A. JEYARAJ AP/EEE

UNIT-I PRINCIPLES OF SOLAR RADIATION

1. INTRODUCTION TO ENERGY :

Energy is the Capacity for doing work, generating Heat and Emitting Light.

- It is measured as the total amount of work that the body Can do. Energy is measured in Units of Caloric and joule.

- A kilo calorie is the amount of energy or heat required to raise the temperature of 1 kg of water from 14.5°C to 15.5°C.

- The joule is defined as the amount of energy exerted when a force of one newton is applied over a displacement of one meter.

ENERGY :

Energy is a basic Concept in all science and Engineering discipline. A Very important principle is that energy is a Conserved quantity. i.e., the total amount of energy in the universe is Constant.

- As per the Law of Conservation of energy 'Energy Cannot be newly Created, Energy Cannot be destroyed'

- Energy is neither Created not destroyed but Converted or redistributed from one form to another Such as from the Wind energy into electrical energy or from chemical energy into heat etc.,

2. CLASSIFICATION OF ENERGY SOURCES :

a) BASED ON NATURE OF AVAILABILITY OF ENERGY

On the basis of nature of availability of energy Source, the energy can be classified as follows.

i) Primary Resources :

Primary Energy Sources Can be defined as Source which are either found or stored in nature. These Energy Sources Provide a net Supply of Energy.

Examples : Coal, Natural Gas, Oil, Biomass, Solar, Tidal, hydro and Nuclear Energy.

ii) Secondary Resources :

Secondary Sources of energy are derived from the Primary Energy Sources. Ex: Producing Electrical Energy from Coal and Hydrogen from Hydrolysis of water are examples of this type of energy.

b) BASED ON UTILISATION OF ENERGY :

On the basis of Utilization of Energy, the energy can be classified as follows.

i) Direct Source of Energy :

The direct Sources of Energy are obtained directly from the resources such as human labour, bullocks, stationary and mobile mechanical or electric power units such as diesel Engines, Electric motor, Power tiller and tractors

ii) Indirect Sources of Energy :

The Indirect Sources of Energy do not release energy directly but release it by conversion process.

- Some energy is invested in producing indirect Sources of Energy. Seeds, Manures (farmyard and poultry), chemicals, Fertilizers and Machinery can be classified under Indirect Sources of Energy.
- Again, on the basic of their replenishment, It can be further classified into 'Renewable and Non-renewable Indirect Source of Energy

iii) Supplementary Sources of Energy :

Supplementary Sources are defined as the energy Sources whose net energy yield is zero. Those energy Sources requiring higher investment in terms of Energy Insulation (Thermal) is an example for this Source.

C) BASED ON TRADITIONAL USE :

On the basis of traditional use of energy Source, the energy can be classified as follows :

i) Conventional Energy :

Conventional Energy Source can be defined as a Source which are used traditionally and provides a net Supply of Energy.

Example : THERMAL ENERGY and HYDRO POWER ENERGY.

ii) New or Non-Conventional Energy :

New or Non-Conventional Energy Sources are developed in recent past and produce no net Energy. Though it may be necessary for the economy, they may not yield net energy

Example : SOLAR ENERGY, WIND ENERGY, TIDAL ENERGY and BIOMASS ENERGY.

d) BASED ON LONG TERM AVAILABILITY :

On the basis of long term availability of Energy Source, the energy can be classified as follows :

i) Non-Renewable Energy Sources

These are the energy sources that are derived from finite and static stocks of Energy.

- Coal, oil, Fossil Fuels and Nuclear Fuels are example of Conventional Sources of energy

- these resources often exist in a fixed amount and are consumed much faster than Nature can create them

ii) Renewable Energy Sources :

In this category, the energy sources which are direct in Nature but can be subsequently replenished are grouped

- The energies which may fall in this group are Solar Energy, Wind Energy, Tidal Energy, Biomass Energy etc,

e) BASED ON ORIGIN :

On the basis of origin of Energy Source, the energy can be classified as follows.

i) Fossil Fuel Energy :

- energy obtained from Fossil Fuels such as Coal, oil, Natural Gas etc,

ii) Nuclear Energy :

- energy obtained from Nuclear Fuels such as Uranium, Plutonium, Thorium etc,

iii) Hydro Energy :

- energy obtained from water

iv) Solar Energy :

- energy obtained from Solar Radiation.

v) Wind Energy :
- energy obtained from Natural wind Force

vi) Tidal Energy :
- energy obtained from tides and Waves

vii) Biomass Energy :
- energy obtained from biomass Fuels such as Cow dung, Vegetable

viii) Geothermal Energy :
- energy obtained from Natural Temperature Variation of Present in the Various depth of the earth.

ix) Ocean Thermal Energy :
- energy obtained from Natural Temperature Variation present in the Various depth of the Ocean.

3. SOURCES OF ENERGY :

Today, every Country draws its electrical Energy needs from a Variety of Sources.

- There are Six Sources of useful Energy Utilised by human beings on planet Earth. These Sources are given below :

a) Fossil Fuels Such as Coal, Petroleum products and Natural gases which produce thermal, Mechanical and electrical Energy.

b) Chemical Energy from reactions among Mineral sources

c) Nuclear Energy from Nuclear Reactions of the Nuclear Fuels available on the Earth.

d) The Sun which produces Solar Energy in the form of Mechanical or Electrical Energy.

e) Geothermal Energy from Cooling, Chemical Reactions and Radio-active decay in the earth.

f) the gravitational potential and planetary motion among Sun, Moon and earth which produce Wind, Tidal and wave Energies

Non-Renewable Energy is derived from sources a), b) and c) whereas Renewable Energy is derived from Sources d), e) and f).

1. CONVENTIONAL ENERGY SOURCES : (NON-RENEWABLE)

Conventional Energy Sources are as follows :

a) Fossil Fuel Energy
b) Hydraulic Energy
c) Nuclear Energy.

a) FOSSIL FUEL ENERGY

Coal, Petroleum and Natural gas are Called 'Fossil Fuel' as these are formed by the decomposition of the remains of dead plants and Animal buried under the Earth for a long time

- These are Non-Renewable Sources of Energy, if exhausted. which cannot be replenished in a Short time. Their potentials are limited and are Considered Very Precious
- These Should be used with care and caution to let them last long. They are also contributing to the Global Enviromental Pollution.

i) Coal :

Since the advent of Industrialization, Coal has been the most Common Source of Energy.

- In the last three decades, the world Switched over from Coal to oil as major Source of Energy because it is Simple and clean to Obtain useful Energy from oil.
- Coal is a Complex mixture of Compounds of Carbon, Hydrogen and oxygen. Small amount of Nitrogen and sulphur Compounds are also present in Coal.
- On Strong heating, Coal breaks up to produce Coal gas, Ammonia, Coal tar and Coke. Coke is 98 % Carbon, Obtained after lossing all its Volatile Constituents during destructive distillation of coal.
- It Can be used as smoke free fuel.

ii) Petroleum :

It is a dark coloured, Viscous and Foul smelling Crude oil. The petroleum means rock oil. It is normally found under the crust of earth trapped in rocks.

- The Crude oil is a Complex mixture of Several Solid, Liquid, Gaseous hydrocarbons mixed with water, Salt and Earth particles.

- It is a Natural product obtained from oil wells.
- The crude oil is refined by the process of Fractional distillation to obtain more useful petroleum products
- The crude petroleum is heated to a temperature of about 400°c in a furnace and vapors. then they are passed into a tall fractioning column from near its bottom
- As the mixture of hot vapours rises in the column, it starts getting cooled gradually

The products obtained from crude petroleum as follows:

i) petroleum Gas (below 40°c) used as LPG
ii) Petrol (40°c to 170°c) for Light Vehicles.
iii) Kerosene (170°c to 250°c) for household and industrial use
iv) Diesel oil (250°c to 350°c) for heavy Vehicles.
v) Residual oil : a) Lubrication oils b) Paraffin Wax c) asphalt.
vi) Fuel oil (350°c to 400°c) for boilers and Furnaces.

iii) Natural Gas :

It Consists of about 95% Methane and rest Ethane and Propane. It occurs deep under the crust of the earth either alone or a long with oil above petroleum deposits.

- It is a product of Petroleum Mining.
- The Gas is available in Tripura, Jai salmer, off-shore areas of Bombay High and in the Krishna - Godavari delta.
- It is used as domestic and Industrial Fuel. The Natural Gas is now also available as CNG (Compressed Natural Gas) a substitution of Petrol in Automobiles.

b) HYDRAULIC ENERGY (WATER POWER) :

Water power is developed by allowing water to fall under the force of gravity. It is used almost exclusively for Large scale electric power generation.

- Potential Energy of water is converted into Mechanical Energy by using prime moves known as 'Hydraulic Turbines'
- Water power is quite cheap where water is available in abundance.

- Although the Capital cost of Hydro electric power plants is high as Compared to other types of power plants but their operating costs are quite Low as no fuel is required in this Case

C) NUCLEAR ENERGY :

According to Modern Theories of atomic structure, a matter Consists of Minute Particles known as 'atoms'

- Heavier Unstable atoms such as U^{235} and Th^{239} liberate Large amount of heat energy.

- The energy released by the Complete Fission of one kg of U^{235} (Uranium) is equal to the heat energy obtained by burning 4500 tonnes of Coal (or) 220 tonnes of oil.

- The heat produced by Nuclear Fission of atoms of Fissionable Material is utilized in special heat exchangers for the production of steam which is then used to drive turbo-generators as in Conventional Power plants.

Limitations : High Capital Cost of Nuclear Power Plants, Limited availability of Raw Materials, Difficulties associated with disposal of Radio active Waste and shortage of Well-trained personnel to handle the Nuclear power plants.

- About 3% of the Energy produced in India obtained from 'Nuclear Power Plants'

2. NON CONVENTIONAL ENERGY SOURCES (RENEWABLE)

The Sources of Energy which are being Produced Continuously in Nature and are in Exhaustible are Called 'Renewable Sources of energy or Non-Conventional Energy Sources'

Some of these Sources are as follows :

a) Solar Energy
b) Wind Energy.
c) Tidal Energy
d) Wave Energy
e) Geo thermal Energy
f) Biomass Energy

a) Solar Energy :

Solar Energy is Collected from Sun light.

- It Can be used in many ways such as generating electricity using PhotoVoltaic cells, generating electricity using Flat plates and Concentrating Solar power.
- PhotoVoltaic Cells have a Low Efficiency Factor.

b) Wind Energy :

A Wind mill converts the kinetic Energy of moving air into the Mechanical Energy which can be either used directly to run the Machine or to run the generator for producing Electricity.

c) Tidal Energy :

Tides are generated primarily by Gravitational Attraction between the Earth and Moon. They arise twice a day in Mid-Ocean.

- The tidal ~~reg~~ Range is only a Meter. Basically in a Tidal Power Station, Water at high tide is first trapped in an Artificial Basin and it is allowed to escape at Low Tide
- The escaping Water is used to drive Water Turbines which in turn drive Electrical Generators.

d) Wave Energy :

Ocean Waves are Created by the Interaction of winds with the Surface of Sea Water.

- Wave Energy is the energy of Interchanging Potential and Kinetic Energy in the wave. Ocean wave energy can be either Converted into Mechanical Energy or Electrical Energy through Wave Energy Conversion plants.
- Ocean Wave Energy is needed to be developed in Coastal Areas. Usually, Power extracted from Ocean Energy is the range of 10 KW/m to 70 KW/m with respect to Amplitude and Wave length.

e) Geo thermal Energy :

- Geo thermal Energy is obtained by tapping the heat of earth below its Surface.
- Hot Underground Water or Steam is used to Produce Electricity

- Its use Covers a range of option from power generation to Space heating or Air Conditioning

f. Biomass Energy :

Biomass Energy is another Important Renewable Energy Source Which Covers a wide Spectrum of Energy Activities from direct Production heat through Combustion of Fuel wood and Other Biomass Residues to generate Electricity, and the production of gases, Liquid fuel and Chemicals

- It is globally used. Various Sources of Biomass Energy are as follows:

i) Biogas :

It is produced from Wastes of Paper and Sugar Industries, Animals and So on. CH_4 is the Product.

ii) Bio fuel :

Bio diesel, Ethanol etc, are derived from plants.

iii) Solid Biomass :

Wood Fuel, Biogenic Portion of Municipal waste and Certain Plants are Solid biomass.

- Biomass may be used in a number of ways to produce Energy
- The Common methods are gasification, Combustion, Fermentation and Anaerobic digestion.
- India is Very Rich in Biomass.

ROLE OF NEW AND RENEWABLE ENERGY SOURCES

Renewable Energy plays an important role in meeting the Future Energy needs in both rural and Urban Areas

- The use of Renewable Energy is rapidly increasing in the World especially, in developing and industrialized Countries

- Renewable Energy Resources play an important role in Sustainable development for the following Primary Reasons :

i) They generally cause less Environmental Impact than other Energy Sources due to reduced green house Gas Emissions.

ii) A Variety of Renewable Energy Resources provides a Flexible Array of options for their use.

iii) They cannot be exhausted. If used carefully in appropriate Applications, Renewable Energy Resources can provide a reliable and Sustainable Supply of Energy almost indefinitely.

iv) They Provide power to Remote Areas that are unapproachable by National power Grid Network.

v) They enhance the Flexibility of the System and Provide economic benefits to Small isolated populations

vi) The Renewable Energy Resources are generally well distributed all over the world even though wide spatial and temporal Variations occur.

vii) They can be cheaply and continuously harvested and are therefore a Sustainable Source of Energy.

1. ADVANTAGE OF RENEWABLE ENERGY SOURCES :

a) Non-Conventional Sources are available in Nature at free of cost

b) They Produce No or little pollution. Thus, they are Environment Friendly

c) They are inexhaustible

d) They have a Low Gestation Period.

f) They donot deplete Natural Resources

g) They can sustain Energy Supply for many generations

h) Being simple in ~~cost~~ design, Maintenance Cost of these plant is Very Less

e) Better choice for single plant use because these plants can be installed remotely and at locations completely OFF Grid.

2. DISADVANTAGE OF RENEWABLE ENERGY SOURCES

a) The energy available in dilute form from these sources.

b) Though available freely in Nature, the cost of harnessing Energy from a Conventional Source is generally high.

c) Availability is uncertain which means that the Energy flow depends on Natural phenomena beyond human Control

d) Difficulty in Transporting Such forms of Energy

e) Low Energy Density is another problem in these plants

THE SOLAR ENERGY OPTIONS

Solar Energy Technologies use the Sun's Energy and Light to provide heat, Light, hot water, Electricity and even Cooling for homes, Businesses and Industry.

- There are a Variety of technologies that have been developed to take the advantage of Solar Energy. Some of the Technologies are described here.

i) PhotoVoltaic Systems (PV):

Solar Cells Convert Sunlight directly into electricity. Solar Cells are often used to power Calculators and Watches.

- They are made of SemiConducting materials, ~~the Solar Energy~~ Similar to those used in Computer chips.

- When Sunlight is absorbed by these materials, the Solar Energy Knocks electrons loose from their atoms and allows the electrons to flow through the material to produce 'Electricity'

This process of Converting Light (photons) to electricity (Voltage). is called the 'PhotoVoltaic' Effect'

- Solar Cells are typically Combined into modules that hold about 40 cells. A Number of these modules are mounted in PV Arrays that can measure up to Several meters on a Side

- These 'flat-plate PV Arrays' Can be mounted at a fixed angle facing South or they can be mounted on a tracking device that follows the Sun, allowing them to capture the most Sunlight over a day.

Several PV Connected PV Arrays Can provide enough Power for house hold, Large Electric Utility or Industrial Applications and Hundreds of Arrays Can be Inter Connected to form a 'SINGLE LARGE PV SYSTEM'

ii) Solar Water Heating Systems :

Solar Water heaters are Natural Sun light to heat water This System works on the Thermosiphon principle and it is designed to provide hot water without Consuming expensive Electricity.

- This is the most effective way to generate hot water thereby Saving Costly power and It is also environment friendly.

Solar Water Heating Systems include Storage Tanks and Solar Collectors. There are two types of Solar Water Heating Systems.

a) Active Solar Water Heating Systems

Active, which have Circulating Pumps and Controls and Passive which don't. There are two types of Active Solar water heating Systems

1. Direct Circulation system
2. Indirect Circulation System

b) Passive Solar Water Heating Systems :

Passive are typically Less Expensive than active Systems. but they are usually not as efficient

- However, Passive Systems can be more reliable and may last longer

iii) Solar Electric Systems :

Many Power plants today 'fossil Fuels' as a heat Source to boil water. The Steam from the boiling water rotates a large turbine which activates a generator that Produce 'Electricity'

- However, a New generation of Power plants with Concentrating Solar Power Systems, uses the 'Sun' as a heat Source

There are three main types of Concentrating Solar Power Systems.

I) Parabolic - trough ii) Dish / Engine System iii) Power Tower System

a) Parabolic - Trough Systems Con

- Concentrate the Sun's Energy through long Rectangular Curved (U-Shaped) mirrors. The mirrors are tilted towards the Sun, focusing Sun Light on a pipe that runs down the Center of the trough.

- It heats the oil flowing through the pipe. The hot oil then is used to boil water in a Conventional Steam Generator to produce electricity.

b) Dish / Engine System :

- It uses a mirrored dish (Similar to a Very Large Satellite dish). The dish-shaped Surface Collects and concentrates the Sun's heat on to a Receiver which absorbs the heat and transfers it to fluid within the Engine

- The heat causes the fluid to expand against a piston or turbine to produce Mechanical Power. The Mechanic Power is then used to run a Generator or Alternator to Produce Electricity.

c) Power Tower System :

- It uses a large field of Mirrors to Concentrate Sun light on to the top of a tower where a receiver sits

It heats Molten Salt flowing through the Receiver. Then the Salt's heat is used to generate electricity through a Conventional Steam Generator. Molten Salt retains heat efficiently.

iv) Solar Process Space Heating and Cooling Systems :

Solar Process heating Systems are designed to provide large quantities of hot water or space heating for Non-residential buildings.

- A typical System includes Solar Collectors that work along with a pump, a heat Exchanger and or more Large Storage tanks.

The two main types of Solar Collectors used a) Evacuated-tube Collector and a P b) Parabolic - trough Collector. These Collectors can operate at high temperatures with high Efficiency.

a) Evacuated - Tube Collector :

It is a shallow box full of many glass, double-walled tubes and reflectors to heat the fluid inside the tubes

- A Vacuum between two walls insulates the inner tube and holds Heat.

b) Parabolic - trough Collector :

Parabolic - troughs are long, Rectangular, Curved (U-shaped) Mirrors tilted to focus Sunlight on a tube which runs down the Center of the trough.

- This heats the fluid within the tube.

Solar Cooling systems :

The heat from a Solar Collector can also be used to Cool a building. A home air Conditioner uses an electrical Energy Source to Create Cool air

- Solar Absorption Coolers use a similar approach, Combined with some Complex chemical technology, to Create Cool air from Solar Energy.

Solar Energy can also be used with Evaporative Coolers to extend their usefulness to more humid climates using another Chemical technology called 'desiccant Cooling'.

There are other three main types of solar power systems available. ~~Each type of solar~~

i) Grid - Tied Systems :

As the name implies, this type of Solar power system is Connected to home wiring and the Electrical Grid.

- A home with grid-tied Solar System uses energy from Solar Panels when the Sun is shining and from the grid when it is not

It means that a grid-Tied System does not have to meet the entire Electricity needs.

ii) Grid - Tied Systems with Energy Storage :

In this type of System, Solar battery is provided to Store Energy. when the Sun goes down and the Solar Energy System is not producing required energy, this Solar Battery Provides excess Electricity required, Instead of from the Electric Grid.

iii) OFF-Grid Systems :

Off-grid System Combines the Capabilities of PV Panels and Solar Batteries to remove the electric Grid Component.

- An off-grid solar power system is grid-tied system with energy Storage that has enough storage capacity installed to allow for Complete Energy independence.

ENVIRONMENTAL IMPACT OF SOLAR ENERGY

The Utilization of Energy, no matter whether it is Renewable or Non-Renewable, bound to have Certain environmental Consequences (Land Consumption, Pollution) that need to be Identified and Evaluated, Preferably in advance.

