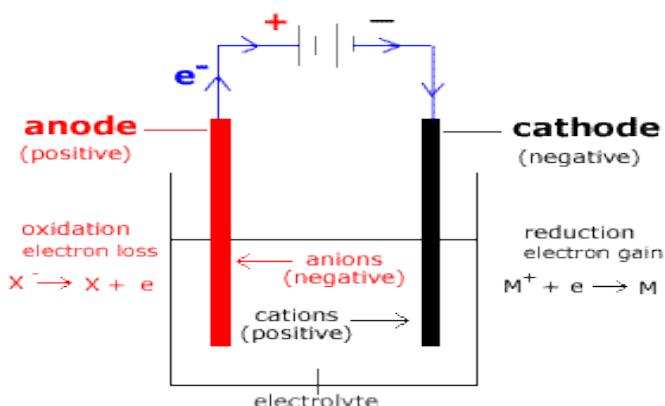


Fig. Simple electrolytic cell

The process of splitting water into H₂ & oxygen by means of a direct electric current is known as **Electrolysis**; this is the simplest method of H₂ production.

In principle, an electrolysis cell consists of two electrodes, commonly flat metal or carbon plates, immersed in an aqueous conducting solution called the electrolyte.

A source of direct current voltage is connected to the electrodes so that an electric current flows through the electrolyte from the positive electrode [or anode]

to the negative electrode [or cathode]. As a result, the water in the electrolyte solution is decomposed into H₂ gas which is released at the cathode, & O₂ gas; released at the anode. Although only water is split, an electrolyte [ex: KOH solution] is required because water itself is a very poor conductor of electricity.

Ideally, a voltage of 1.23 volts should be sufficient for the electrolysis of water at normal temperature & pressure. For various reasons, especially the slowness of the electrode processes that lead to the liberation of H₂ & O₂ gases, higher voltages are required to decompose water.

The decomposition voltage increases with the current density [i.e., the current per unit area of electrode]. Since the rate of H₂ production is proportional to the current strength, a high operating current density is necessary for economic reasons. Hence, in practice the decomposition voltage [per cell] is usually around 2 volts.

Theoretically, 2.8 KW-hr of electrical energy should produce 1m³ of H₂ gas. Because of the higher than ideal decomposition voltage, however the actual electric energy requirement is generally from 3.9 to 4.6 KW-hr/m³. This means that the efficiency of electrolysis is roughly 60 to 70%.

The electrolysis efficiency can be increased by decreasing the decomposition voltage for a given current density by catalyze the electrode surface [ex platinum catalyst].

Diaphragms prevent electronic contact between adjacent electrodes & passage of dissolved gas or gas bubble; from one electrode to another. Asbestos is the most common material for cell diaphragms.

Three major factors determine the usefulness of an electrochemical cell for H₂ production. One is the energy efficiency, related to the cell's operating voltage: another is the capital cost of the plant, related to the rate of H₂ production from a cell of a given size. These two factors are closely inter-related. The third factor is the lifetime of the cell & its maintenance requirements, which involve the materials used in its construction & operating conditions selected.

Two types of electrode arrangements are used by industry for the electrolysis of water. On this basis they are classified as:

A] Tank type Electrolyzer [unipolar or monopolar]

B] Filter press or Bipolar Electrolyzer.

A] Tank type Electrolyzer [unipolar or monopolar]: In this type a series of electrodes, alternating anodes [+] & cathode [-] are suspended vertically & parallel to one another in a tank filled [most commonly] with a 20-30% solution of potassium hydroxide in demineralized water. Alternate electrodes, usually the cathodes, are surrounded by porous diaphragm [ex: asbestos] impermeable to gas but permeable to the cell's electrolyte, that prevent the passage of gas free from one electrode to compartment to another. The whole assembly is hung from a series of gas collectors. All the anodes in the tank are connected to the same positive terminal of the direct current voltage source, & all the cathodes are connected to the same negative terminal. Ref fig: [a].

By connecting the electrodes in parallel in this manner the voltage required for a tank of several electrode pairs, regardless of the number is little more than for a single pair [or cell], i.e., about 2 volts. As a rule, a number of tanks are connected in series: the operating voltage is then roughly 2n volts, where n is the number of tanks so connected.

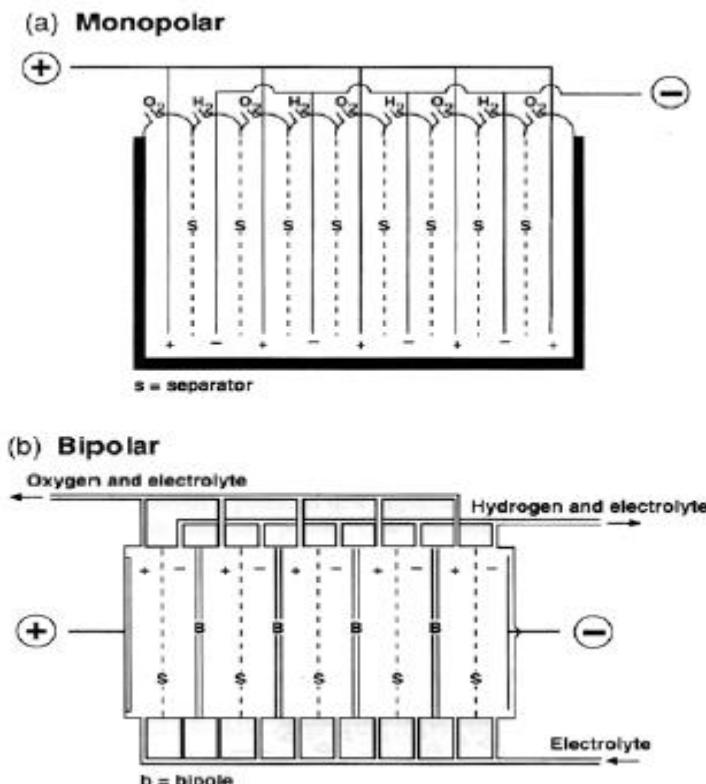
ADVANTAGES:

- Only few parts are required & those needed are relatively inexpensive;

- Individual cells may be isolated for repair or replacement simply by short-circuiting the 2 adjacent cells with a temporary bus bar connection.

DISADVANTAGES:

- + Inability to handle high current densities because of cheaper component parts.
- + Inability to operate at high temperatures because of heat losses from the large surface areas of connected cells.



B] filter-press Electrolyzer [Bipolar Electrolyzer]:- The bipolar design (Figure B), often called the filter-press, has alternating layers of electrodes and separation diaphragms that are clamped together. The cells are connected in series and result in higher stack voltages. Since the cells are relatively thin, the overall stack can be considerably smaller than the unipolar design. The advantages to the bipolar design are the reduced stack footprints, higher current densities, and its ability to produce higher pressure gas. The disadvantage is that it cannot be repaired without servicing the entire stack. Fortunately, it rarely needs servicing. Previously asbestos was used as a separation diaphragm, but manufacturers have replaced or are planning to replace this with new polymer Materials such as Ryton.

Bipolar membranes are of considerable interest because their water dissociation capability is an energy efficient process to produce acids and bases. The theoretical potential difference across a 100% perm selective bipolar membrane for the generation of a one molar acid and base solution at 25 °C can be calculated to be 0.83 Volt [53]. The actual potential drop across the bipolar membrane would be higher than this theoretical value because of irreversible effects due to the electrical resistance of the cation and anion exchange layers and the interphase region of the membrane.

An alternative method to produce acids and bases is electrolysis in which water is split by electrode reactions for obtaining the desired H⁺ and OH⁻. Compared to electrolysis the electrodialytic production of acids and bases with bipolar membranes have several advantages. The cell unit for electrodialytic water dissociation is much simpler in construction. A large number of membranes are assembled between one set of electrodes. In contrast, electrolysis needs a set of electrodes for each cell unit, resulting in much higher costs of electrodes and electrical connections. Additionally, electrolysis requires considerably more energy, because of the co-production of oxygen and hydrogen gas at the electrodes. The theoretical energy requirement for the production of acid and base by electrolysis depends on the salt being used; for most salts the theoretical potential to produce one molar acid and base varies between 2.1 and 2.2 Volts at 25 °C. The advantage of electrolysis is that usually higher concentrations and higher purities of the acid and base can be obtained. The production of acid and base solutions with bipolar membranes offers a broad spectrum of possible applications. Aqueous salt streams are generated as waste streams in many diverse chemical processing operations. Disposal of such waste streams not only means a loss of resource but has also become very unattractive due to stringent environmental regulations nowadays. With bipolar membranes these streams can be regenerated into acids and bases, which usually are the precursor chemicals for such waste streams. Some other examples of bipolar membrane applications are the regeneration of ion exchange resins, the removal of sulfur dioxide from flue gases, the recovery of acid from pickle liquor in the steel production industry and, based on the decreasing demand for chlorine, the production of sodium hydroxide as an alternative to the chloralkali process. An overview of possible applications in the field of pollution control, resource recovery and chemical processing can be found in references. Despite the many possibilities that have been identified, electrodialysis with bipolar membranes is still in a development stage.