- The Sun provides a tremendous Resource for generating Clean and Sustainable electricity without toxic pollution or Global Warming Emissons. However, it also has the following Environmental Impacts.

i) Land Use and Habitat Loss

ii) Water Use

iii) Use of Hazardous Materials in Manufacturing

iv) Life-Cycle Global Warming Emissons

The Severity of Impacts depends on the Scale of the system and the technology used Such as PhotoVoltaic (PV) Solar Cells or Concentrating Solar thermal plants (CSP).

i) Land Use :

Depending on their location, Larger Utility-Scale Solar Facilities Involve Land Degradation and habitat Use

- The estimate for Utility-Scale PV Systems ranges from 3.5 to 10 acres per Megawatt but the estimate for CSP facilities is between 4 to 16.5 acres per mega watt.

There is less opportunity for Solar power Systems to share land with Agricultural uses dissimilar to Wind Power Systems.

the land impacts from Utility-Scale Solar Systems can be minimized by installing them at Lower-quality locations such as brown fields, Abandoned mining Land or Existing Transportation and Transmission Corridors.

- Small Scale Solar PV arrays can be built on homes or Commercial buildings to obtain the minimal land use impact

Land Consumption for small scale systems can be avoided by installing them on roofs and Facades.

ii) Water Use :

Solar PV cells do not use water for generating Electricity. However, as in all manufacturing Processes, some amount of water is used to manufacture Solar PV Components.

- Concentrating Solar thermal plants (CSP) need water for Cooling similar to Thermal power plants. The amount of water use depends on the plant design, plant location and type of cooling system.

iii) Hazardous Materials Use :

The PV cells manufacturing Process Involves a number of hazardous materials which are used to clean and purify the Semiconductor Surface.

- These chemicals are Hydrochloric Acid, Sulfuric Acid, Nitric Acid, Hydrogen Fluoride, 1,1,1 Trichloro.ethane and Acetone

* the amount and type of chemicals depends on the type of cell, amount of cleaning and size of silicon wafer.

Workers also face Risks associated with inhaling silicon dust. So PV manufacturers must follow 'National Laws' to ensure the Safety measures because workers should not be harmed by the exposure to these chemicals. Also the manufacturing waste products are disposed Properly.

* thin-film PV cells Contain a number of more Toxic materials than Traditional Silicon PV cells such as Gallium Arsenide, Copper-gallium-diselenide and Cadmium-telluride

If they are not handled and disposed Properly, these materials could pose Serious Environmental or Public Health Threats.

The use of Solar Energy via Collectors or photo voltaic Systems places no Immediate material burden on the Environment. However, the Collector System can be expected to contain a Heat Transfer Medium (Fluid), the escape of which could result in 'pollution'.

* Additional Environmental Impacts derive from the Manufacture of materials used in the production of collectors and Solar Cells. ~~Steep~~ Steel, Copper, and Aluminium are used frequently. These materials cause Environmental problems in the form of Emission, Particularly for Aluminium.

iv) Life-Cycle Global Warming Emissions :

While there are no Global Warming Emissions associated with generating electricity from Solar Energy, there are Emissions associated with other Stages of the Solar Life-cycle Such as Manufacturing, Materials Transportation, Installation, Maintenance, De Commissioning and Dismantlement.

FUNDAMENTALS OF SOLAR RADIATION

The Sun radiates Energy uniformly in all directions in the form of Electromagnetic Waves

– When a body absorbs this radiation, the temperature of the body is increased. It provides the energy needed to Sustain the life in Our Solar System.

* Solar Energy is an Important, Clean, cheap and abundantly available Renewable Energy. It is produced and radiated by the Sun more specially, It refers to the Solar Energy that reaches the Earth

– Solar Energy received in the form of radiation, can be Converted directly or Indirectly into other forms of energy Such as heat and electricity which can be utilized by us

* The major drawback of Solar Energy is that it is a dilute form of energy with Very Low power density from 0 to 1 kW/m^2 which is available intermittently, Uncertainly and Continuously but not Steadily

– Solar Energy received on the ground level is affected by Atmospheric Clarity, Degree of Latitude etc.,

1. PHYSICS OF THE SUN :

It is still mysterious to know how the energy Generation happens in the Sun. The Sun Contains nearly all the known elements in the world which is Confirmed by the 'spectral Measurements'.

- But it contains mostly two elements i.e, 80% Hydrogen and 19% helium, remaining 1% Consists of more than 100 elements which with Very tiny fractions of the composition

Therefore it is generally accepted that the Source of the SUN's Energy is due to 'hydrogen-to-helium thermo nuclear Reaction'.

* The Sun is a large Sphere Comprised of many layers of gases which are Increasingly hotter toward its Center. Its diameter is 1.39×10^6 Km.

The outermost layer from which energy is radiated is approximately at a temperature of 5485°c. But the Center of the Sun may be predicted to have 20×10^6 °C. Ther rate of energy Transmission from the Sun is 3.8×10^{23} KW. Out of this, only tiny fraction is 1.7×10^{14} KW is intercepted by the earth.

- The mean distance between the Sun and Earth is 150 million km. Figure 1 illustrates the relationship between the Sun and Earth.

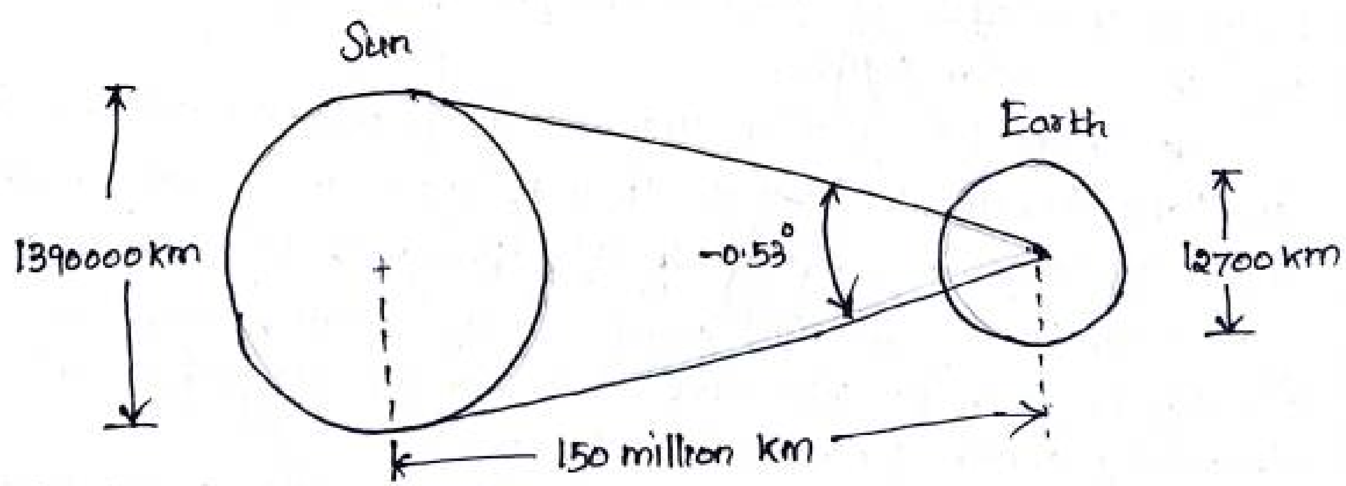


Fig. 1. Relationship between the Sun and the Earth

Solar Energy is the world's most abundant Permanent Source of energy. The amount of energy received by the earth is 5000 times greater than the Sum of all other energies i.e., Nuclear, Geothermal and Gravitational Energy. Out of great amount of energy, 30% is reflected to space, 47% is converted to low-temperature heat and 23% powers the Evaporation

2. SOLAR CONSTANT :

The rate at which Solar energy arrives at the top of the atmosphere is called 'Solar Constant' (I_{sc})

– It is defined as the amount of energy received in unit time for unit area perpendicular to the Sun's direction at the mean distance of the Earth from the Sun.

The Solar Constant is expressed in three common units as per the 'World Radiation Centre'. They are as follows :

1) 1.367 KW/m^2 or 1367 W/m^2
2) 1165 $Kcal/m^2$/ per hour
3) 432 Btu per Sq.ft per hour.

This value has been accepted and adopted ~~univer~~ universally as a standard value for solar constant.

3. SOLAR BEAM RADIATION AND DIFFUSE RADIATION

The energy produced and radiated by the Sun is called 'Solar Energy'. Energy is radiated by the Sun as Electromagnetic waves of which 99% have wavelength in the range of 0.2 to 4.0 micrometers (μm)

– The Energy from the Sun reaching the top of the earth's atmosphere consists of about 8% Ultraviolet (UV) Radiation (Short wavelength less than 0.39 μm, 46% Visible light (0.39 to 0.78 μm) and 46% infrared Radiation (Long wavelength More than 0.78 μm).

Irradiance :

The term irradiance is defined as the measure of power density of sun light and measured in W/m^2.

– It is the amount of Solar Radiant Energy falling on a surface per unit Area and per unit Time.

Irradiation is the measure of energy density of Sun light and it is measured in kWh/m². Irradiance and Irradiation apply to all Components of 'Solar Radiation'.

* Solar Radiation which is not absorbed or Scattered and reaches the ground directly from the Sun is called 'direct Radiation' or 'Beam Radiation'

Diffuse Radiation is the Solar Radiation received from the Sun after its direction has been Changed by reflection and Scattering by the Atmosphere.

* The total Solar Radiation received at any point on the earth's Surface is the Sum of the direct and diffusion Radiation. These three direct, diffuse and total Radiations are shown in fig.2.

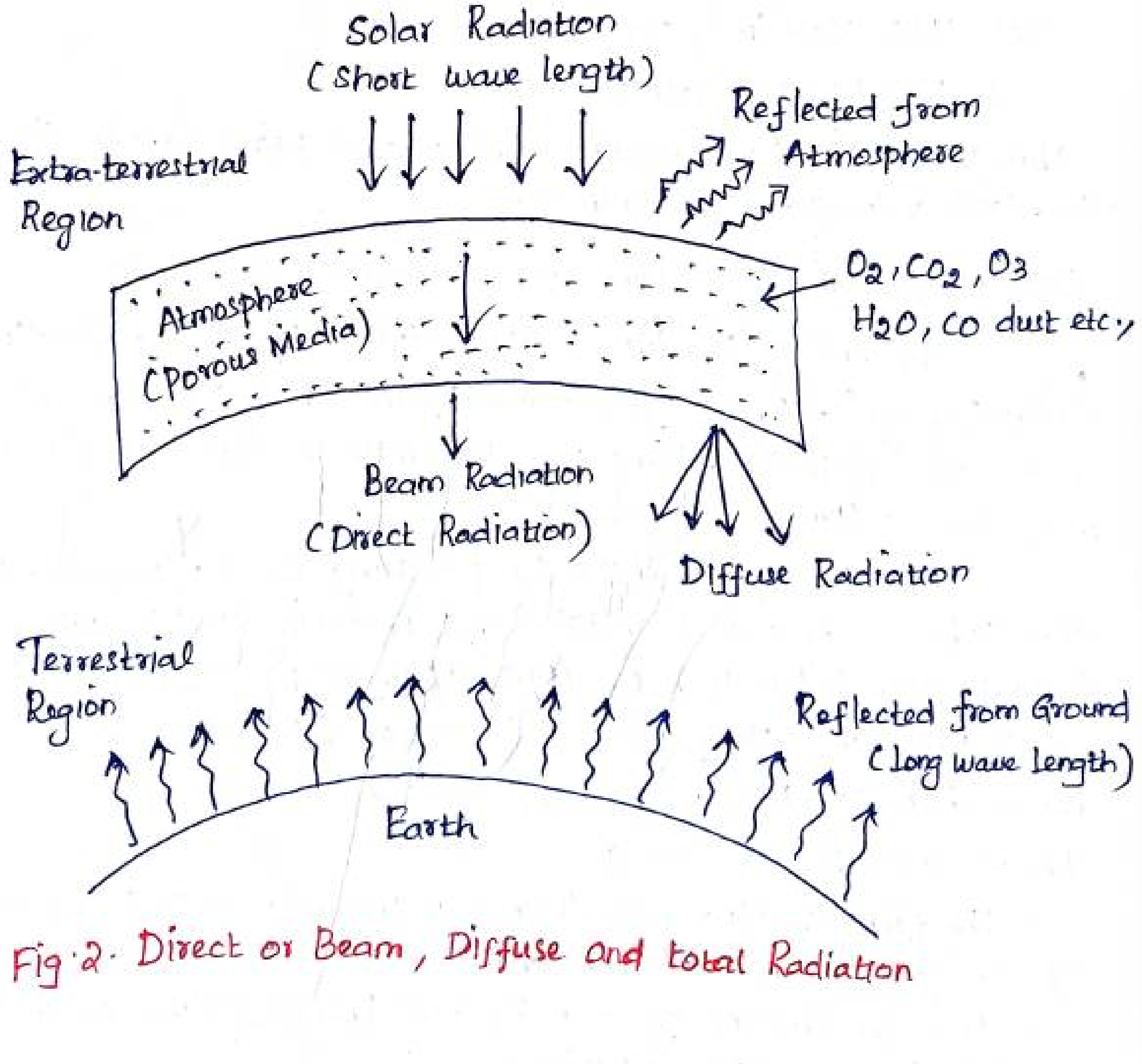


Fig.2. Direct or Beam, Diffuse and total Radiation

4. Extra-terrestrial and Terrestrial Solar Radiation

Solar Radiation incident on the outer atmosphere of the Earth is known as 'Extra-terrestrial Solar Radiation'. Solar Radiation received at the Surface of the earth is entirely different due to Various reasons.

- The Extra-terrestrial Radiation deviates from the Solar Constant Value due to Various reasons

i) The first is the Variation in the Radiation emitted by the sun itself. The Variation due to this reason is less than ± 1.5 % with different periodicities

ii) The second is the Variation of earth-sun distance arising from earth's slight Elliptical path. The Variation due to this reason is ±3%.

* The Extra-terrestrial Radiation is not affected by the Change in atmospheric Conditions as it is outside the atmosphere.

- while passing through the Atmosphere, it is subjected to mechanisms of Atmospheric Absorption and Scattering depending on Atmospheric Conditions and depleting its density

Terrestrial Solar Radiation :

The Solar Radiation that reaches the earth Surface after Passing through the earth's Atmosphere is known as terrestrial Solar Radiation.

The positions of Extra-terrestrial and Terrestrial Regions are indicated in fig.2.

5. Solar Radiation Geometry :

The Variation in Seasonal Solar Radiation availability at the Surface of the earth can be understood from the geometry of the relative movement of the earth around the Sun.

- The distance between the earth and Sun changes throughout the year, minimum being 1.471×10^8 km at winter Solstice (December 21) and Maximum being 1.521×10^8 km at Summer Solstice (June 21).

* The year round average earth Sun distance is 1.496×10^8 km. Therefore, the amount of Solar Radiation Intercepted by the earth Varies throughout the year, the Maximum being on Dec.21 & Minimum being on Jun 21

- The axis of the earth's daily Rotation around itself is at an angle of 23.45° to the axis of its ecliptic Orbital plane around the Sun.

This tilt is the major cause of the Seasonal Variation of the Solar Radiation available at any location on the Earth.

* In the Solar Radiation Analysis, the following angles are useful.

i) Latitude of Location (ϕ) :

The latitude of a place is the angle subtended by the Radial line joining the place to the center of the Earth with the projection of the line or the equatorial plane.

- The Latitude is taken as positive for any location towards the Northern Hemisphere and Negative towards the Southern Hemisphere.

For Example, the latitude at Equator is 0° while at North and South poles are +90° and -90° respectively.

ii) Declination (δ) :

Declination (δ) is the angular distance of the Sun rays North or South of the Equator.

- It is the angle made by the line joining the centers of the Sun and the Earth with its projection on the Equatorial plane.

* The Value of this angle Varies from a maximum of +23.45° on june 21 to Minimum of -23.45° on December 21

The declination of any day can be calculated from Cooper Equation given by

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+n)\right] \text{ degree}.$$

where, n = Day of the year.

iii) Hour Angle (ω) :

It is the angle through which the earth must turn to bring the meridian of the plane directly in line with the Sun rays.

- The hour Angle (ω) is equivalent to 15° per hour. This angle can also be defined as the Angular displacement of the Sun, East or West of the local meridian due to rotation of the earth on its axis at angle of 15° per hour.

The latitude, hour angle and Sun's declination angle are shown in figure 3.

iv) Solar Azimuth Angle (γ_s) :

The Solar Azimuth Angle is the angle of the Sun's rays measured in the horizontal plane from due South (true South) for the Northern Hemisphere or due North for the Southern Hemisphere.

- In other words, it is horizontal Angle measured from North to the horizontal projection of the Sun rays. This angle is positive when measured from west.

* The Mathematical Expression for the Solar Azimuth Angle is given by.

$$\sin \gamma_s = \frac{-\sin \omega \times \cos \delta}{\cos \alpha}$$

Where, δ - Declination Angle
ω - Hour Angle
α - Altitude Angle

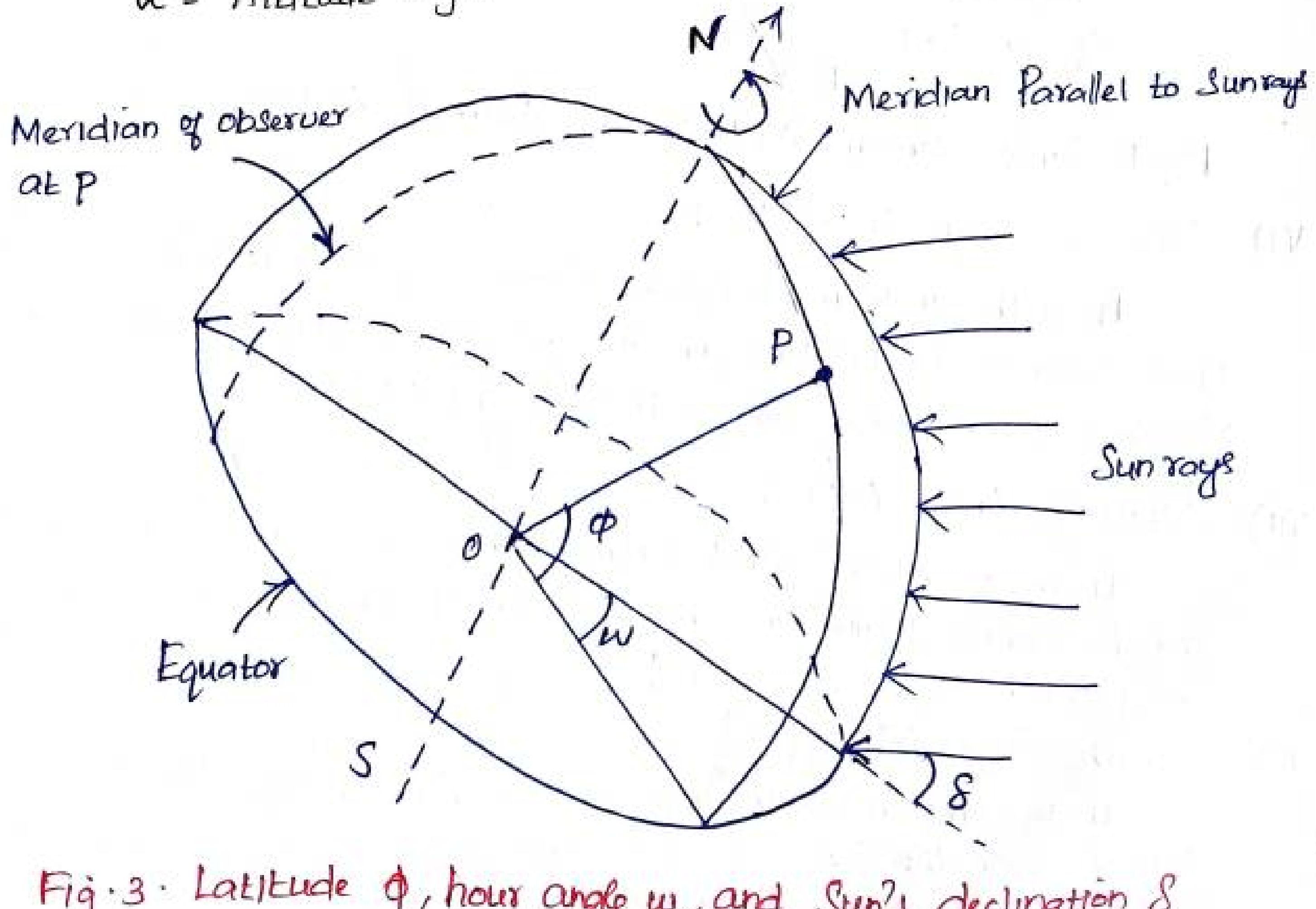


Fig. 3. Latitude ϕ, hour angle ω, and Sun's declination δ

v) Surface Azimuth Angle (γ) :