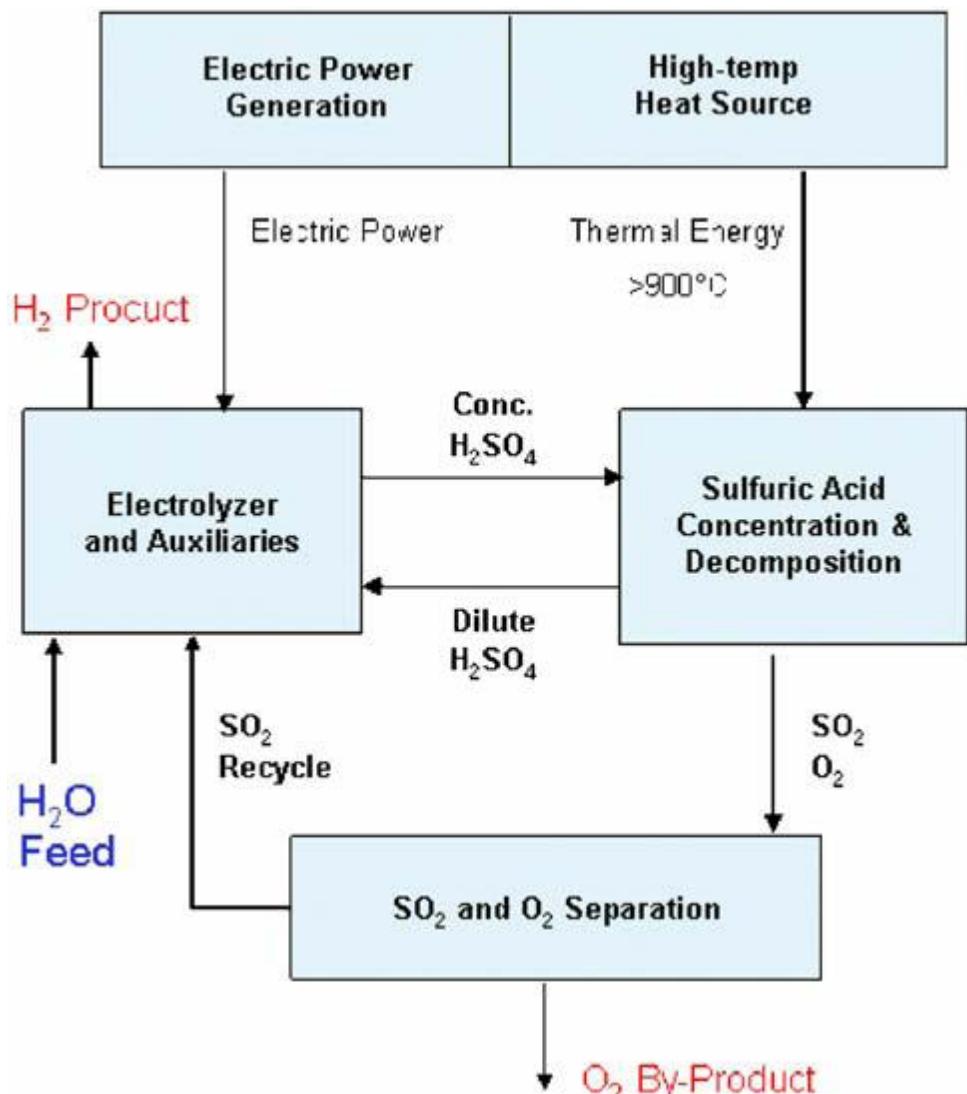
THERMOCHEMICAL METHODS:

A sequential chemical reaction series can be devised in which H₂ & O₂ are produced, water is consumed & all other chemical intermediates are recycled. The operation is called a thermo chemical cycles, it is so called because energy is supplied as heat at one or more of the chemical stages.

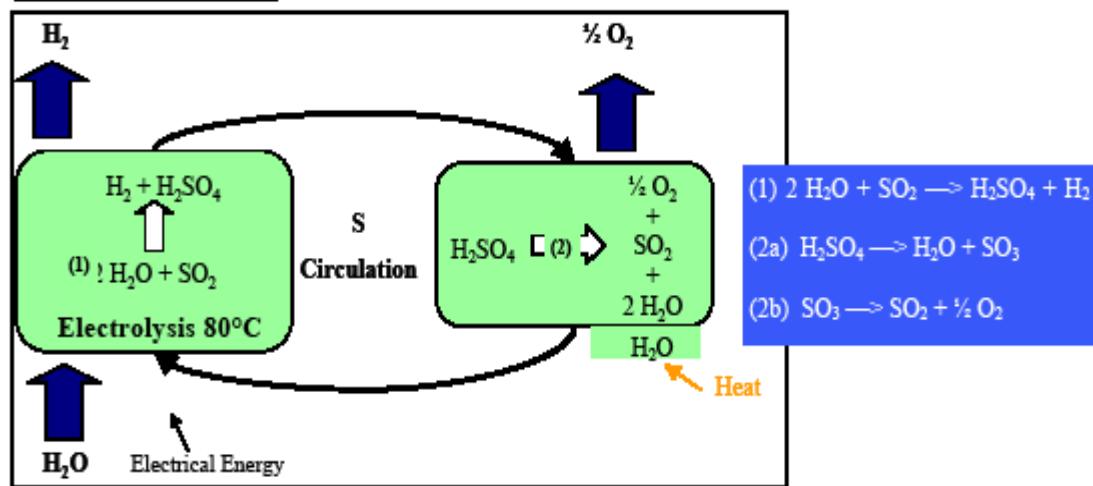
In the reaction series, water is taken up at one stage & H₂ & O₂ are produced separately in different stages. The net result is the decomposition of water into H₂ & O₂. This multistep thermo chemical method offers the potential for processes that could use high temperature nuclear heat & can be obtained in conventional or developable chemical equipment. For practical reasons, the max temperature in a thermo chemical cycle is considered to be about 950° C.

Mainly we consider there are 3 types of this thermo chemical methods are
1] Westing-house sulphur cycle, 2] The Ispra Mark 13 bromine-sulphur cycle, 3]
General-Atomic Co. iodine-sulphur process.

1] Westing-house Electrochemical Thermal sulphur cycle:



IEA/HIA TASK 23 : HIGH TEMPERATURE HYDROGEN PRODUCTION PROCESS

Hybrid Sulfur cycle**Process principle****Current status :**

The Hybrid Sulfur (Westinghouse) Cycle is a two-step thermochemical cycle for decomposing water into hydrogen and oxygen. Sulfur oxides serve as recycled intermediates within the system.

- Significant research activity for nuclear and solar.
- Chemical reactions all demonstrated.

Advantages :

- Uses common / inexpensive chemicals.
- Cycle has the potential for achieving high thermal efficiencies.
- Only one intermediary species (oxides of sulfur).

Challenges :

- Requires high temperature.
- Corrosion by H_2SO_4 .

Hybrid Sulfur**Process description :**

- (1) SO_2 electrolysis at 80°C
- (2) H_2SO_4 decomposition : (2a) Starts at 450°C
(2b) Starts at 800°C

Heat source :

Nuclear or Solar heat source

Materials :

Electrodes : carbon-supported platinum catalysts
 H_2SO_4 Decomposition : Ceramics such as silicon carbide, silicon nitride and cermets

Efficiency :

The cycle efficiency is 42 % which has the potential to be increased to 48.8 % ¹.

Cost evaluation :

Between 4.4 and 6.8 \$/kg for a nuclear heat source ¹²
 Between 1.6 and 5.6 €/kg for a solar heat source ^{13,14}

Flow-sheet

I E A / H I A T A S K 2 5 : H I G H T E M P E R A T U R E H Y D R O G E N P R O D U C T I O N P R O C E S S

The Hybrid Sulphur cycle, also named Ispra

Mark 11 cycle or Westinghouse Sulphur cycle was developed in the 70's by Westinghouse Electric corporation. The stages of this two-step process are :

- produce hydrogen and sulphuric acid from the electrolysis of a solution of sulphur dioxide in sulphuric acid;
- decompose sulphuric acid to regenerate sulphur dioxide (thermochemical step). Energy is supplied to the system as high temperature heat (approximately 1173 K) and electricity. Advanced nuclear reactors (Generation IV) or central solar receivers can be the source of the primary thermal energy. Direct electrolysis of water requires 1.23 V while SRNL estimated that the theoretical reversible cell voltage required to dissociate water in a 50 % acid media at 289 K is only 0.29 v. Moreover, in 1976, a NASA conceptual design calculated a cell voltage of 0.48 V and a cell current density of 200 mA/cm² under an acid concentration of 80 % w., at 2586 kPa and 361 K. Nevertheless, this cell voltage level seems to be unrealistic. Recent SRNL works on lab-scale electrolyzers indicate that only a cell voltage around 0.6 V can be attained.