It is the angle of deviation of the normal to the Surface from the Local Meridian, the Zero point being South, East positive and West Negative

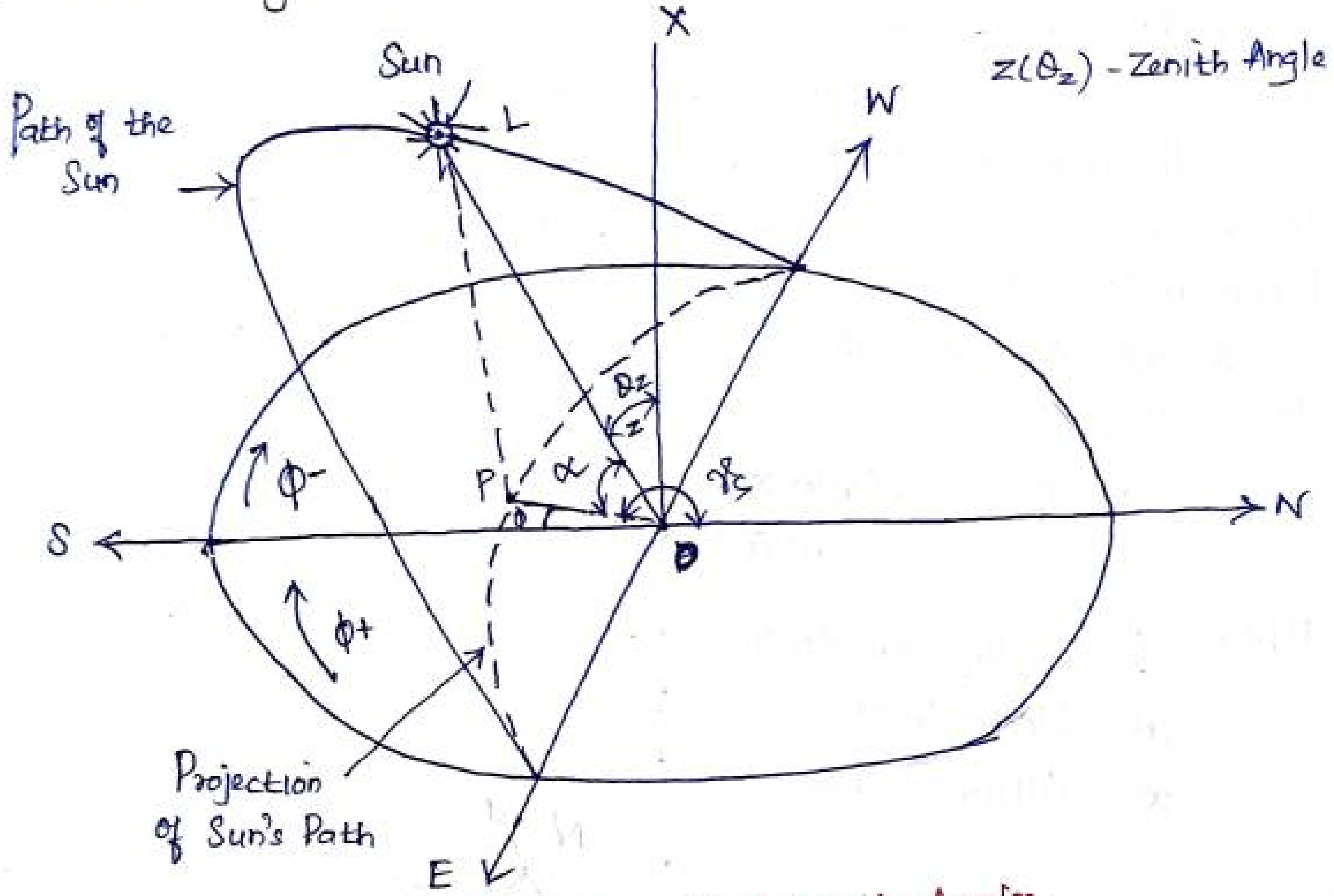


Fig.4. Sun's Zenith, Altitude and Azimuth Angles.

vi) Slope or Tilt Angle (β) :

It is the angle made by the plane Surface with the horizontal. It is taken to be positive for Surfaces Sloping towards the South and Negative for Surface Sloping towards the North.

vii) Altitude Angle (α) :

It is a Vertical Angle between the projection of Sun rays on the horizontal plane and the direction of Sun rays passing through the point.

viii) Zenith Angle (θ_z or z)

It is Complimentary angle of Sun's Altitude Angle. It is a Vertical angle between the Sun rays and a line perpendicular to the horizontal plane through the point.

$$\theta_z = \frac{\pi}{2} - \alpha = 90^\circ - \alpha$$

ix) Incidence Angle (θ) :

It is the angle at which the Sun's rays Strike the Earth's Surface. It is the angle between the Sun's rays and normal on a Surface. Radiation intensity falling normal to the Surface is given by $I \cos\theta$.
- Here θ is known as 'Incidence Angle'.

6. Sum at Zenith and Air mass (m) :

Sum at Zenith is defined as the position of the Sun directly Over head.
- Air mass (m) is the Ratio of the path of the Sun rays through atmosphere to the Length of Path when the Sun is at the Zenith

$m = 1$, when the Sun is at zenith

$m = 2$, when the Zenith angle is 60°. θ_z - Zenith Angle in degree

$m = \sec\theta_z$ when $m \geq 3$

$m = 0$ just above the earth's Atmosphere.

Transmission Coefficient or Transmittance :

It is defined as the ratio between the intensity of Solar Radiation received on the earth's Surface and Intensity of Extra terrestrial Radiation.

7. Attenuation Of Beam Radiation :

Attenuation is the Variation of Solar Radiation reaching the Earth and received at the outside of the Atmosphere.
- It is due to Absorption and Scattering in Atmosphere.

a) Absorption :

As the Solar Radiation passes through the earth's Atmosphere, the Short-wave Ultra Violet Rays (UV) are absorbed by the ozone In the Atmosphere and the Long-wave Infrared waves are absorbed by the Carbon dioxide (CO_2) and moisture in the Atmosphere.

b) Scattering :

As the Solar Radiation Passes through the earth's Atmosphere, the Components of the Atmosphere Such as Water Vapour and dust Scatter a portion of Radiation.

- The portion of this Scattered Radiation always reaches the earth's Surface as 'diffuse Radiation'.

* Scattering is much greater than absorption. Since the Attenuation by Scattering and absorption by dust Particles are difficult to Separate.

Angstrom's Turbidity Formula which is given by

$$\boxed{K_\lambda = \tau \lambda^{-\phi}}$$

Where,

K_λ - Aerosol optical depth in Vertical direction.

τ - Angstrom's Turbidity coefficient.

ϕ - Wavelength Exponent and

λ - wavelength in microns.

8. Clarity Index and Concentration Ratio :

i) Clarity Index :

It is defined as the ratio of radiation received on earth's Horizontal Surface over a given period to radiation on Equal Surface area beyond the earth's Atmosphere in direction Perpendicular to the beam

- It depends upon the clarity of Atmosphere for the passage of Solar Beam Radiation. Clarity Index can be between 0.1 and 0.7

ii) Concentration Ratio : (CR)

It is the ratio of Solar Power per unit Area of the Concentrator Surface (kW/m^2) to Solar power per unit area on the line focus or point focus (kW/m^2).

- For flat plate Collectors, CR = 1.

9. Solar Insolation :

Solar Insolation (Insident Solar Radiation) is defined as the Solar Radiation received on a flat horizontal Surface on earth at a particular Instant of time. It depends on the following Parameters.

1. Daily Variation (How Angle)
2. Seasonal Variation.
3. Atmospheric Clarity
4. Shadows of trees, tall structures etc.,
5. Degree of Latitude
6. Area of Exposed Surface, m^2
6. Angle of tilt of Solar Panel.

10. Solar Radiation on Tilted Surface

Generally, Solar Radiation (global as well as diffuse) is measured on a horizontal Surface.

- The Solar Radiation at which the Solar Energy received on a given Surface depends on the orientation of the Surface with reference to the Sun.

* A fully Sun-tracking Surface that always faces the Sun receives the maximum possible Solar Energy at a Particular Location. A Surface of the Same area oriented in any other direction will receive a Small amount of Solar Radiation.

- Most of the Solar Collectors or Solar Radiation Collecting devices are tilted at an angle to horizontal. Therefore, it is necessary to convert data for an hourly Radiation on a horizontal Surface of Radiation on a tilted Surface.

There are three types of Solar Radiation Such as

i) Beam Radiation (H_b)

ii) Diffuse Radiation (H_d)

iii) Reflection Radiation (H_r). (Total Solar Radiation).

i) Beam Radiation

The tilted Surface faces due to South i.e., $\gamma = 0$ for this case

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

For horizontal Surface ($\theta = \theta_z$)

$$\boxed{\cos\theta_z = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega}$$

The tilt Factor for Beam Radiation R_b is given by

$$R_b = \frac{\text{Hourly Beam Radiation Incident upon the tilted Surface}}{\text{Hourly Beam Radiation incident upon a horizontal Surface}}$$

$$\boxed{R_b = \frac{\cos\theta}{\cos\theta_z}}$$

ii) Diffuse Radiation :

For cloudy or hazy days, diffuse Radiation can be assumed as uniformly distributed over the sky.

* Conversion Factor for diffuse Radiation (R_d) is given by

$$R_d = \frac{\text{Hourly diffuse Radiation incident upon the tilted surface}}{\text{Hourly diffuse Radiation incident upon a horizontal surface}}$$

$$\boxed{R_d = \left(\frac{1+\cos\beta}{2}\right)}$$

iii) Reflected Radiation :

The reflected component comes mainly from the ground and other surrounding objects.

* The Reflected Radiation (R_r) is given by.

$$\boxed{R_r = \left(\frac{1-\cos\beta}{2}\right)}$$

iv) Total Radiation :

The total Radiation on a surface of Arbitary orientation is given by the formula

$$H_r = H_b R_b + H_d R_d + \rho R_r (H_b + H_d).$$

$$\boxed{H_r = H_b R_b + H_d \left(\frac{1+\cos\beta}{2}\right) + \rho \left(\frac{1-\cos\beta}{2}\right)(H_b + H_d)}$$

Where,

H_b - Beam Radiation

H_d - Diffuse Radiation

ρ - Diffuse Reflectance

The Values of diffuse Reflectance is given by.

$\rho = 0.2$ when there is no snow.

$= 0.7$ when there is snow cover.

11. Day Length, Sunrise and Sun Set :

It is evident from our day-to-day life that during Summer, Sun rises early and Sets later and during Winter, the Sun rises late and Sets early.

- Therefore, the day is longer during Summer and shorter during Winter. It is due to the fact that the angle of Latitute Increases during Summer and decreases during winter.

* Hence, the Sun rise Hour, Sun Set Hour and Day Length depends upon the latitute of location and Season and day in the year

12. Local Solar Time or Local Apparent Time :

The time used for Calculating the hour Angle is the local solar Time. The Solar time can be obtained from the Standard time observed on a clock by applying two Corrections.

- The first Correction has a magnitude for of 4 minutes for every degree difference in Longitude.
- The Second Correction called 'Equation of Time Correction'.

$$LST = \text{Standard Time} \pm 4\left[\left\{\begin{matrix}\text{Standard}\\\text{Time}\\\text{Longitude}\end{matrix}\right\} - \left\{\begin{matrix}\text{Longitude}\\\text{of}\\\text{Location}\end{matrix}\right\}\right] + \left\{\begin{matrix}\text{Equation of}\\\text{Time}\\\text{Correction}\end{matrix}\right\}$$

13. Apparent Motion of Sun :

The rotation of the earth about its axis Causes the 'Apparent Motion of Sun'. It changes the angle at which the direct Component of Light Strikes the Earth.

- The position of the Sun depends on the location of a point on Earth, Time of day and Time of a year.

INSTRUMENTS FOR MEASURING SOLAR RADIATION AND SUN SHINE

Solar Radiation Measurements are important because of the Increasing number of Solar Heating and Cooling Applications and the Need for accurate Solar ~~tra~~ Irradiation Data to Predict the performance.

- Solar Radiation requires Instruments which will measure the heating effect of direct Solar Radiation and Diffuse Solar Radiation.

* there are two basic types of instruments used for measuring Solar Radiation. They are as follows.

1. Pyrheliometer :

It is an instrument for the measurement of direct Solar Radiation flux at normal incidence.

- The instrument is usually attached to an electrically driven Equatorial mount which tracks the Sun.

2. Pyranometer :

It is an Instrument for the measurement of the direct and diffuse solar Radiations arriving from the whole hemisphere.

- This hemisphere is usually the Complete Sky dome. Pyranometer Can be used in a tilted position as well, in which case it will also receive the ground reflected Radiation.

* pyrheliometer and pyranometer are basically a Radiometer Which absorbs the Solar Radiation at its Sensor, transforms it into heat and measures the resulting amount of heat

3. Sun Shine Recorder :

Sun Shine Recorder is used for measuring the Sun Shine.

I. MEASUREMENT OF DIRECT RADIATION USING PYRHELIOMETER :

A pyrheliometer is an instrument which measures the direct beam Solar Radiation.

- It is an Instrument which Collimates the radiation to determine the beam Intensity as a function of Incident Angle. The instrument is usually mounted on a Sun-tracking device called an 'Equatorial Mount'.

In this device, a Sensor disc is located at the base of tube whose axis is aligned with the direction of the Sun rays. Thus, the diffuse radiation is essentially blocked from the Sensor Surface.

* Most of the Pyrheliometers operate on the principle of 'thermopile Effect'. The diffuse Component is avoided by installing a Collimator tube over the Sensor with a Circular Cone angle of about 5°.

Three types of Pyrheliometers are used to measure the Normal Incident Beam Radiation. They are as follows.

1. Angstrom Pyrheliometer
2. Abbot silver disc pyrheliometer
3. Eppley Pyrheliometer

1. Angstrom Compensation pyrheliometer :

In this type, a thin blackened Shaded Manganin Strip (Size 20 x 2 x 0·1 mm) is heated electrically until it is at the Same temperature as a Similar Strip which is exposed to Solar Radiation.

- Fig.1 shows the electric Circuit of this pyrheliometer. Under the Steady State Conditions (both Strips at Identical Temperature), the energy used for heating is equal to the absorbed Solar Energy.

* the thermocouples on the back of each Strip is Connected in Opposition through a Sensitive galvanometer to test the Equality of Temperature.

The energy H of direct Radiation is calculated by using the formula

$$H_{DN} = KI^2$$

Where

H_{DN} - Direct Radiation Incident on the Area Normal to Sun rays.

I - Heating Current in Amperes.

$$K = \frac{R}{W\alpha}$$

K - Dimension and Instrument Constant.

R - Resistance per unit length of the absorping strip (Ω/cm).

W - The Mean Width of the Absorping Strip

α - the Absorping Coeffiuent of the Absorping strip.

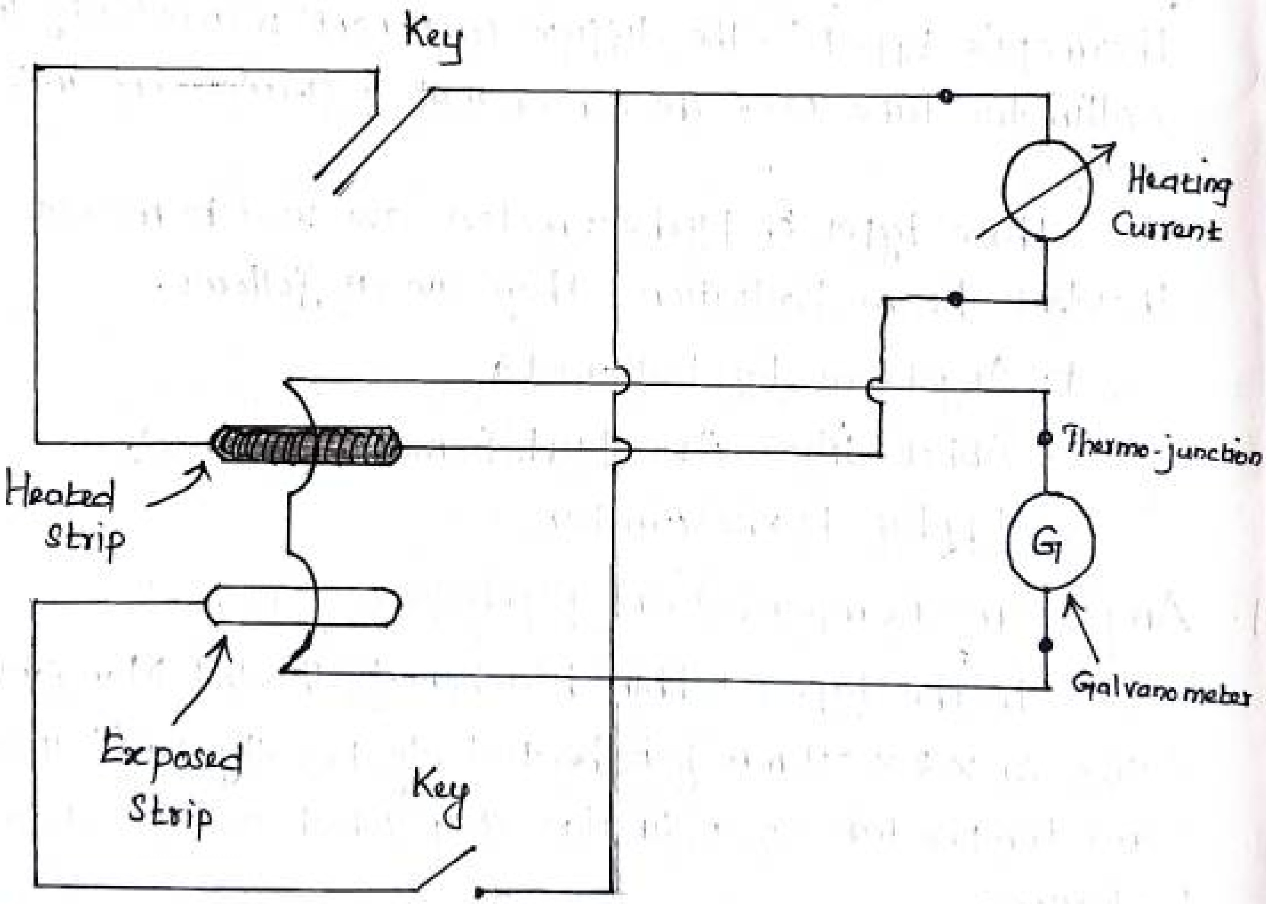


Fig.1. Electric Circuit of Angstrom Compensation Pyrheliometer.

2. Abbot Silver Disk PYRHELIOMETER :

This Instrument was designed by Abbot in 1902 for the Radiation measurement. A schematic diagram of this device is shown in fig. 2.

In this pyrheliometer, a silver disk painted black on its Radiation Receiving side which is 3.8 cm is diameter and 0.7 cm thick is positioned at the Lower end of a tube with diaphragms to limit the whole aperture to 5.7°.

– The disk is Suspended by three fine Steel wires inside a copper box which is enclosed in a wooded box to protect the instrument from the temperature change of the Surrounding.

* Mercury in glass thermometer is used to measure the temperature at the disk. A good Contact between Silver disk and thermometer bulb is maintained by using Mercury.

The thermometer stem is bent at right angle to make this instrument more compact and easy to use. It is also supported in a metallic protective tube.

– A cylinder with diaphragms inside is fitted in the Wooden Container to let the direct Solar Radiation falling onto the silver disk. There is a metallic-plate shutter at the top end of the cylinder to block or allow the passage of Solar Radiation to the disk.