2] The Ispra Mark 13 bromine-sulphur cycle:

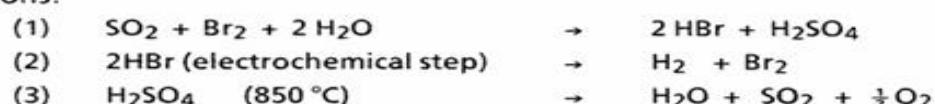
1. Introduction

The most common method actually used for flue gas desulphurization is the wet method, consisting of lime or limestone scrubbing. This method, although almost universally applied, has some intrinsic drawbacks: costs are incurred in handling the lime and limestone and the resulting large quantities of wet slurries, considerable amounts of waste water are produced and the disposal of large quantities of gypsum will cause problems.

For these reasons, new regenerative processes may still offer considerable advantages.

2. Process History

The basic idea for the ISPRA MARK 13A process was generated in the Joint Research Centre of the European Communities at Ispra (Italy) in 1979 as a spin-off of the hydrogen energy research programme of the European Community [1]. Research on the thermochemical decomposition of water into hydrogen and oxygen was started in 1970 in several places of the world. In 1974, a variant of the purely thermochemical cycles was introduced in the hybrid cycle. Here electrical energy is used in one reaction of the process. One example of potentially promising hybrid cycles is the ISPRA MARK 13 (13 = process development numbers) sulfur-bromine cycle [1]. The cycle consists of the following three reactions:



A continuous laboratory-scale plant of the process was constructed and operated at the JRC Ispra. The nominal hydrogen production rate of the plant was 100 l/h. The separation of SO_2 and O_2 was performed primarily by cooling down the gas mixture to -48°C. The gas mixture, leaving the cooling trap consisted of 93-95% O_2 and 5-7% vol. SO_2 .

The remaining SO_2 was removed by contacting the gas with a diluted bromine water solution, the sulphur dioxide was oxidised and SO_2 -free oxygen leaves the

process. This purification step was the basic idea for the creation of the new desulphurisation process.

2.1 The ISPRA MARK 13A desulphurisation process.

The new process ISPRA MARK 13A was invented in 1979 and the first tests with a air/SO₂ gas mixture were started in 1981 [2]. In 1981/82 a preliminary feasibility study was carried out by Prof Gestrich of the T.U. Berlin [3].

Bench scale experiments with flue gas connected to an oil fired power station in Ispra were carried out in 1982. At the end of 1982 the construction of a transportable unit for testing the process on a coal fired furnace in Livorno was started. In the meantime we started also the determination of physical properties (vapour pressure of liquid mixtures of HBr/H₂SO₄) and did other supporting work. Between 1983 and 1984 tests on a coal-fired experimental furnace were done at the laboratories of ENEL in Livorno.

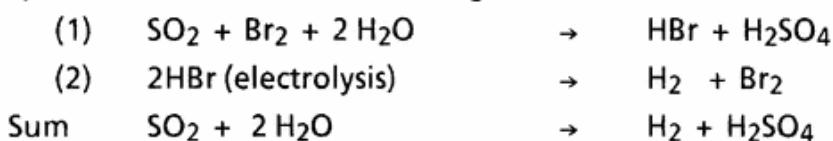
In the same period, the firm COMPRIMO in Amsterdam carried out a preliminary engineering design and cost evaluation study for a pilot plant of 20.000 Nm³/h [4] and the firm UHDE in Dortmund prepared a detailed study for an electrolyser for this plant [5].

Both studies served as a basis for the ISPRA MARK 13A Pilot Plant Project, which was started in 1985 with the call for proposals and negotiations with the different candidate firms. In 1986 a contract was signed for the construction of a pilot plant of 32.000 Nm³/h with the firm FERLINI TECHNOLOGY. The engineering, construction and start up was subcontracted to KRAFTANLAGEN Heidelberg. The site of construction in the SARAS Refinery in Sarroch, Sardinia. Construction started in 1987 and the plant was started up at the beginning of 1989. The test programme will be finished at the end of 1991.

3. Process description

The ISPRA MARK 13A process is a wet scrubbing regenerative process, producing two valuable chemicals, sulphuric acid and hydrogen. It does not generate any waste water. A simplified diagram of the process principle is given in Fig. 1.

The process is based on the following two reactions:



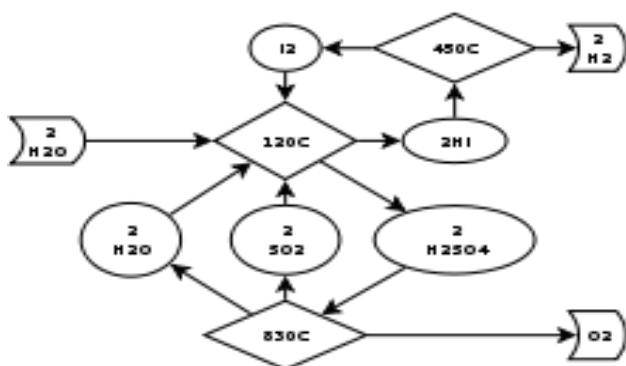
The reactive agent is a dilute aqueous solution of 10-20 wt% H₂SO₄ and HBr containing a small amount of bromine (<0,5 wt%). The SO₂ containing flue gases are brought in contact with this solution in the reactor. Sulphur dioxide is absorbed in the solution and reacts immediately in the liquid phase according to reaction 1).

3] **IODINE SULPHUR CYCLE:** The **sulfur-iodine cycle** (S-I cycle) is a three-step thermochemical cycle used to produce hydrogen.

The S-I cycle consists of three chemical reactions whose net reactant is water and whose net products are hydrogen and oxygen. All other chemicals are recycled. The

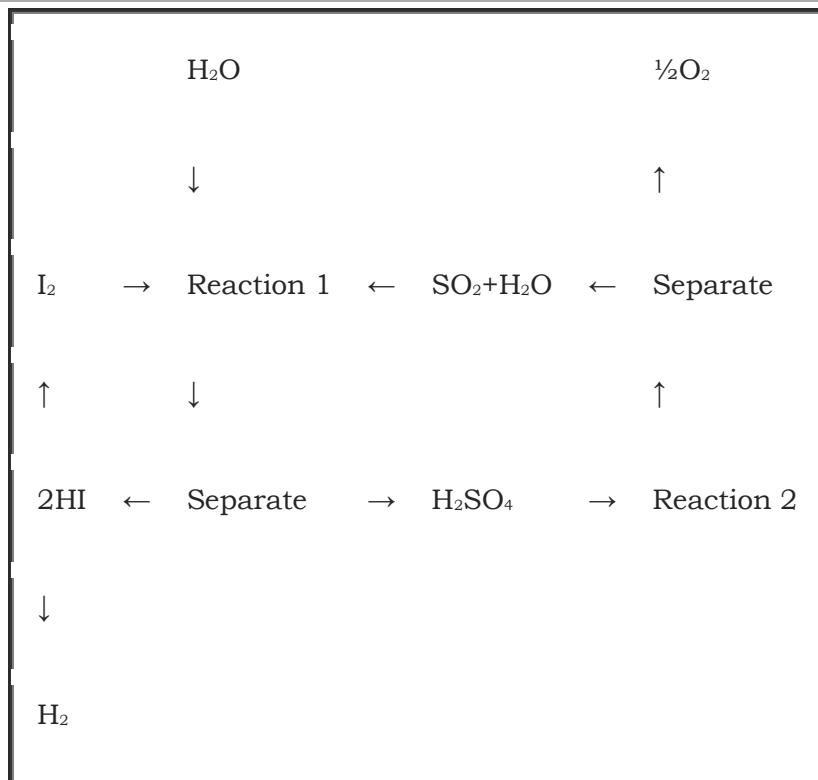
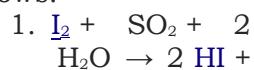
S-I process requires an efficient source of heat. Sulphur-iodine cycle as shown in below fig.

Sulfur-Iodine Cycle



Process description

The three reactions that produce hydrogen are as follows:



- The HI is then separated by distillation or liquid/liquid gravitic separation.
- 2. $2 \text{H}_2\text{SO}_4 \rightarrow 2 \text{SO}_2 + 2 \text{H}_2\text{O} + \text{O}_2$ (830 °C)
 - The water, SO₂ and residual H₂SO₄ must be separated from the oxygen by-product by condensation.
- 3. $2 \text{HI} \rightarrow \text{I}_2 + \text{H}_2$ (450 °C)
 - Iodine and any accompanying water or SO₂ are separated by condensation, and the hydrogen product remains as a gas.

Net reaction: $2 \text{H}_2\text{O} \rightarrow 2 \text{H}_2 + \text{O}_2$

The sulfur and iodine compounds are recovered and reused, hence the consideration of the process as a cycle. This S-I process is a chemical heat engine. Heat enters the cycle in high-temperature endothermic chemical reactions 2 and 3, and heat exits the cycle in the low-temperature exothermic reaction 1. The

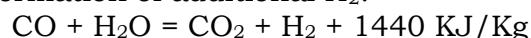
difference between the heat entering and leaving the cycle exits the cycle in the form of the heat of combustion of the hydrogen produced.