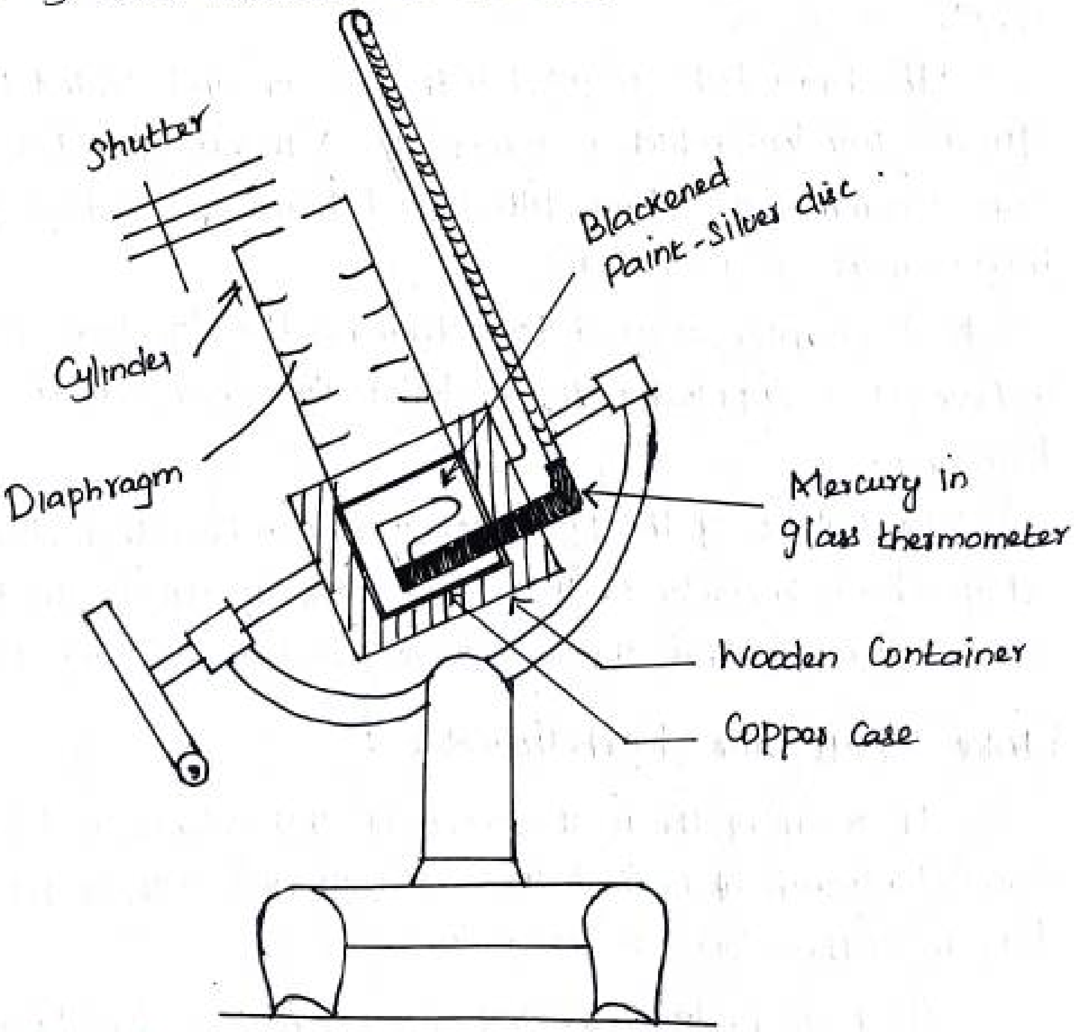


Fig.2. Abbot Silver disk Pyrheliometer.

During the measurement phase, the disk is heated by Solar Radiation and its temperature Rises.

- The intensity of this Radiation is ascertained by measuring the temperature change of the disk between measurement phase and shading phase with the mercury in glass thermometer. This type is widely used for calibrating Pyranometers.

3. Eppley Pyrheliometer :

The Eppley normal incidence pyrheliometer has a found a wide acceptance in many Parts of the world. It uses a thin silver disk of 9mm in diameter as a Receiver which is coated with optical black paint.

- Fifteen junctions of fine bismuth-silver thermocouples are in thermal Contact with a electrical insulation from the lower surface of the disk. The cold junctions are in contact with the copper tube of the Instrument.

* The unit is mounted at the base of a double walled brass tube which is chromed externally and Blackened Internally. A series of limiting diaphragms limits the aperture to a Circular cone of full angle of 5.7°.

- the brass tube is filled with dry air and sealed with a crystal quartz window which is removable. A manually rotatable disk which can accommodate three filters and leave one aperture for total spectrum measurement is provided.

* A diopter is used to determine the direction of the sun. the Instrument is supplied with an electrically driven equatorial mount for solar tracking.

The output of the pyrheliometer can be either directly recorded on a strip chart recorder or Integrated over an appropriate time period and registered. this Instrument is found to be Very stable.

4. Linke - Feussner Pyrheliometer :

It is one of the most convenient instruments used for measuring the direct Radiation at normal Incident with and without Filters. A schematic diagram of this device is shown in fig. 3.

The main body of the Instrument Consists of Six Massive Copper Rings.

these rings are contoured on the inside of a tube to produce a set of Radiation diaphragms for decreasing internal reflections, defining the acceptance angle of the instrument and limiting turbulent air currents inside the instrument.

- Thus it secures a high stability and good sensitivity. A rotating disk with filters is positioned in the upper end of the tube. At the upper extremity of the tube is a special screening head which eliminates the unwanted reflection in filter measurements.

* This pyrheliometer employs a specially designed Moll thermopile Receiver consisting of 40 manganese - constantan thermo couple arranged in a circle of 1cm diameter. The two thermo couples are in two equal sectional Arrays

- One section is exposed to the radiation being measured and other is shaded. Thus the sections tend to compensate each other for short Period Temperature fluctuations of the environment. The aperture angle is approximately 10°.

In this instrument, five Filters are usually Provided fitted in the Rotating disk. The filter mount is as well fitted with a double walled opaque disk for the use in zeroing the instrument.

- This instrument is installed on a manually operated azimuth - elevation mount by which it can be oriented in any direction

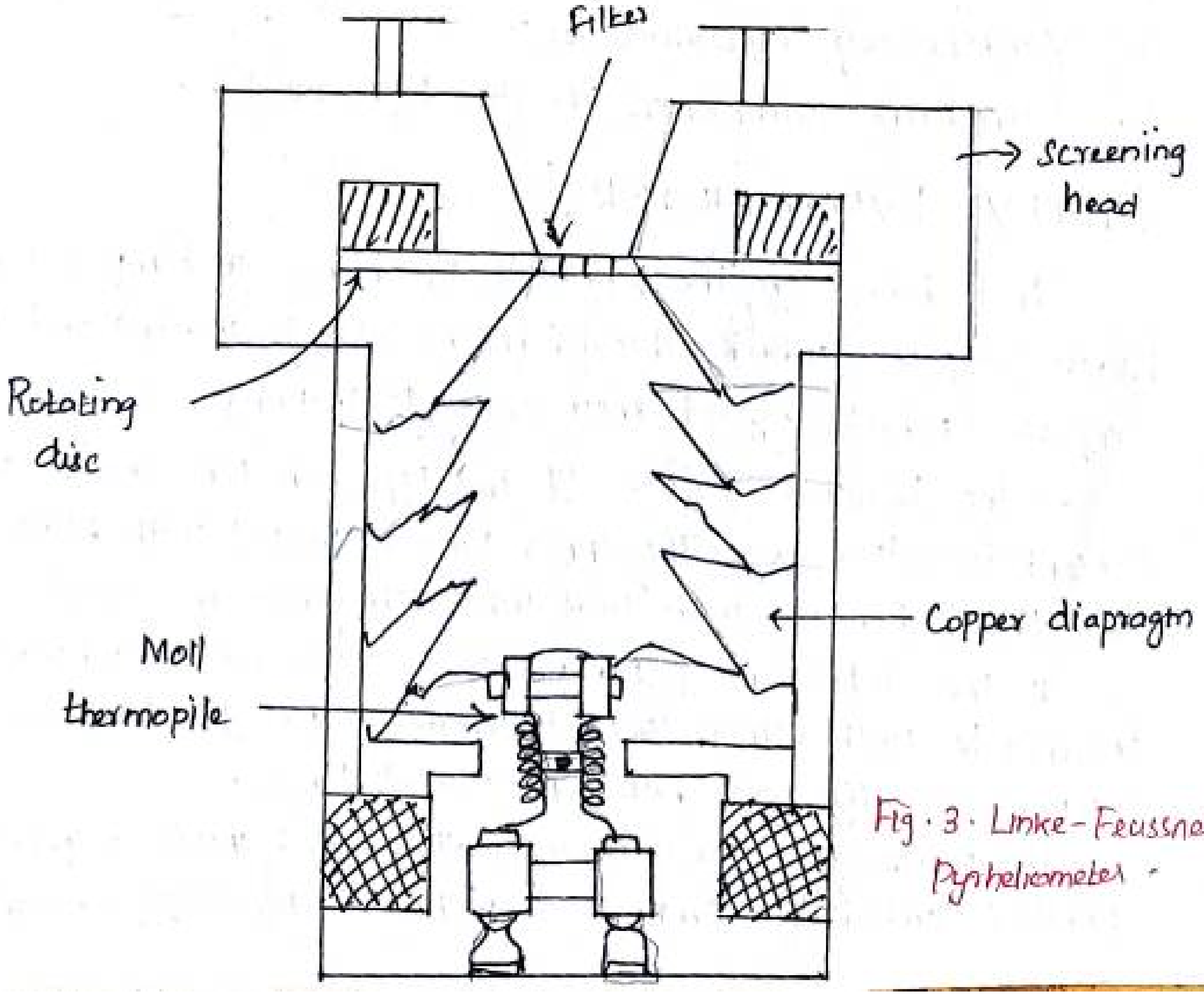


Fig. 3. Linke-Feussner Pyrheliometer.

MEASUREMENT OF GLOBAL RADIATION USING PYRANOMETERS

Pyranometer is an Instrument which measure the total or global Radiation over a hemispherical field of view

- If a Shading Ring is attached, the beam Radiation will be Prevented from falling on the Instrument Sensor and then it measures the diffuse Component of the Radiation.

* The Sun's Radiation is allowed to fall on a black Surface to which the hot junctions of a thermopile are attached in most of the pyranometers.

The Cold junctions of the thermopile are located in Such a way that they donot receive the Radiation. As a result, an e.m.f Proportional to the Solar Radiation is generated.

- The following are the different types of Pyranometers.

1. Eppley Pyranometer
2. Yellot Solarimeter (photovoltaic cell pyranometer)
3. Moll - Gorczynski pyranometer.
4. Bio metallic Actionograph.
5. Yanishevsky Pyranometer.
6. Dirmhirn - Sauberer or Star Pyranometer.

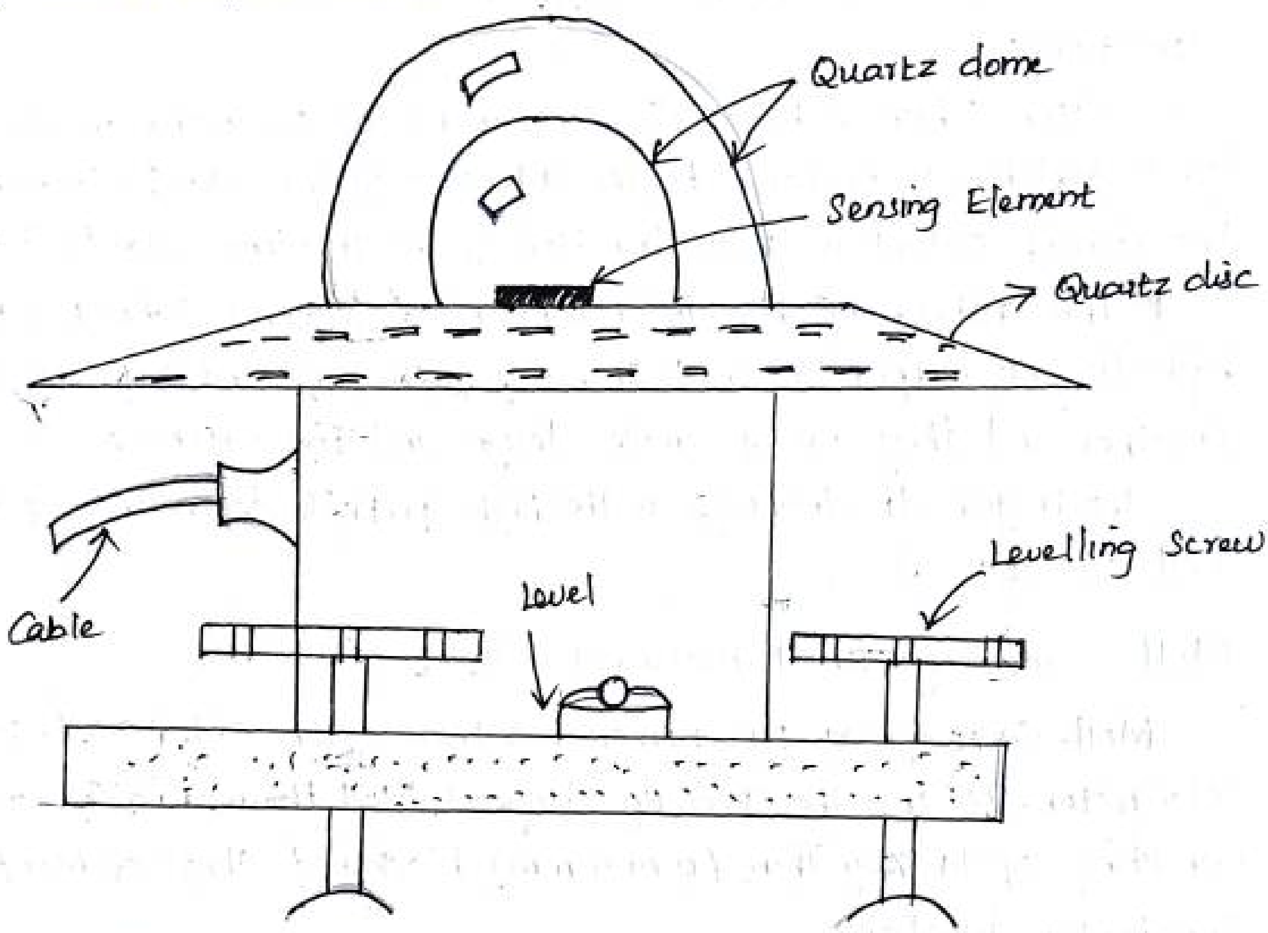
1. EPPLEY PYRANOMETER:

It is based on the principle of change in temperature between black Surface (which absorbs most Solar Radiation) and white Surface (which reflects most Solar Radiation).

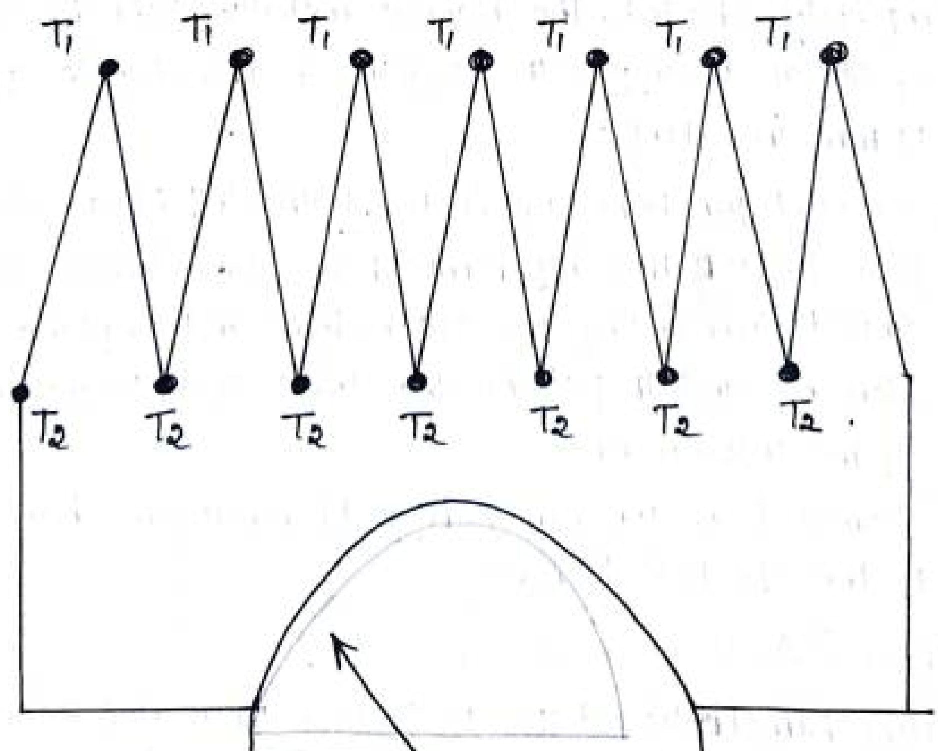
- The Receiver Surface of this Pyranometer Consists of two Concentric silver rings. The Inner Ring is Coated with black colour and the outer one with wat white magnesium oxide.

* The detection of temperature difference is achieved by a thermopile with either 10 or 50 thermocouple junctions to detect the temperature difference between Coated Rings.

The whole assembly is hermetically Sealed inside a specially blown Spherical lamb bulb, 76mm in diameter and made of glass about 0.6mm thickness filled with dry air. Fig.1 Shows the general arrangement of a typical Pyranometer and thermopile arrangement consisting of a battery of thermocouples connected in Series.



a) Typical Pyranometer



b) Thermopile consisting of a Battery of thermocouples connected in Series
Fig.1. Pyranometer

2. YELLOT SOLARIMETER (PHOTOVOLTAIC CELL PYRANOMETER)

Pyranometers have been used in photovoltaic detectors. Silicon Photovoltaic cells are the most common Solar cell for Solar energy Calculations.

– Silicon Photovoltaic cells are Capable of Producing an electrical Signal which is proportional to the Intensity of the Solar Radiation. the Current Output is linear Function of the Incident Solar Radiation.

* This Instrument has an Instantaneous Response (about 10 μs), high Current Output, Overall Stability with time and exposure to weather and they are of Simple design and Low expense.

The major disadvantage is the high spectral dependence of the cell output.

3. Moll - Gorczynski PYRANOMETER :

Moll-Gorczynski pyranometers is more often Called Moll-Gorczynski Solarimeter. It uses the Specially designed Moll thermopile Receiver Consisting of 14 Very thin (0.005 mm) blackened Strips of Manganese-Constantan junctions.

– Half of the thermopile is exposed to the Sun whereas the other half is Completely Shaded. The narrow metallic Ribbons which form the thermopile are arranged in the form of a rectangle approximately 12 mm × 11 mm in extent.

* The exposed junctions are Coated with dull black colour paint and Protected from the weather by hemisphere glass domes. 30 cm diameter Radiation Shield Surrounding the Outer dome and Coplanar with this Sensitive Element and it prevents the direct Solar Radiation from heating the base of the Instrument.

– The domes have uniformly high transmission Characteristics throughout the Spectral Range.

4. BIMETALLIC ACTIONOGRAPH :

It uses bimetallic Strips as Sensors. It is not recommended for the general use because of its large temperature Coefficient and equally large azimuth and Cosine Errors and long Response Time.

It is Suitable only for daily total Radiation in which accuracies of ± 10% are adequate. However, it is used for observing the daily total Irradiance because, it is a simple and sturdy Instrument and it requires no electric power supply for its operation.

- Hence it is particularly Suitable for Remote Areas. The Receiver is blackened bimetallic strip (Nickel-Iron) of about 85 mm × 115 mm which is simply a bimetallic Thermometer.

* One end is free to move as the change of temperature causes a distortion of the strip. The change which is a function of Solar Irradiance is recorded on a Recorder chart mounted on a clock-driven drum.

- The main sensor is covered by a hemispherical glass dome and the other mechanism is enclosed in a sealed metal case because of the relatively large mass of the bimetallic strip and large Response time of the Instrument.

5. YANISHEVSKY PYRANOMETER :

The Sensor is constructed either in a Square chess board pattern of alternate black and white Squares and Rectangles or in a Radial pattern of alternate Black and White Segments.