Advantages and disadvantages

The characteristics of the S-I process can be described as follows:

- All fluid (liquids, gases) process, therefore well suited for continuous operation;
- High utilization of heat predicted (about 50%), but very high temperatures required (at least 850 °C);
- Completely closed system without by-products or effluents (besides hydrogen and oxygen);
- Corrosive reagents used as intermediaries (iodine, sulphur dioxide, hydriodic acid, sulphuric acid); therefore, advanced materials needed for construction of process apparatus;
- Suitable for application with solar, nuclear, and hybrid (e.g., solar-fossil) sources of heat;
- More developed than competitive thermo chemical processes (but still requiring significant development to be feasible on large scale).

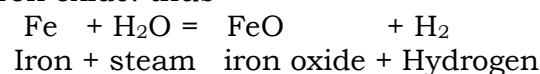
Fossil fuel methods: Mostly a gaseous mixture of carbon monoxide & H₂ is formed in the 1st stage, in the production of H₂ by using a fossil fuel {natural gas, petroleum product or coal}. To remove the CO, the mixture is submitted to the water gas shift reaction with steam. The CO is thereby converted into CO₂ with the formation of additional H₂.



The CO₂ gas is an acid gas that can be absorbed in an alkaline medium. If the small amounts of CO & dioxide remaining are undesirable, they can be converted into methane which can be separated as a liquid by cooling to a moderately low temperature.

1] Hydrogen production by the iron process:

This method, which depends on the reaction of steam with iron at a temperature of about 815°C at a pressure of 7 MPa. The products are fairly pure H₂ gas & solid iron oxide: thus



The iron is recovered from the oxide in a separate vessel & returned for further reaction with steam.

The reduction of iron oxide to iron is achieved by means of a reducing gas mixture of CO, H₂ & N₂ at a temperature of 1095° C made by the air stream chat process. CO & N₂ are absent from the product, as the iron steam reaction occurs in separate vessel.

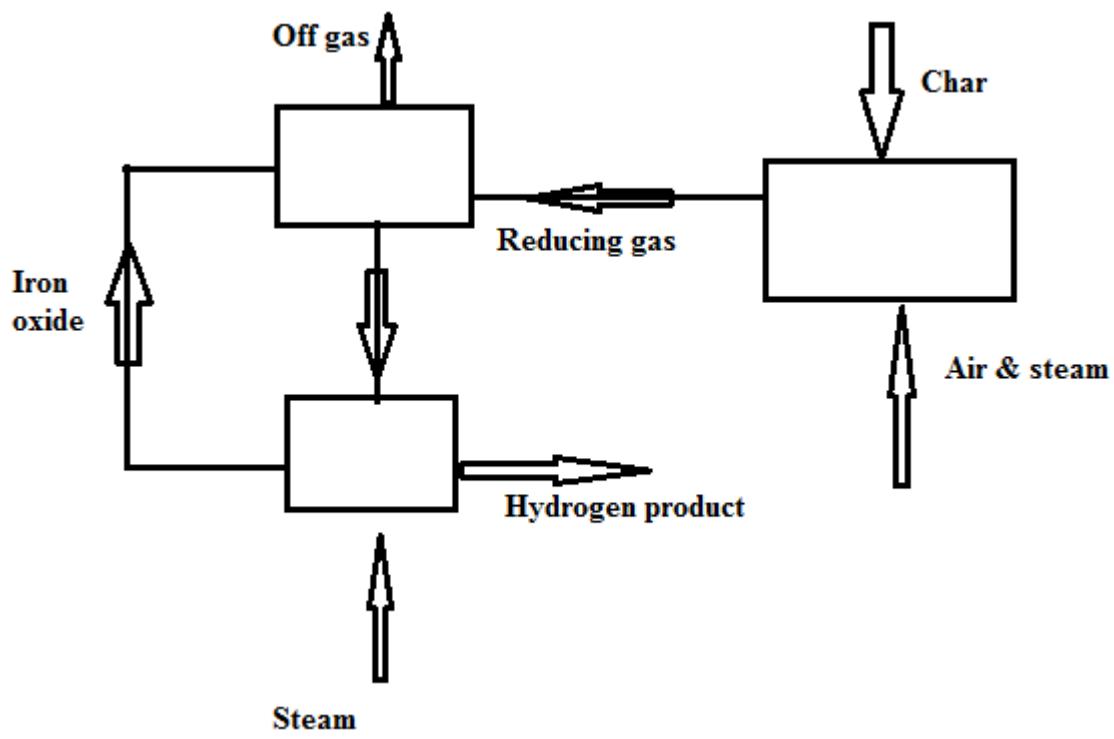


Fig: Hydrogen production by the iron process.

COAL GASSIFICATION PLANTS:

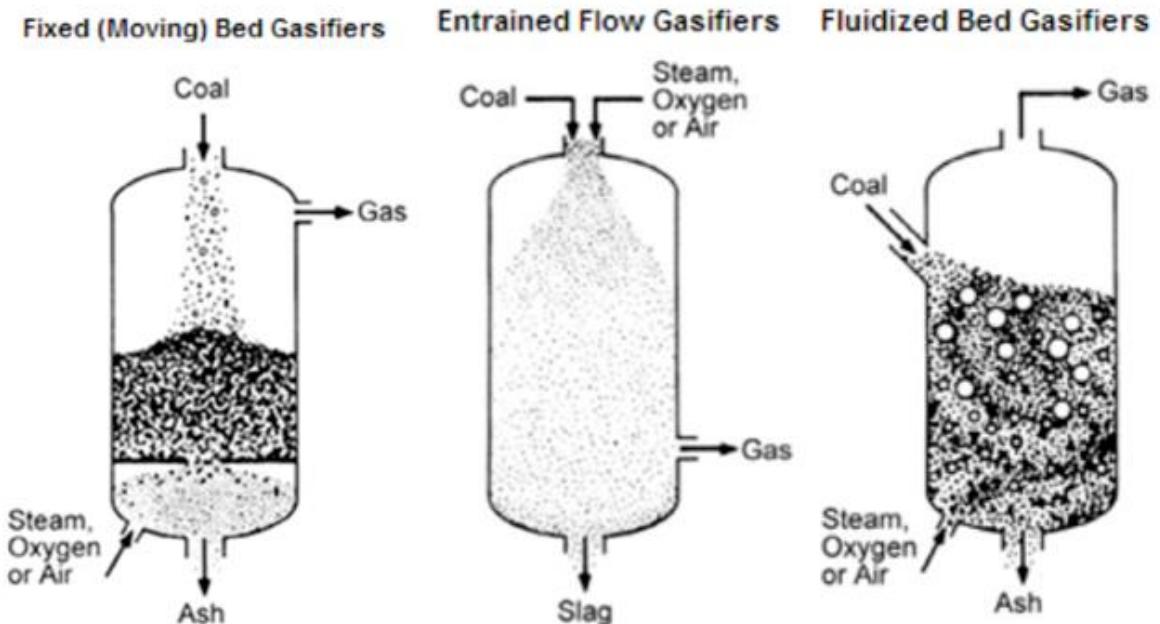


Fig: Gas generators for present-day industrial coal gasification.

The coal gasification plants used in industry throughout the world today have gas generators of the type illustrated in above fig. they are based exclusively on autothermic processes in which coal is gassified with steam & O₂.

In the **Lurgi gas generator**, gasification is carried out in a fixed bed in which the coal & gassifying agent are introduced in counter current flow. This results in the formation in the generator of a temperature profile & separate zones, in

which with increasing temperature, the coal is dried & devolatilized & then gasified & combusted. The process takes place under pressure of between 25 & 35 bar. The coal is therefore fed into the generator via a lockhopper system & the ash is removed via a smaller system. The generator is a water-cooled pressurized vessel 3-4m in diameter.

The **Fluidized-bed process**, called the Winkler process after its inventor, was developed for coal gasification on a large industrial scale as long ago as the 1920. Here, coal is gasified in a fluidized bed with steam & O₂ in a cylindrical gas generator that tapers to a conical shape at that bottom. The coal is fed in near the centre of the bed via a screw conveyor. The gasifying agent is introduced firstly at the bottom & secondly also above the fluidized bed. This ensures that entrained coal particles being carried out with the gas can also be gasified, resulting in a high-carbon burn-up & because of the high temperatures that build up above the bio fluidized bed-considerable reduction of the by-products. Up till now, the Winkler process has been operated solely at atmospheric pressure.

In the Koppers-Totzek entrained-flow reactors pulverized coal is gasified with O₂ & steam in an entrained flow of coal dust. Because of short resident times, the introduction of relatively large quantities of oxygen-produces very high temperatures & high conversion rates are therefore achieved. The ash runs down the walls as liquid slag & is removed from beneath the generator. Directly above the generator there is a waste-heat boiler for heat recovery.

SOLAR ENERGY METHODS: The following 2 approaches are under considerations i.e.

I] Bio-photolysis & 2] Photo Electrolysis.

I] Bio-photolysis:-