- the thermocouple is composed of alternate strips of Manganese and Constantan. The hot junctions are painted black in colour and cold junctions are coated with white Magnesia

* The hemispherical glass cover prevents wind effects. This pyranometer is used as relative instrument and therefore it requires calibration against a standard.

An additional correction is also applied for the wavelength sensitivity of the Instrument ~~an~~ when it is used for measuring only the 'diffuse Radiation'

6. DIRMHIRN - SAUBERER OR STAR PYRANOMETER

This pyranometer is used all over the world and it is recommended as a Suitable Instrument for the measurement of 'Global and Sky Radiation' by the 'Commission of the World Meteorological Organisation'.

- the Receiver consists of 32 Small Copper Plates which are 0.05 mm thick, half of which are blackened and the remaining half of which are covered with a highly Reflecting white paint.

The two Sets of plates are mounted as alternate black and white Segments radiating as a Star from a central point thus forming a flat Circular disk of about 50 mm in diameter.

- The two types of plates are thermally insulated from each other by being mounted on poorly conducting Concentric Rings which are themselves thermally isolated from the main base plate of the Instrument.

* The thermopile Consists of Manganese - Constantan or Copper-Constantan Junctions which are Soldered to a plate. The Receiver is covery by a polished glass hemisphere which is 2 to 3 mm thick and 70mm in diameter.

MEASUREMENT OF DIFFUSE RADIATION

The Same Instrument Dirmhirn - Sauberer or Star Pyranometer which is used for the measurement of total or global Radiation can be used for the measurement of diffuse Radiation, Provided that a Suitable device is used to prevent the "direct Solar Radiation" from reaching the Receiver.

Shading of the Pyranometer from direct Solar Radiation is done either by a disk which is made to move with the Sun to cast its shadow ring or. The Shadow Ring is more popular of two devices because a Shading disk needs constant Supervision and Maintenance and Equatorial mount is expensive.

- In the latter case, a Small Correction Factor is applied to the part of the 'diffuse Radiation' which is Cut off from the Sensor by the "Shadow ring". This correction can either be Computed or determined experimentally.

* The Correction Factor Can be determined experimentally by Successive Measurements with a ring and disk of Suitable diameter. The amount of diffuse Radiation which is Cut off is added to the results Obtained with above Ring.

MEASUREMENT OF SUN SHINE

Knowledge of the daily and hourly records of the amount of Sunshine is necessary for estimating Solar Radiation Values. It is also used for optimising the design of a particular Solar Collector.

– This measurement is Simple and far less Expensive than Solar Radiation measuring devices. The duration of bright Sun shine in a day is measured by means of a 'Sun Shine Recorder'. The Campbell-Stokes Sun Shine Recorder is shown in figure. 1 and it is extensively used all over the world.

* It consists of a glass sphere of about 10 cm in diameter mounted in a Section of Spherical metal bowl having three Partially overlapping grooves for holding a Recorder Card strip and glass sphere.

The recording Cards for use in Summer, winter or spring and autumn are set in these grooves.

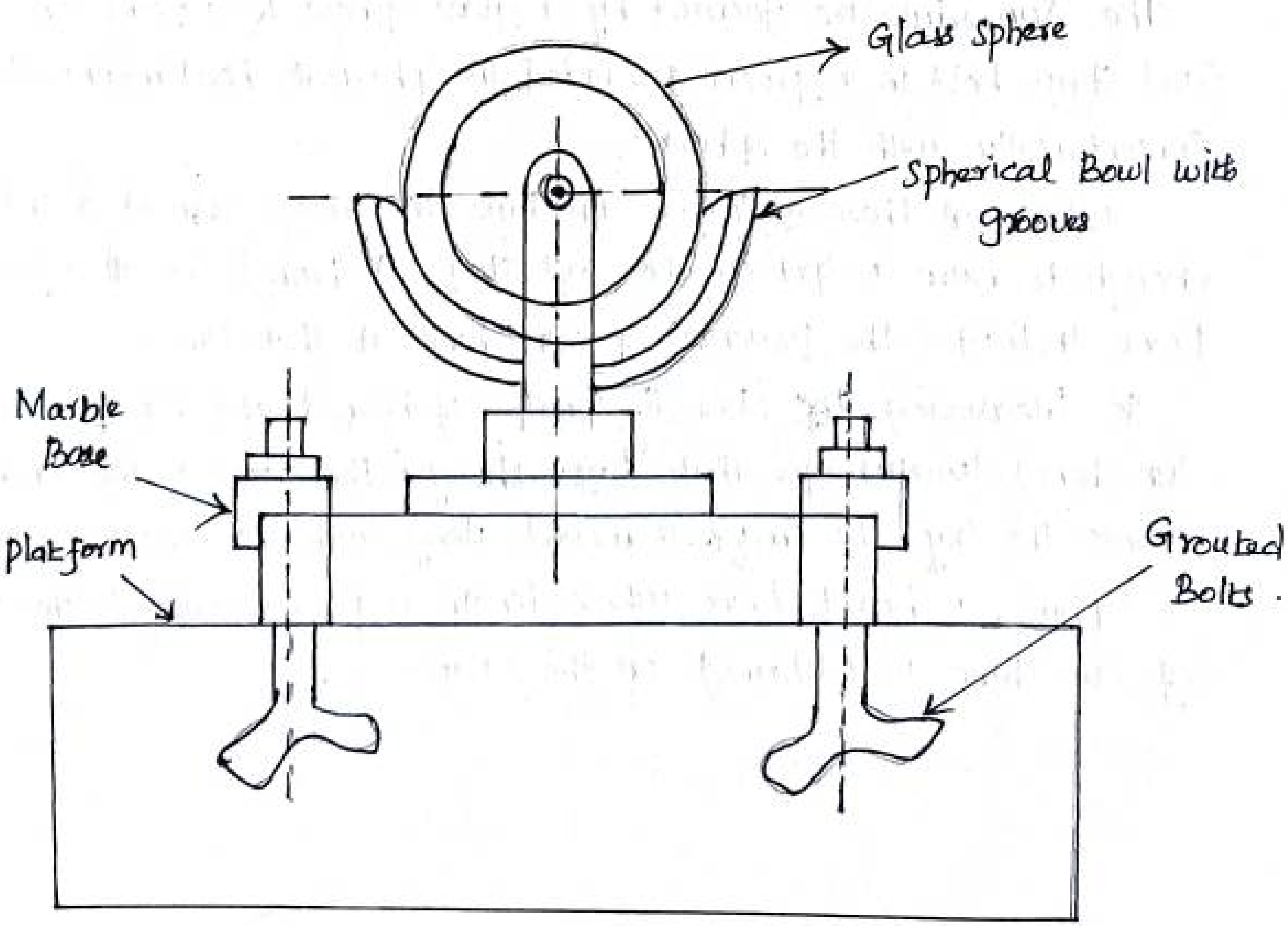


Fig. 1. Sun shine Recorder

Fig.2 Shows three different Recording cards are used depending on the Season. The important Requirements of the glass sphere are that it should be uniform, well-annealed and Made of colourless glass.

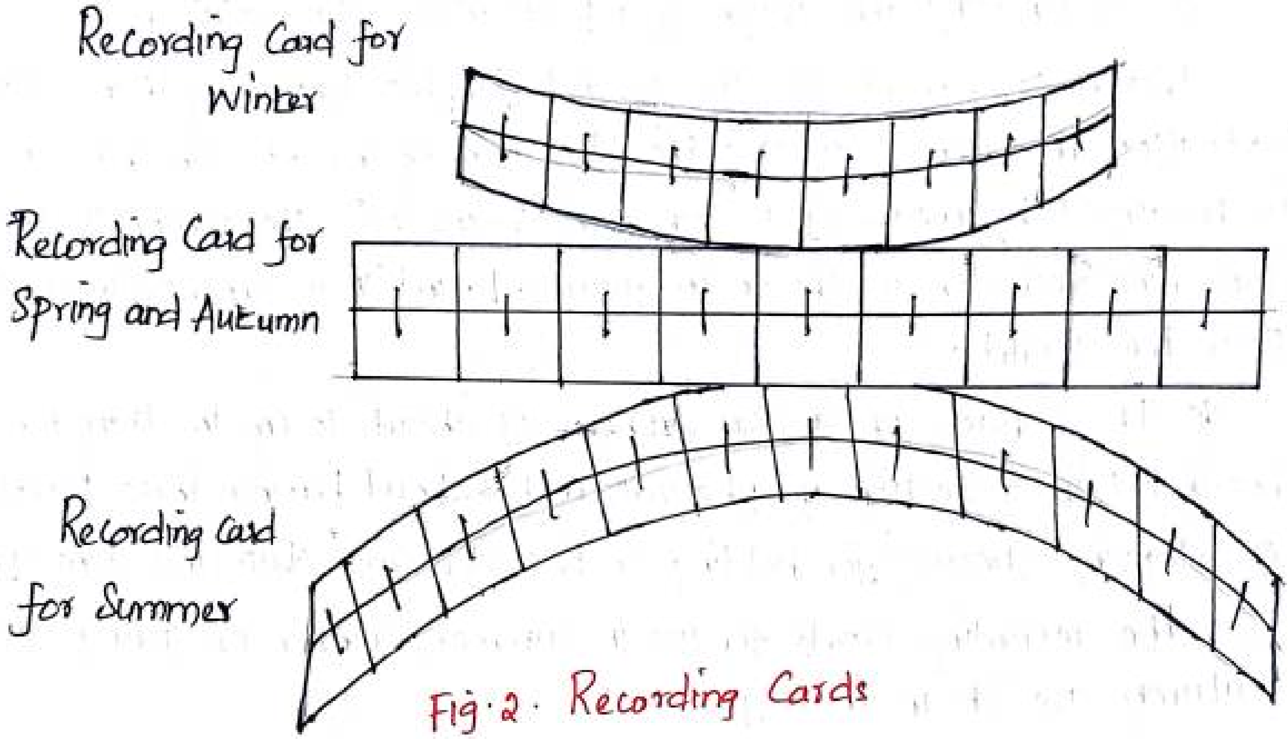


Fig.2. Recording Cards

The Sun rays are focused by a glass sphere to a point on a Card Strip held in a groove provided in Spherical bowl mounted Concentrically with the sphere.

– whenever there is bright Sun shine, the image formed is intense enough to burn a spot on the card strip. A burn trace at a particular point indicates the presence of Sun shine at that time.

* Measuring the overall length of burn traces reveals the Sun shine duration for that day. Though the day, as the Sun moves across the Sky, the image is moved along with the Strip.

Thus, a burnt trace whose length is proportional to the duration of Sun shine is obtained on the Strip.

SOLAR RADIATION DATA

When designing a Solar Energy System, the best way to Predict its energy-Production performance would be to know what the minute-by minute Solar irradiance levels will be, over the Life time of the System and at the exact location where the System will be built.

- Since weather patterns are somewhat random in time and place and they are extremely difficult to Predict, the system designer is forced to accept the histtorical data and recorded at a different location with Values reconstructed from incomplete data records.

* Historical records are an extremely useful analytical tool and appropriate for a wide range of applications. ~~Ho~~

INFORMATION CONTAINED IN SOLAR RADIATION DATA:

Solar Radiation data for many locations of the world are available in Several forms. The Radiation data are mostly measured on horizontal Surface on the Earth.

However, before using the data, the designer should clearly know the following information.

i) ~~Weather~~ Whether it is measured or Computed.

ii) Whether it is direct, diffuse or global

iii) Whether it is hourly, daily or Monthly

iv) What type of instrument is used for Measurement

MEASUREMENT OF SOLAR RADIATION DATA:

An instrument Called Solariometer is used to measure the most of the data on Solar Radiation on the Earth's Surface.

- this Solariometer gives readings for instantaneous Measurement of rate of Total Radiation Energy received throughout the day on a horizontal Surface.

Spectral distribution of the Sun is plotted by integrating the rate of Radiation received on a horizontal surface.

The first measurement of the spectral distribution of the sun was made by Samuel Langley in 1884. Hence, to honour Samuel Langley, Solar Radiation flux is often reported in 'langleys per hour or per day' the unit, 1 Langley = 1 cal/cm².

* A typical daily record of the global and diffuse Radiation measured on a clear day is shown in fig. 1

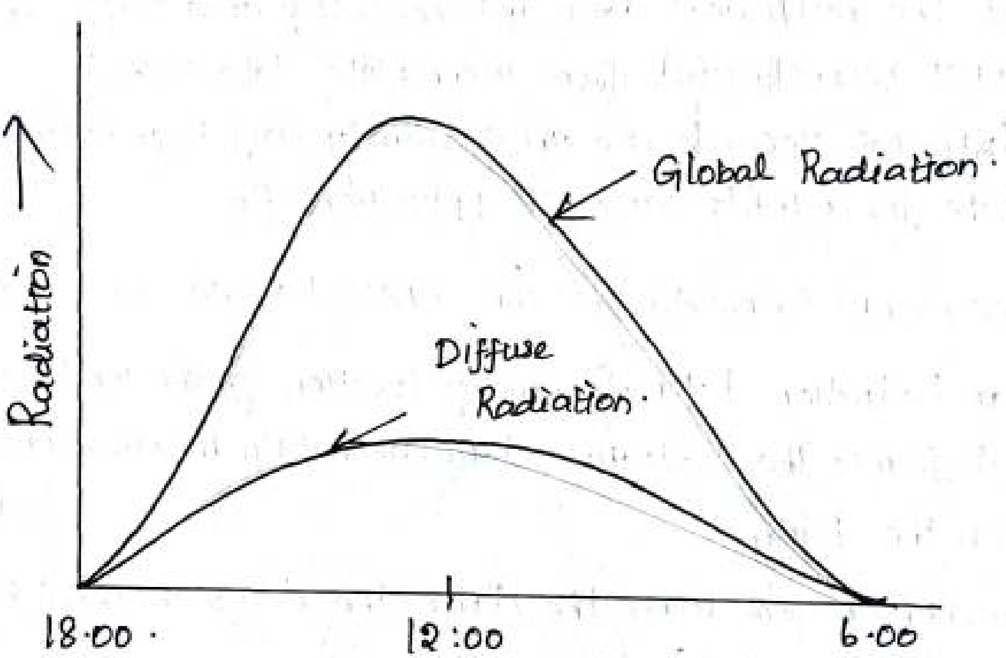


Fig. 1. A typical daily record of global and diffuse Radiation on a clear day.

TYPES OF SOLAR RADIATION DATA

Solar Radiation data is collected for various locations in the world on the basis of following factors.

a) Solar power calculations with reference to the movement of the Sun, latitude of the location etc.,

b) Hourly measurements of Solar Radiation at the location and calculation of daily average global Radiation for the month, Monthly average global Radiation for the year and yearly average global Radiation for few years.

UNIT- II SOLAR ENERGY COLLECTION

SOLAR THERMAL ENERGY SYSTEMS :

Solar thermal Energy Systems are broadly characterized as follows depending on the way they capture, convert and distribute Solar Energy.

1. Passive Solar thermal Energy Systems
2. Active Solar thermal Energy Systems.

1. PASSIVE SOLAR THERMAL ENERGY SYSTEMS :

In Passive Solar Energy Systems, the heating is Carried out without any special device for energy Conversion

– Heat is directly received and used for heating. Heating the houses, water, cooking, drying etc., are the examples of this application.

* these are the Low temperature applications of solar Energy. These systems are a simple and cost effective way to take the advantage of the Sun's free, renewable Energy.

Examples of basic passive Solar structures are green houses, Sun rooms and Solariums. As the Sun rays pass through the glass windows, the Interior will absorb and retain the Heat.

– In Passive Solar Energy Systems, the energy Collected through Solar System is distributed according to a law of 'thermodynamics'

It is States that the heat moves from warm to cool areas and Surfaces. The simple way of transferring heat from Passive Solar Collectors is by Convection mode.

* Ancient People used Passive Solar Energy Systems. They build their houses out of Stones or clay which absorbed the Sun's heat during the day and Stayed warm after dark, Providing heat throughout the Night.

– Hence the Properties of building materials and building design both plays a role in the energy balance of the system. However, it requires a careful design and is often difficult to implement

2. ACTIVE SOLAR THERMAL ENERGY SYSTEMS

In an active Solar thermal Energy system, a Solar collector holding a heat-transfer medium Such as Air or Liquid Captures the Solar Radiation which is then distributed through the building via electric fans or pumps.

For Example, a Solar collector positioned on the roofs of buildings heats the fluid and then pumps it through a system of pipes to heat the whole building

* The technology is simple and used in many possible Applications of Low temperature heat use systems. The most Common application of these Systems is the Production of domestic water Heater Known as "Water Heaters".

– The typical basic Components of an active Solar Heating System Include the following :

i) Solar Collectors
ii) Storage Unit
iii) Load and
iv) Auxiliary Source.

Active Solar Energy Systems are the most Cost-effective in cold climates with good Solar resources when they are displacing more expensive heating fuels Such as electricity, Propane and oil

Drawback : The disadvantage of active Solar Systems is that the use of this device external power sources can fail which needs more Controls and Maintanence

The following Active Solar thermal Energy Systems are Commonly used

i) Solar Water Heaters.
ii) Photovoltaic (PV) cells or Solar Cells
iii) Concentrated Solar Power (CSP)

i) SOLAR WATER HEATERS :

Solar water Heaters (Active) produce thermal energy to Heat Water for households Commerical entities and Swimming pools.

- These heaters are one of the most Commonly implemented Renewable Energy Technologies because of their cost effectiveness and relatively simple installation.

* Solar water heaters typically need a back up Conventional gas or unusually high water demand. Solar water heaters consist of two parts such as Solar Collector and Storage Tank.

In warm climates, collectors heat water directly but in Cold climates, a denser fluid is heated and then transported to a water tank where it heats the water indirectly.

- The heater can be built to use an Active or Passive system for circulating warm fluid depending on climate. The maximum heating temperature Varies with Collector model but water temperature can exceed 90°c, Suitable for Commerical purposes.

* Solar Water Heaters can reduce Conventional Energy Consumption for heating water by 60%. in Commerical Applications and up to 75% in Homes. Although, initial home Installation costs at least double that of Conventional Heaters.

ii) PHOTOVOLTAIC (PV) CELLS OR SOLAR CELLS :

Photovoltaic (PV) Cells or Solar Cells are an Active System in which Small panels are applied with Semi Conducting Material.

- PV panels Convert the Sun's rays into electricity which Can power a Variety of Individual items ffrom Personal Computers and Street lights to water pumps.

* This material, usually made of silicon but potentially other Polycrystalline thin films, generates a direct Current (DC) when Sun light hits the panel

PV cells Can be installed on windows and roof tiles. PV System can be tailored to meet a building energy needs by adding Concentrating or Sun-tracking devices, Dc-Ac Converters and/or Battery Storage.

- PV Systems may or may not be Connected to the electric transmission grid. When the number of PV panels are arranged as an array and it is Connected to the grid, the excess power can be sold to the electric Company.

iii) CONCENTRATED SOLAR POWER (CSP) :

CSP is an Active System distinguished from other Solar Energy Systems by its ability to function as a Utility-Scale power plant.

- CSP uses the fields of Mirrors to Concentrate Solar Energy into Channels holding heat-responsive fluid. The high temperature excite the fluid to a point where it powers a turbine or Engine which in turn runs an Electric generator.

* Without Storage Facilities, CSP Systems Can generate Electricity for about eleven hours on a Sunny Summer day. CSP Systems do have the potential to provide base load power for Utilities.

A CSP system that uses oil or Molten Salt as a medium in the Heat-transfer Process Can retain the thermal energy

APPLICATIONS OF PASSIVE AND ACTIVE SOLAR THERMAL ENERGY

1. Passive Heating Systems (Low Temperature $T < 150^{\circ}C$)
   i) Residual Heating
   ii) Cooking
   iii) Water Heating
   iv) Drying
2. Active Solar Thermal Systems (Medium Temperature $150^{\circ}C < T < 300^{\circ}C$)
   i) Hot water
   ii) Steam Supply
   iii) Process Heat Supply
   iv) Desalination plants.
3. Active Solar thermal Systems (High Temperature $T > 300^{\circ}C$)
   i) High Temperature Steam
   ii) Electrical Power Generation
4. Active Solar PV Systems :
   i) Small low Voltage, Low Wattage Applications
   ii) Medium Voltage and Medium Power Applications in kW about 350 kW
5. Active Concentrated Solar Power (CSP) Plants
   Feed power into electrical Network range 1 MW to 200 MW.

SOLAR COLLECTORS

Solar collector is a device used for collecting the Solar radiation and it transfers energy to fluid passing in contact with it
- The Collectors receive heat from Solar rays and give it to the heat-transport Fluid. Solar Collector Surface is designed for high Absorption and Low Emission. So Utilization of Solar Energy requires Soft Solar Collectors:

* these Collectors are classified into two types. They are as follows

i) Non-Concentrating or Flat Plate type Solar Collector

ii) Concentrating (Focusing) type Solar Collector.

The Solar Energy Collector with its associated Absorper is the essential Component of any Systems for the Conversion of Solar Radiation into more usable form (heat or Electricity).

- In the Non-concentration type, the Collector Area (the area that intercepts the Solar Radiation) is same as the Absorber Area (the area absorping the Radiation)

- In the Concentrating Collectors, the area intercepting the Solar Radiation is greater than flat-plate Collectors and it provides higher Temperature than a Non-Concentrating type.

* It is also used to produce Medium Pressure Steam. They use many different arrangements of mirrors and lenses to Concentrate the Sun rays on the boiler

This type shows better Efficiency than the Flat-Plate type.

~~For the best~~

TYPES OF SOLAR COLLECTORS :

There are two types of Solar Thermal collectors Such as

i) Flat plate collector

ii) Solar Concentrating Collector (Focusing Type).

FLAT PLATE COLLECTOR

Flat plat Collectors are Non-Concentrating type. They are Particularly Convenient for space and Service water heating applications where temperatures below 90°c are adequate.

– They are made in rectangular panels from about 1.7 to 2.9 m^2 in area and they are relatively simple to construct and erect.

Flat plates can collect and absorb both direct and diffuse Solar Radiation

* Flat plate Solar Collectors are mainly divided into three types based on the type of heat-transfer Fluid used. They are as follows:

Feature: The Characteristics features of the Flat plate Collector

a) It absorbs both beam and diffuse Radiation.

b) It can function without Sun tracking.

c) It is Simple in Construction and It requires little Maintenance.

TYPES:

1. Liquid Heating Collectors.
2. Air Heating or Solar Air Heaters.
3. Evacuated Tubular Collector.

1. LIQUID HEATING COLLECTORS:

It is used for heating the water and Non-freezing aqueous Solutions. The constructional details of simple Flat plate Collector are shown in fig. 1

– It is the plate and tube type collector. The majority of the Flat-plate Collectors have five main Components. They are as follows:

i) Transparent Cover (one or two sheets) of glass, Teflon, Marlex or Tedlar.

ii) Blackened Absorber plate usually Copper, Aluminium or Steel typically 1-2 mm thick

iii) Tubes (typically 1-2 cm diameter), channels or Passages in thermal contact with the Absorber Plate.

They are soldered, brazed or clamped to the bottom of the absorber plate. In some designs, the tubes form the integral part of Absorber plate.

iv). Thermal Insulation usually of Foam, Expanded polystyrene or glass wool typically 5-10 cm in thickness

v) Tight Container is to enclose above components.

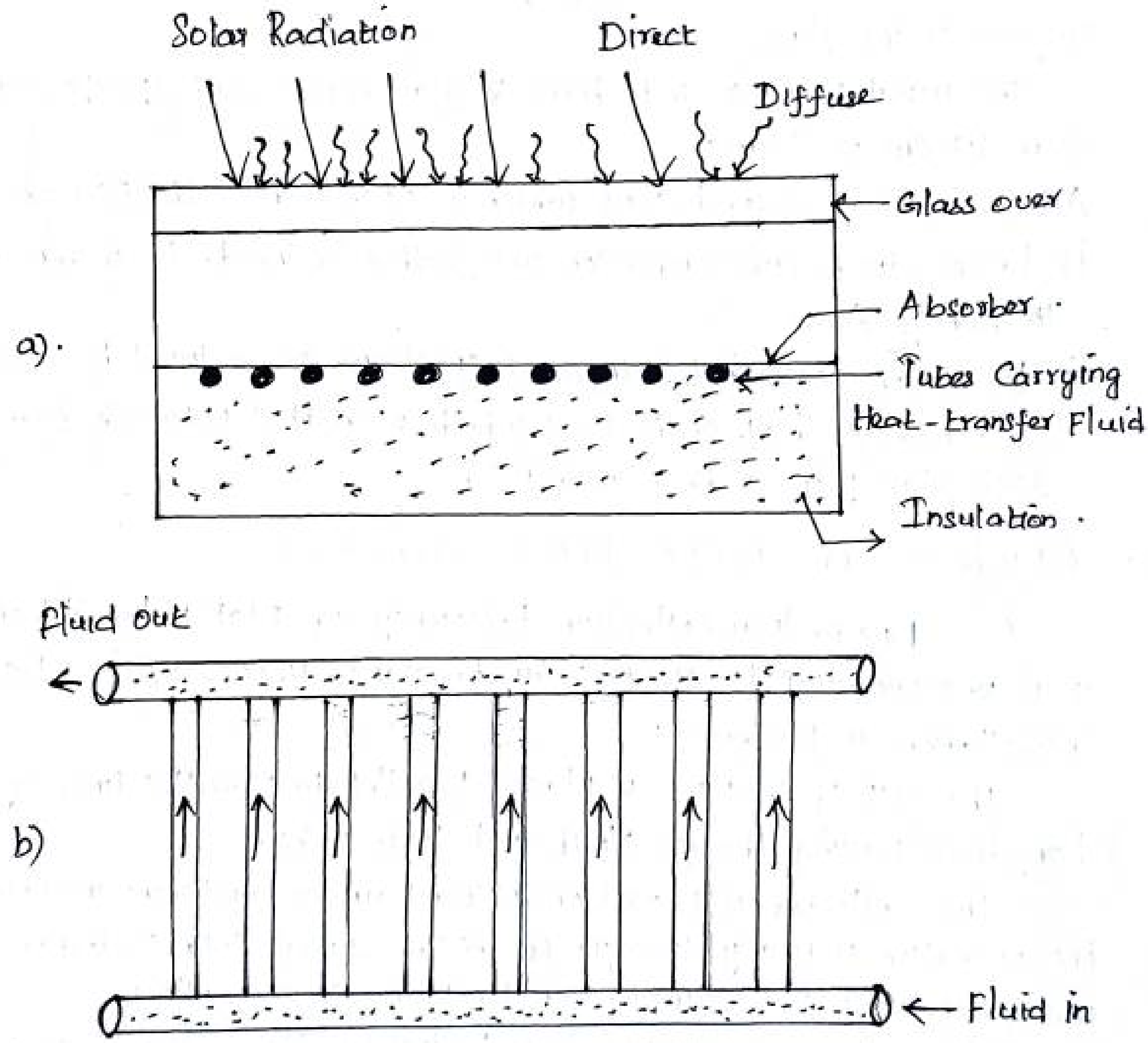


Figure.1 Liquid Heating Collector

WORKING :

As the Solar Radiation Strikes a specially treated absorber plate, It is absorbed and raises It temperature.

- This raised heat is transferred to fluid which is circulated in the tube or (Channels) with the absorber plate as shown in fig.1

Thermal Insulation prevents the heat loss from the Rear Surface of the Collector. The upper glass Cover permits the entry of Solar Radiation as It is transparent for incoming Short wave length.

- But It is largely opaque to longer Infrared Radiation reflected from the absorber. The glass Cover also prevents the heat loss due to Convection by Keeping the Air Stagnant.

* The glass cover may reflect around 15 % of Incoming Solar Radiation Which can be reduced by applying "Anti-reflective Coating" on the outer Surface of the glass

The usual practice is to have 2 glass covers with specific ranging from 1.5 cm to 3 cm.

Advantages of Second class which is added above the first one are:

i) Losses due to air Convection are further Reduced. It is important in Windy Areas.

ii) Radiation losses in the Infrared spectrum are reduced by a further 25 % because half of the 50 % which is emitted outwards from the first glass plate is back radiated.

2. ORIENTATION OF FLAT PLATE COLLECTORS:

Due to low Collection Efficiency of Flat plate Collectors, It is uneconomical to arrange Sun-tracking. Hence, a fixed type Installation is preferred.

The axis of the pipes is placed parallel to parallel lines of Longitude passing through North and South poles.

- the Collector is placed on a Stand under Conditions in which the operation is nearly steady. ~~It m.~~ The global Solar Radiation Can be measured using a Solarimeter on the plane of the Collector.

* To achieve maximum Solar Radiation, the Collectors are rotated to face the Sun towards South facing to reduce the angle of incidence and capacitance Effect.

It means, the Sun must Strike the Surface of Flat plate Collectors at right angle and not be Subjected to any Shade.

- If the angle of the Sun is greater to the glass, the amount of the Sun's Radiation will be more which is reflected off the glass.

A digital Multi-meter is used to measure the output of the Solarimeter in mV (milli-volts) which can be then converted into solar radiation in W/m^2 (Watts per meter square) using a multiplier of $90.34\ Wm^{-2}$ per mV with a Sensitivity of $4.76 \times 10^{-6}\ Wm^{-2}$.

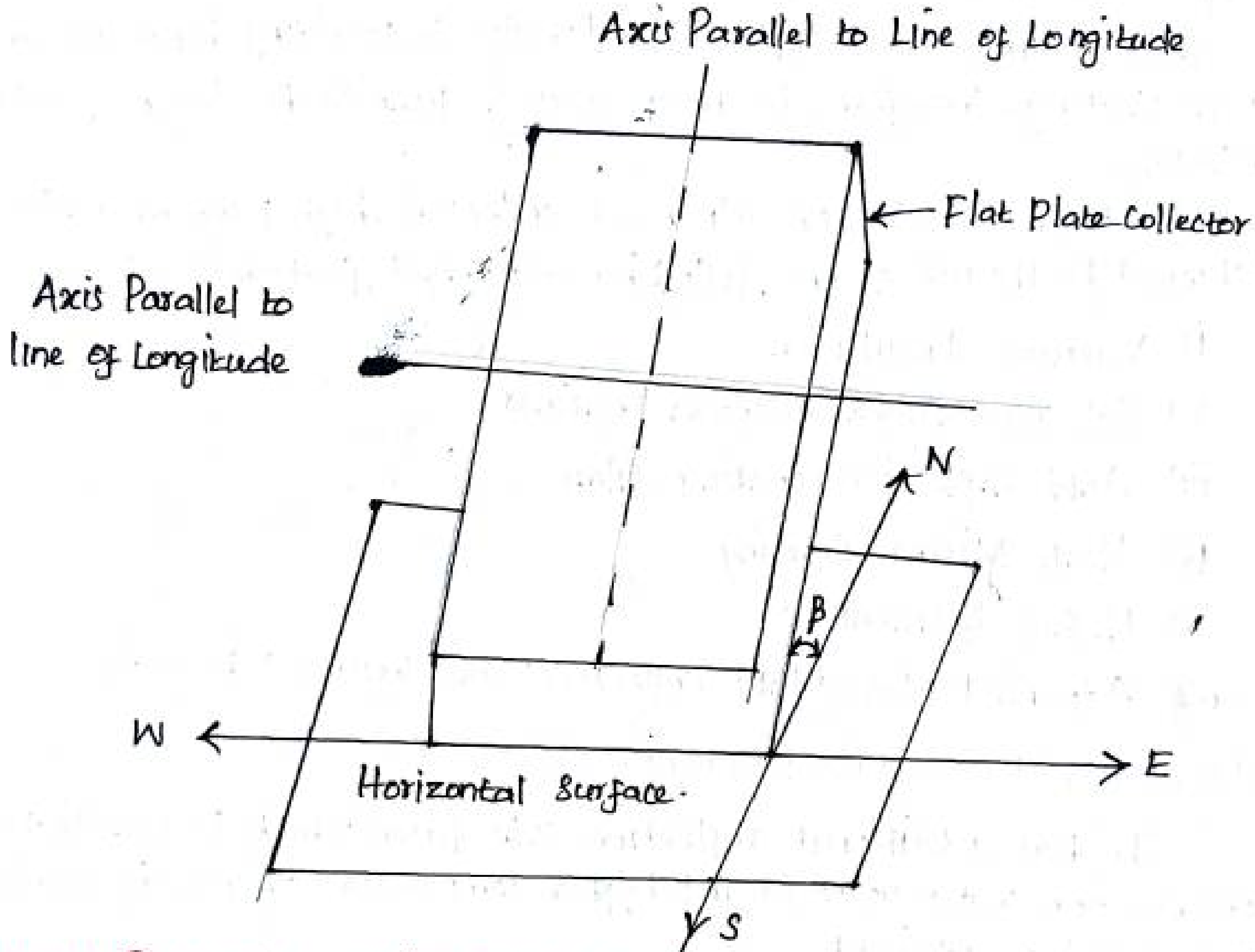


Fig.2. Positioning of Flat plate Collector

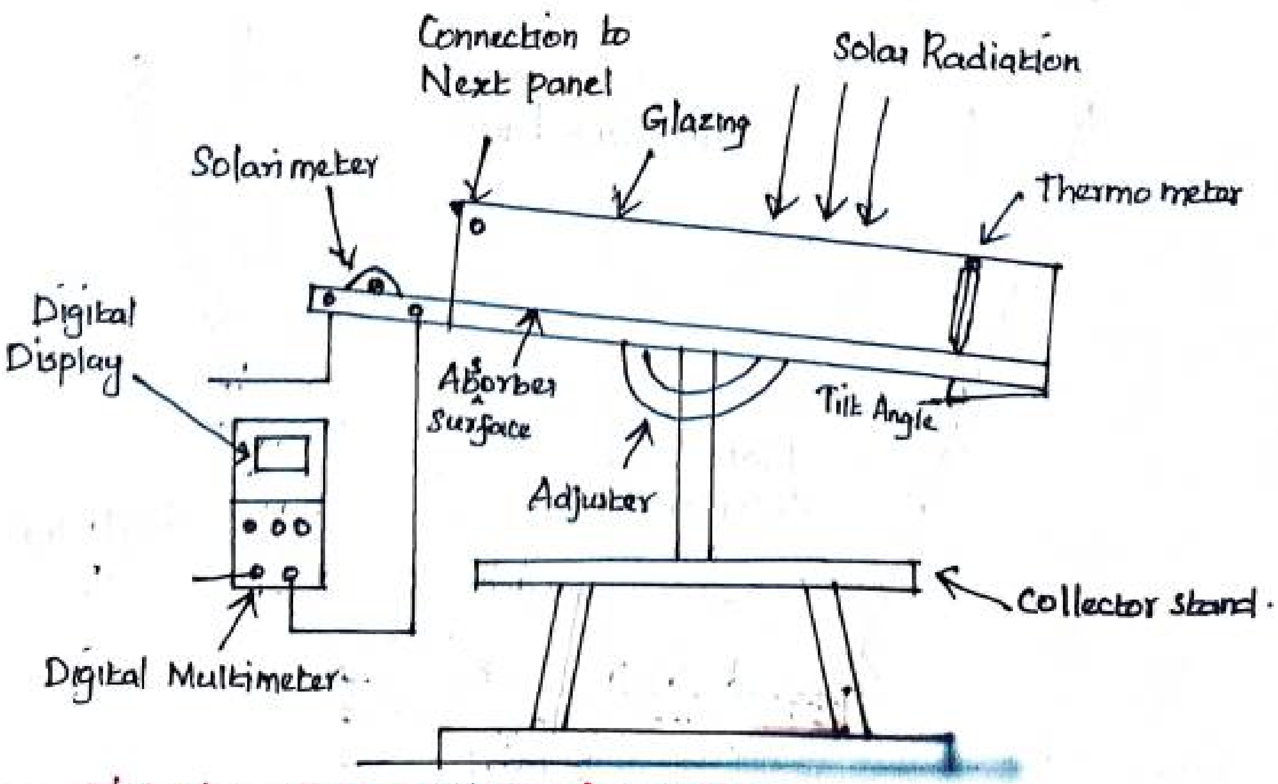


Fig.3. Flat plate Solar Collector Arrangement.

ADVANCED FLAT PLATE COLLECTORS

The disadvantage of the conventional flat plate collector is its stability to operate with reasonable collection efficiencies at temperature around 80°C.

Thus, it limits their applications largely for providing hot water and space heating. Therefore, the main focus is given to the design of solar collector.

- In these tubular or advanced collectors, high performance is achieved by the use of the following advanced features such as

i) Vacuum Insulation

ii) Selective Black Absorber Coatings

iii) Anti-reflective Coating films

iv) Heat Mirror Coating

v) Highly Efficient

Some Advanced Flat plate Collectors are discussed below.

1. MODIFIED FLAT PLATE COLLECTORS

It has additional reflective side faces which provide higher concentration ratio up to 10 and higher temperature of working fluids (up to 200°c) is achieved.

~~The different optimum depth~~

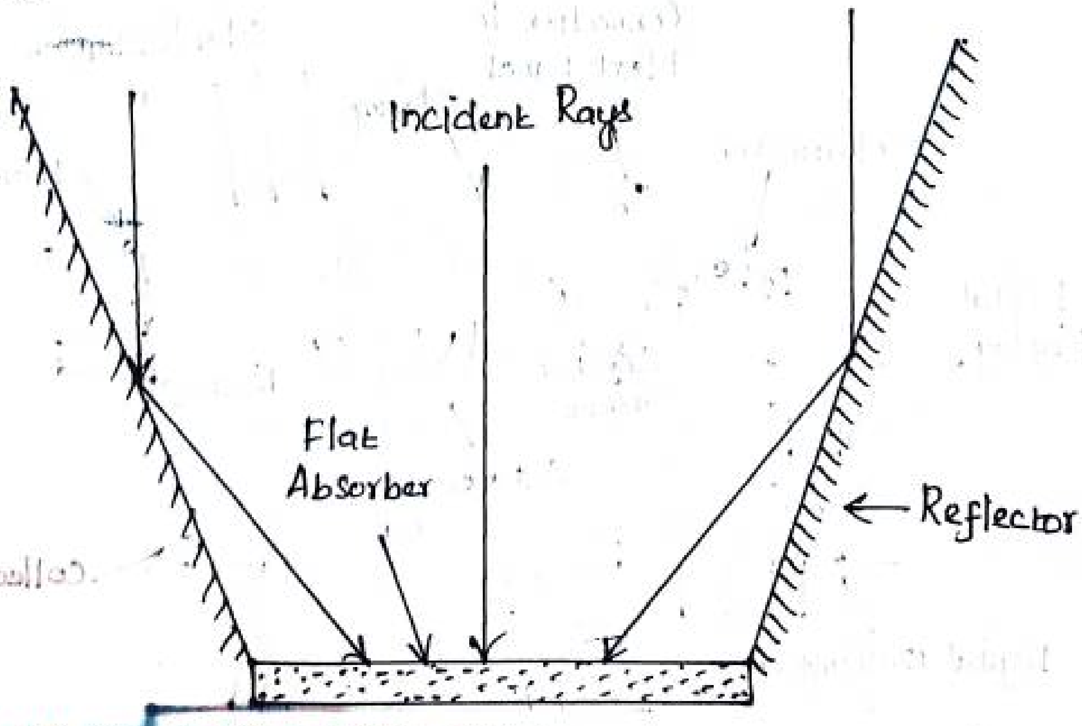


Fig. 1. Modified Flat Plate Collector

Such a design is aligned in East-West direction and it requires a Periodic tilt adjustment.

- The different optimum depth to base width ratios and cone Angles are possible depending on the frequency of Seasonal tilt Adjustment

2. SOLAR AIR HEATERS

Fig. 2 shows a Schematic diagram of Solar Air heaters where an air stream is heated by the backside of the collector plate.

- Fins attached to the plate increase the Contact Surface. In this, the back side of collector is heavily insulated with Mineral Wool or Some other material.

* The favourable inclination Angle to the horizontal is 15° for heating.

TYPES :

Basically, Air heaters are classified into following two types.

1. Solar Air heater with Non-Porous Absorber.
2. Solar Air heater with Porous Absorber.

In a Non-Porous type, the air stream doesnot flow through the absorber plate. Air may flow above the Absorber plate.

In a porous type, the absorber includes silt and expanded metal, transpired honey comb and over-lapped glass plate Absorber.

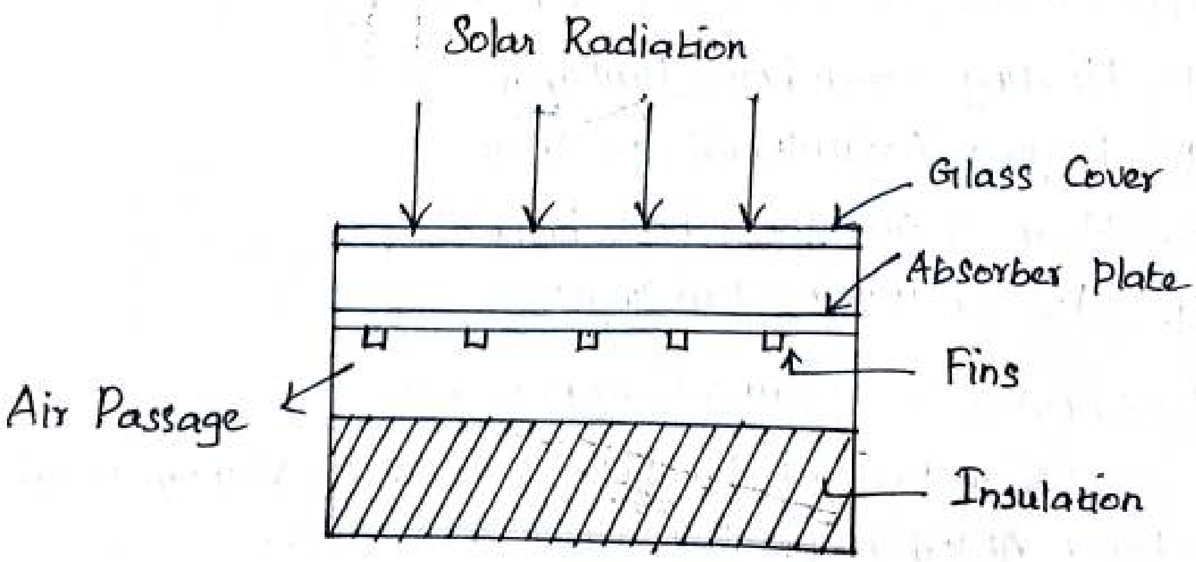


Fig. 2. Typical Solar Air Heater

The performance of air heaters is improved by the following ways:

1. Roughing the rear of the plate to promote turbulence and improve the Convective heat Transfer Coefficient (or)
2. Increasing the Heat transfer Surface by adding Fins.

Advantage of Solar Air Heaters :

1. It is Compact, simple in construction and it requires little maintenance.
2. The need to transfer thermal Energy from the working fluid to another fluid is eliminated as air is used directly as the working fluid
3. Corrosion is Completely eliminated.
4. Leakage of air from the duct is less Severe.
5. Possibility of Freezing of working Fluid is also eliminated
6. The pressure inside the Collector does not become Very high

Disadvantages of Solar Air Heaters :

1. A large amount of fluid is to be handled due to low density.
2. Heat transfer between the Absorber plate and Air is poor.
3. There is less Storage of thermal Energy due to low heat Capacity
4. In the absence of proper design, the cost of an air heater can be very high.

Applications of Solar Air Heaters :

1. Heating Green house Buildings
2. Drying Agricultural products
3. Heat Source for a heat Engine
4. Air-Conditioning Buildings.

3. EVACUATED TUBULAR COLLECTOR :

In an Evacuated Tubular Collector, the Vacuum is created between Absorber and Transparent Glass Cover.

- The Cross-Sectional View of a Solaron type of Evacuated Tubular Collector is Shown in figure. 3.

In this type, the tube cover above the selective surface is evacuated and evacuated tubes are arranged above the absorber surface

- So that there should not be any space left between consecutive tubes. The evacuated tubes provide a vacuum layer above the absorber to reduce the top loss efficient.

* The vacuum layer suppresses the convection heat loss from the absorber to glass cover. Similar to the flat plate collector, an incident solar radiation is absorbed by absorber surface after transmission through the glass cover and transparent evacuated tubes.

- After absorbtion, most of the available thermal energy at the absorber will be first conducted and then it is convected to the working fluid below the absorber.

Rest of the energy is lost by radiative heat loss. Further, there will be convective and radiative heat losses from the upper portion of the evacuated tubes to the glass cover.

* Since the temperature of the upper portion of the evacuated tubes will be small, there will be less heat losses. The working fluid may be either a liquid or air.

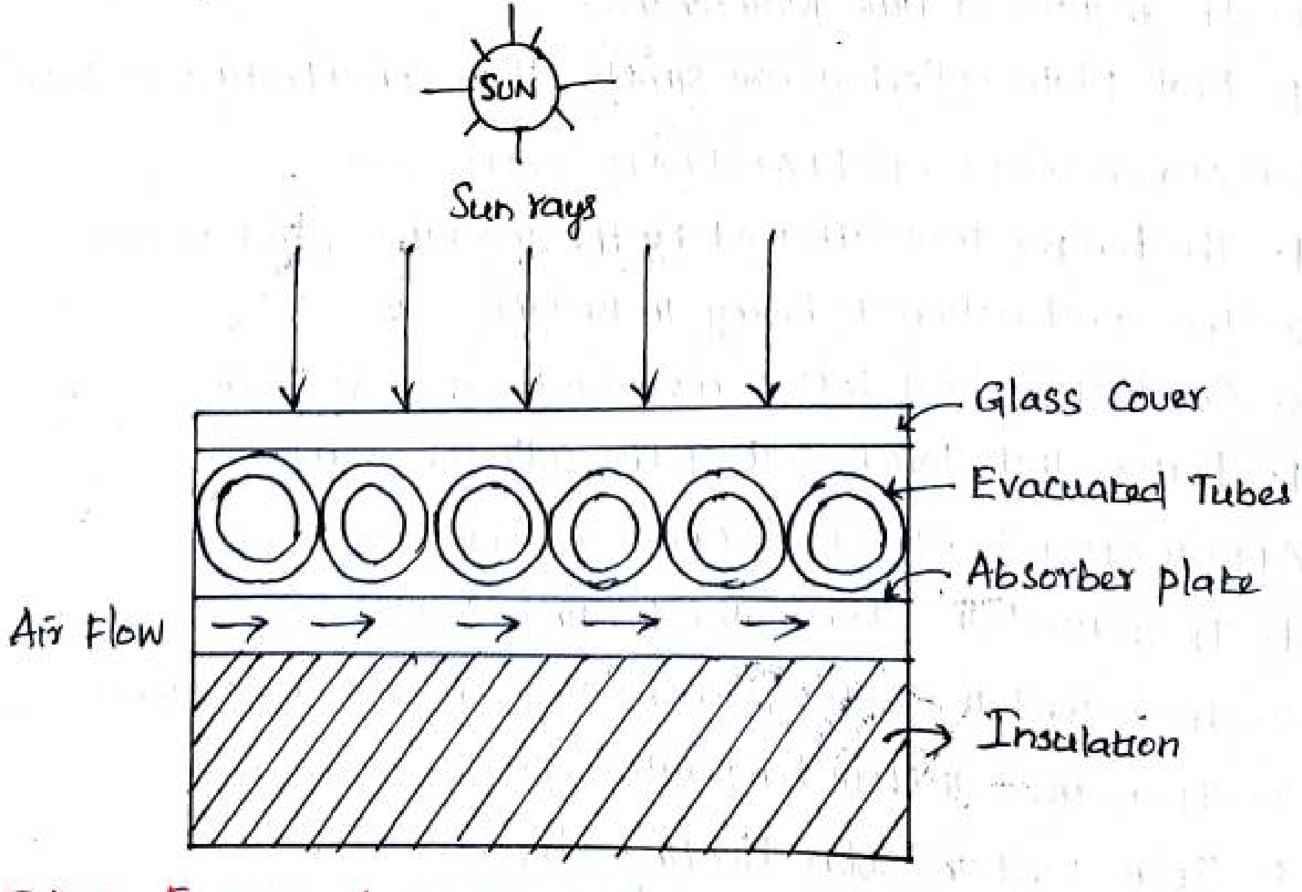


Fig. 3. Evacuated Tubular Collector.

Solar Concentrators may also be classified on the basis of optical Components.

a) Reflecting or Refracting type collector

b) Imaging or Non imaging type collector.

c) Line focusing or point focusing type collector.

Based on the Number of Concentrating Collector geometrics, the solar concentrators may be classified

a) Parabolic trough collector.

b) Minor Strip Reflector

c) Fresnel Lens Collector

d) Flat plate Collector with adjustable Mirrors

e) Compound parabolic Concentrator (CPC)

1. PARABOLIC TROUGH COLLECTOR

It is the most preferable type of a Concentrating Collector. the cross Section of Parabolic Collector is Shown in fig. 1(a).

- the Solar Radiation Coming from the particular direction is Collected over the area of the reflecting Surface and Concentrated at the focus of the Parabola.

* The Solar Radiation is focused along a line. It consists of a Cylindrical parabolic Reflector and a metal tube Receiver at a focal plane as shown in fig. 1(b).

- the dimension of Parabolic trough Collector can be Varied over a wide range. The length of a reflector unit may be roughly 3m to 5m and the width about 1.5 m to 2.4m.

Ten or more Such units are often Connected end to end in a row. Several rows may also be connected in parallel.

* A Parabolic trough Collector with line focusing reflecting Surface / Provides the Concentration ratio from 5 to 30. Hence, higher temperature upto 300°c can be achieved. It have been made of highly polished Aluminium of Silvered glass or thin film of aluminized plastic on a firm base.

SOLAR CONCENTRATING COLLECTOR (FOCUSING TYPE)

Focusing collector is a device to collect Solar Energy with high intensity of Radiation on the energy absorbing Surface.

- It is a special form of flat-plate Collector modified by introducing a reflected surface (concentrator) between Solar Radiation and absorber.

* It uses the optimal System in the form of reflectors or refractors for Concentrating the incident Solar Radiation. It results in an increased flux density on the absorber Surface area.

- In these collectors, the radiation falling on a relatively large area is focused on to a receiver of considerably smaller area. In order to get a maximum Concentration an arrangement for tracking the sun's virtual motion is required.

An accurate focusing device is also required. Thus a Solar Concentrator Consists of a i) focusing device ii) Receiver System and iii) tracking Arrangement.

* As a result of the energy concentration, fluid can be heated to the temperature of 750°c or more. Hence, they have the potential applications in both thermal and power generation (electrical power) at high delivery temperature.

The main difference between flat plate collector and Concentrating Collector is that the flat-plate collector Concentrates only the direct radiation coming from a specific direction whereas the Concentrating collector Collects all types of Radiation.

TYPES OF CONCENTRATING COLLECTORS

Solar Concentrators may be classified on the basis of whether tracking System is Installed or not and type of tracking system installed.

a) Tracking ~~System~~ Type : Continuous or Intermittent.

i) One-axis design

ii) Two-axis design

b) Non-tracking Type :

FACTORS AFFECTING PERFORMANCE OF FLAT PLATE COLLECTORS

1. Incident Solar Radiation falling on the solar collector
2. Number of Cover plates
3. Slope of the flat plate Collector which is tilted at an angle of longitude of the location.
4. Absorbing Surface of the Collector which should withstand high temperature and Corrosion Resistant.
5. Spacing between absorber plate and cover plate. Internal heat loss can be prevented by providing more space
6. Inlet temperature of the working fluid.
7. Dust deposited on the cover which should be minimised to obtain high Efficiency.

ADVANTAGE OF FLAT PLATE COLLECTORS :

1. It has the advantages of using both beam and diffuse solar Radiations
2. It does not require orientation towards the Sun.
3. It requires a little Maintenance
4. Flat plate Collectors are simpler than Concentrating Collectors.

DISADVANTAGES OF FLAT-PLATE COLLECTORS :

1. The temperature attained by the working fluid is Low.
2. The Construction is heavy in Weight
3. Conduction heat Loss is more as the area is Large
4. Initial Installation cost of the collector is more.

APPLICATIONS OF (FLAT-PLATE COLLECTORS) :

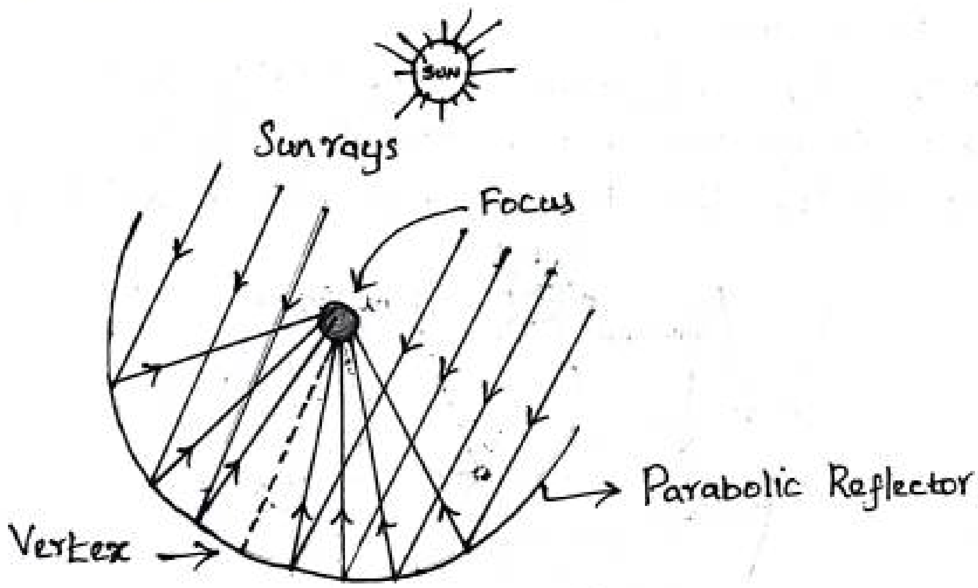
1. It is used in Solar water heating Systems
2. It is used in Solar space heating and Cooling Systems.
3. It is used in Low temperature power Generation
4. It is used in Solar Heating dryers.

The reflected light is focused on a central line of the parabolic trough collector. The tube located along the centre line absorbs the heat and the working fluid is circulated through the pipe.

– The absorber tube may be made of mild steel / copper. A cylindrical parabolic trough may be oriented in any of three directions; East-West, North-South or polar

* Trough type collectors are generally oriented in the East-West or North-South directions. The North-South orientation permits more solar energy to be collected than East-West Arrangement.

a)



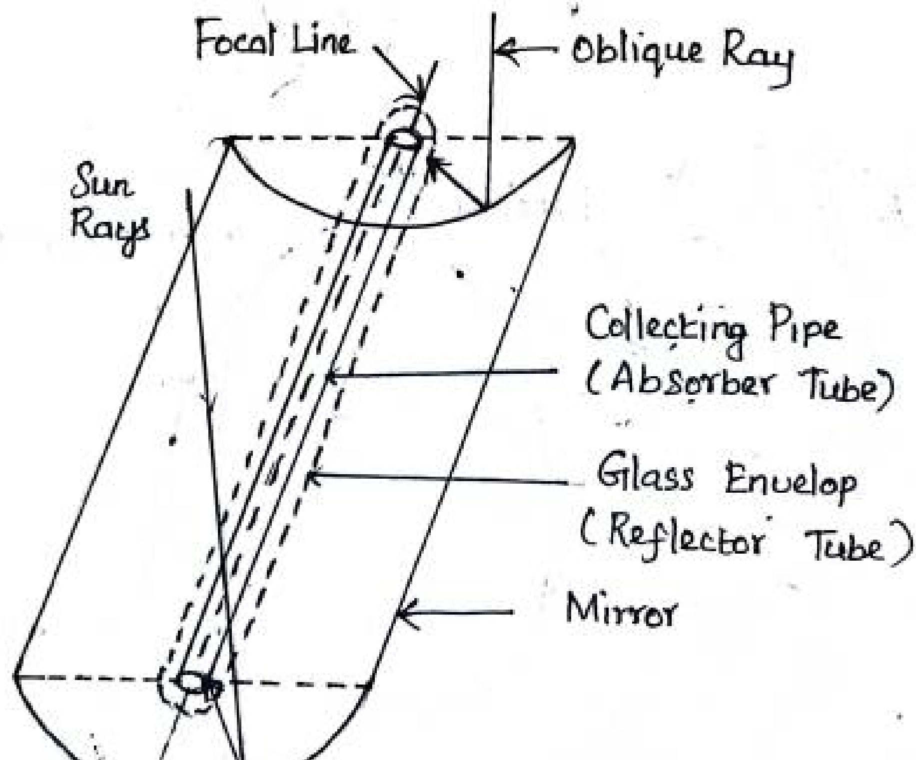


Fig.1. Cross section of Parabolic trough Collector.

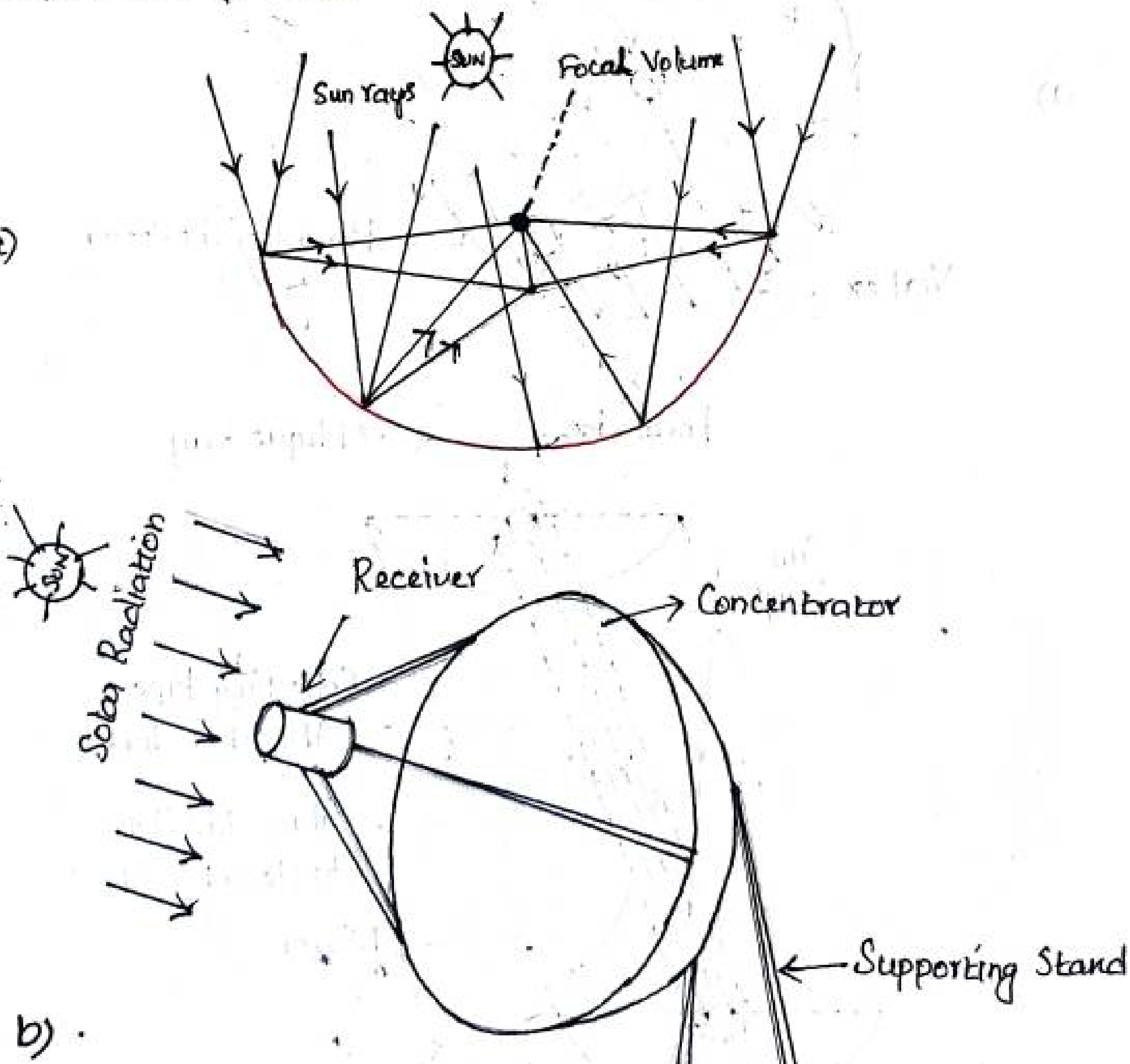
2. PARABOLIC DISH COLLECTOR :

A Parabolic dish Collector brings Solar Radiation to a focus at a Point, actually a Small Central Volume as Shown in fig. 2 (a). A dish (Concentrator) 6.6 m diameter as shown in fig. 2 (b) has been made from about 200 Curved Mirror Segments forming a Paraboloidal Surface.

– the absorber (Receiver) located at the focus is a Cavity made of Zirconium-Copper alloy with a black Chrome Selective Coating. The heat-transfer fluid flows into and out of the absorber Cavity through pipes bonded to the Interior.

* The dish can be turned automatically about two axes so that the Sun is always kept in a line with the focus and the base of the Paraboloidal dish. thus the Sun Can be fully tracked as required all times.

a)



b).

Fig. 2. Parabolic Dish Collector

3. MIRROR STRIP REFLECTOR

In this collector, a numbers of plane or slightly curved (concave) mirror strips are mounted on a flat base

- The angle of individual mirrors is arranged in such a way that they reflect solar radiation from a specific direction on to the same focal line as shown in fig. 3.

* The angle of the mirrors must be adjusted to allow the change in the Sun's elevation while the focal line remains in a fixed position.

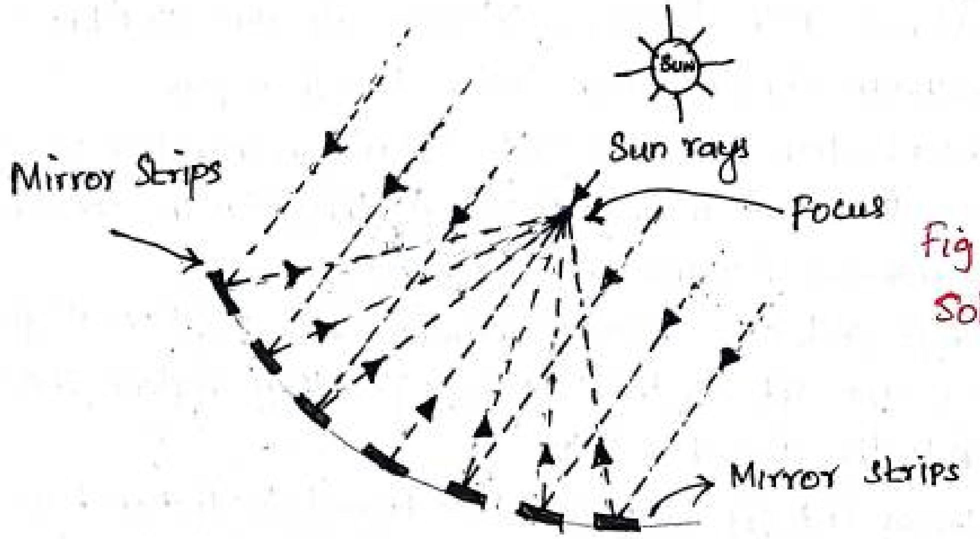


Fig. 3. Mirror strip Solar Collector

4. FRESNEL LENS COLLECTOR

It has a refracting type focusing collector. It utilizes the focusing effect of a Fresnel lens shown in fig. 4.

- To be fully effective, the fresnel lens must be continuously aligned with the Sun in two directions both along and perpendicular to its length.
- In the fresnel lens collector, the solar radiation is focused into the absorber from top rather than from bottom as in parabolic type.

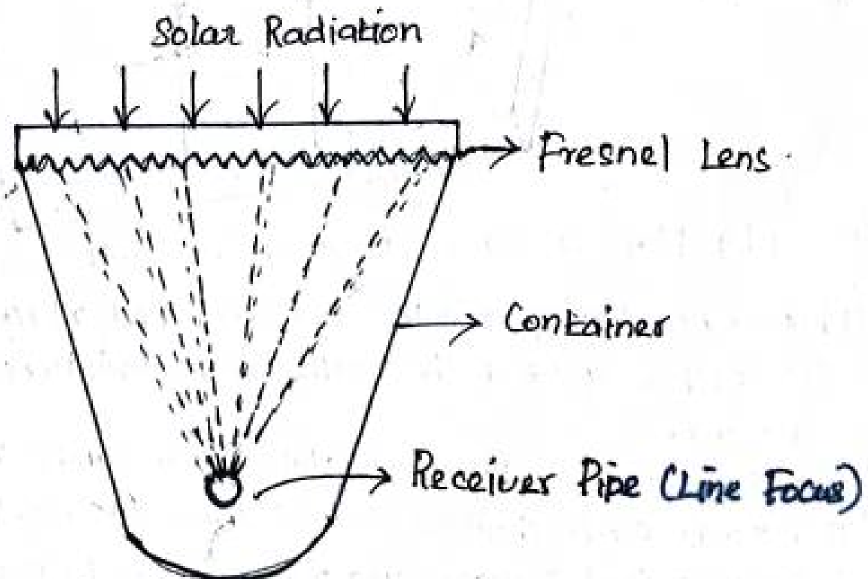


Fig 4. Cross Section of Fresnel Lens Collector

For a trough type collector, the lens is rectangle about 4.7 m in overall length and 0.95 m width. It is made of Acrylic plastic and it can be probably produced in quantity at low cost.

5. FLAT PLATE COLLECTOR WITH BOOSTER MIRRORS :

It is the simplest type of concentrating collector. It consists of a flat plate facing South with mirrors attached to its North and South edges as shown in fig. 5.

- Reflectors reflect the total Radiation in addition to a beam Radiation incidence on the Receiver. Mirrors are also called 'boost Mirrors'. It has a Maximum Concentration Value less than four.

* The Concentration Ratio of such Solar Concentrators is relatively Low and hence it is not widely used. As the Solar Incidence Angle increases, the mirrors become less effective.

For a single collector, booster mirrors can be used on all four sides. If the mirrors are set at the proper angle, they reflect the solar Radiation on to the absorber plate.

- The mirrors cut off part of the scattered Radiation have reached the absorber plate and only a part of the scattered Radiation falling on mirrors will be reflected on to the absorber.

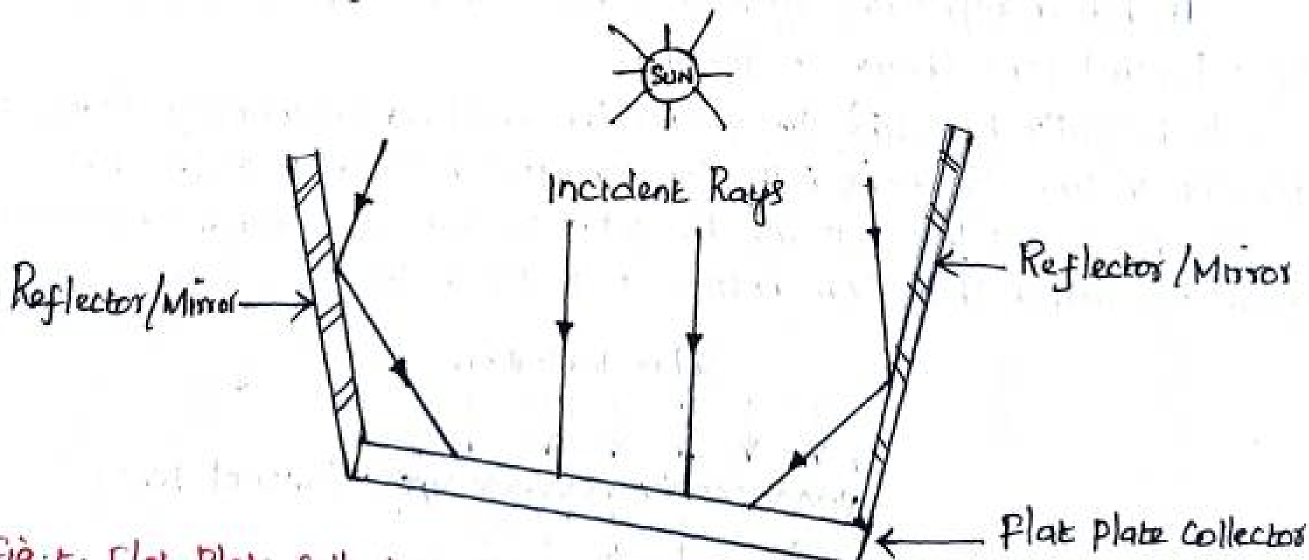


Fig. 5. Flat Plate Collectors arrangement with Reflector Mirrors.

When a number of collectors are combined in two or more rows, the rows must be set further apart in the North South directions to allow for the additional sun shading.

- The efficiency of a boost flat plate system can be increased if the angle of the flat mirrors can be changed several times during the year. The advantage of such system is that it makes use of the diffuse Radiation in addition to Beam Radiation

6. COMPOUND PARABOLIC CONCENTRATOR (CPC)

It is a Non-focusing type but the Solar Radiation from many directions is reflected towards the bottom of the trough

- Due to this Characteristic, a large proportion of the Solar Radiation including diffuse (Scattered) Radiation entering the trough opening is collected on a Small Area.

* A CPC with two facing Parabolic Mirrors is shown in fig 6. In addition to collecting both direct and diffuse Radiations, an advantage of this Collector is that it provides moderately good Concentration, although less than a focusing collector in an East-West direction without adjustment for Sun tracking.

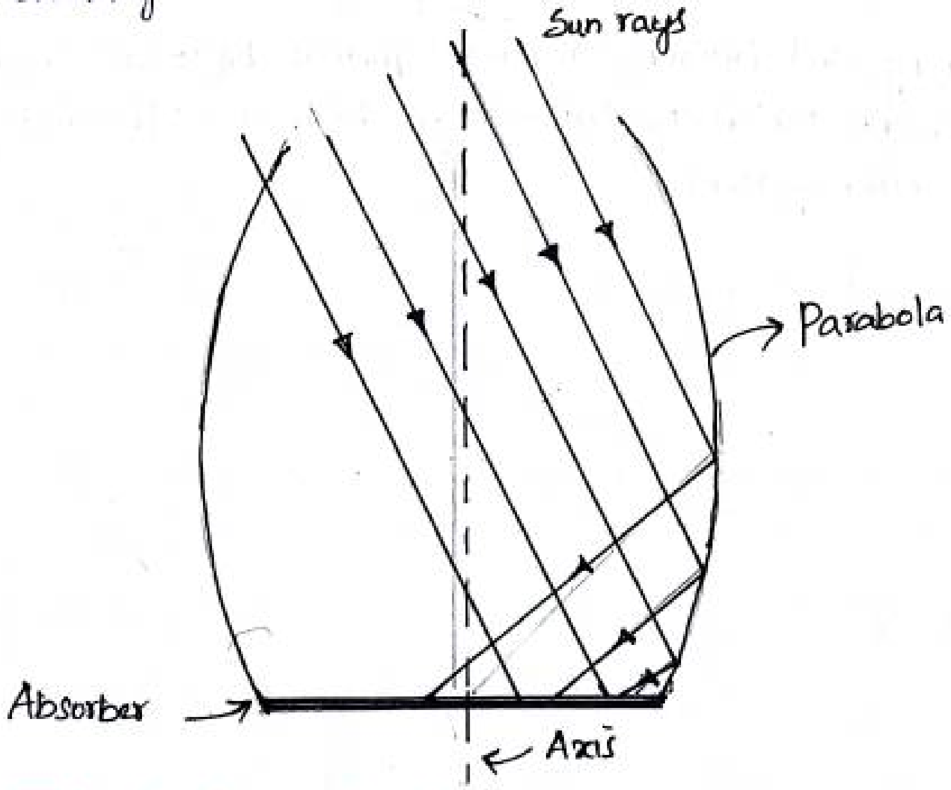


Fig. 6. Compound Parabolic Concentrator.

ADVANCED CONCENTRATING COLLECTOR SYSTEM

For Concentrating Solar Power (CSP) to be a Significant Contributor to Utility-Scale based load power, the Industry must achieve the drastic Cost Reductions and performance Increase.

- So the heavy glass Mirrors can be replaced with long-lasting reflective films Supported by a Light weight and rigid Structure.

It can be done in the following ways such as

i) Developing a new set of technology elements including advanced Reflective films, optically Accurate Reflector panels, Low cost space frames, Adaptive optics and Accurate Tracking drives.

ii) Designing and building a Large-format heliostat design with these new elements which are Suitable for high and Ultra high Concentrating Power Tower Systems.

THERMAL ANALYSIS, PERFORMANCE, EFFICIENCY AND OUTLET FLUID TEMPERATURE OF FLAT PLATE COLLECTOR

1. THERMAL ANALYSIS OF FLAT-PLATE COLLECTOR :

When a body is Subjected to Solar Radiation of Intensity I It is Partially absorbed by the body and the remaining is partially transmitted and rest reflected.

- As per the heat transfer Concept, the Sum of absorbed, transmitted and reflected energy is equal to Unity

$$\alpha + \tau + \rho = 1$$

Where,

α - Absorption Coefficient

τ - Transmission Coefficient

ρ - Reflection Coefficient.

The absorption part of energy is used for increasing the temperature of the body. But a portion of the energy is lost by Conduction, Convection and Radiation.

- Let us assume for thermal Analysis purpose, Conduction and Convection losses are negligible. So,

Absorbed energy due to Solar Radiation $= \alpha I$

Energy lost due to Radiation $= \varepsilon \sigma T^4$

Where, ε - Emission Coefficient of a Flat plate

σ - Stephen Boltzman's Constant

T^4 - Absolute Temperature on a Flat plate.

For thermal Equilibrium.

$$\alpha I = \varepsilon \sigma T^4$$

This Equation Can be rewritten by Re arranging the Coefficient as

$$\frac{\alpha I}{\varepsilon} = \sigma T^4$$

This equation can be rewritten by including the diffuse Radiation absorption and Convective losses as follows.

THERMAL ANALYSIS OF A CYLINDRICAL PARABOLIC CONCENTRATING COLLECTOR

The analysis of Performance of Concentrating Collector Systems is done by energy Balance.

- The useful energy gain by Parabolic cylindrical collector is given by

$$q_u = \frac{H_b R_b \rho \gamma (\tau \cdot \alpha) A_a}{A_a} - \frac{U_L A_r (T_r - T_a)}{A_a}$$

Where, q_u - Useful Heat gain per unit Aperture Area

$H_b R_b$ - Beam Radiation intensity on a Reference Surface.

ρ - Specular Reflectance of the Reflector Surface

γ - Intercept Factor.

$\tau \cdot \alpha$ - The effective Product of Transmittance and Absorbance.

U_L - Overall heat loss Coefficient of the Collector.

T_r - Temperature of the Solar Receiver

T_a - Ambient Temperature

A_a - Effective Area of the Aperture.

A_r - Effective Area of the Receiver.

If the whole Receiver is at a uniform Temperature T_r then the total energy gain is given by

$$Q_u = H_b R_b \rho \gamma (\tau \cdot \alpha) \times A_a - U_L A_r (T_r - T_a)$$

Heat gain per unit Collector Length L is expressed by

$$q_u = \frac{A_a}{L} H_b R_b \rho \gamma (\tau \cdot \alpha) - \pi D_o U_L (T_r - T_a)$$

Where $$U_L = \left(\frac{1}{h_{wind}} + \frac{1}{h_r} \right)^{-1}$$

Here, $$h_{wind} = 5.7 + 3.8 V_1 \ W/m^2 \, ^\circ C$$

$$h_r = \frac{e_r (T_r^4 - T_a^4)}{T_r - T_a}$$

$$\sigma = 5.67 \times 10^{-8} \ W/m^2 \, ^\circ C = \text{Stefan - Boltzmann Constant}$$

4. COLLECTOR EFFICIENCY FACTOR (F′) :

The flat plate Collector Efficiency factor (F′) is defined as the ratio of actual rate of useful heat collection to the rate of useful heat collection rate when the collector absorpting plate (T_p) is placed at the Local fluid Temperature (T_{fi})

$$F' = \frac{Q_{useful}}{Q_u \text{ at } (T_p = T_{fi})} = \frac{Q_{useful}}{A_c(q_a - U_L(T_{fi} - T_a))}$$

$$Q_{useful} = F' A_c [q_a - U_L(T_{fi} - T_a)]$$

5. OUTLET FLUID TEMPERATURE OF FLAT PLATE COLLECTOR (T_{fo}) :

The Outlet Fluid Temperatures (T_{fo} at $x = L_r$) from a Flat plate Collector can be obtained as

$$T_{fo} = T_f \Big|_{x=L_r} = \left(\frac{q_a}{U_L} + I_a \right) + \left(T_{fo} - T_a - \frac{q_a}{U_L} \right) \exp\left[\frac{-A_c U_L F'}{m c_f} \right]$$

where, A_c - Collector Area

C_f - Specific Heat Capacity of the Fluid

L_r - Length of riser in the flow direction

6. COLLECTOR HEAT REMOVAL FACTOR (F_R)

Heat Removal Factor (F_R) of a flat plate Collector is defined as the Ratio of the Actual useful energy gain to the useful Energy gain.

It can be expressed as

$$F_R = \frac{m c_f (T_{fo} - T_{fi})}{A_c [q_a - U_L (T_{fi} - T_a)}$$

7. OPTIMUM INCLINATION OF FLAT PLATE COLLECTOR :

On the basis of a literature Survey, an optimum Inclination of the Surface receiving maximum Radiation for winter / Summer Condition is by

$$\beta_{optimum} = \phi \pm 15^\circ$$

where the positive sign refers to winter Conditions and Negative sign refers to Summer Conditions.

$$\alpha I + \alpha' I' = \varepsilon \sigma T^4 + h_c (T - T_a)$$

Where, h_c - Convective Heat Transfer Coefficient.

α' - Absorption Coefficient of diffuse Radiation.

I' - Intensity of diffuse Radiation.

T_a - Atmospheric Temperature.

2. PERFORMANCE OF FLAT PLATE COLLECTOR :

The performance of a flat plate Collector is described by an Energy balance Equation. It indicates the distribution of incident solar Energy into useful Energy gain and various losses.

- The useful thermal energy output (Q_u) per unit time of a flat plate collector of Area (A_c) is the difference between the absorbed solar Radiation q_a and thermal loss.

It is given by the Equation

$$Q_u = A_c q_a \qquad q_a = (\tau\alpha) I_p$$

$$Q_u = A_c [q_a - U_L (T_{fi} - T_a)]$$

Where,

U_L - Overall Heat loss coefficient of the collector.

T_{fi} - Inlet Temperature of the Fluid

I_p - Intensity of Solar Radiation on the Collector Surface.

$(\tau\alpha)$ - Effective product of transmitivity of the transparent Cover and Absorptivity of absorber Surface of the Collector.

3 INSTANTANEOUS EFFICIENCY OF FLAT-PLATE COLLECTOR

The thermal Instantaneous Efficiency (η) of a flat plate collector is given by the equation

$$\eta = \frac{Q_u}{A_c I_p} = \frac{q_u}{I_p} = \frac{U_L (T_{fi} - T_a)}{I_p}$$

The overall thermal collection Efficiency of a flat-plate Collector (the ratio of the daily useful gain to the daily incident solar Energy) is given by

$$\eta_c = \frac{\int Q_u \, dt}{A_c \int I_p \, dt}$$

The collector Efficiency is given by

$$\eta_c = \frac{Q_u}{H_b R_b}$$

where

$$Q_u = F_R A_a \left[S - \frac{A_r U_L}{A_a} (T_{fi} - T_a) \right]$$

$$F_R = \frac{\text{Actual gain}}{\text{Gain if collector Surfaces were at Inlet Temperature } T_{fi}}$$

$$= \frac{m C_p}{A_r U_L} \left[1 - \frac{\left(T_{fo} - T_a - \frac{A_a}{A_r} \frac{S}{U_L} \right)}{\left(T_{fi} - T_a - \frac{A_a}{A_r} \cdot \frac{S}{U_L} \right)} \right]$$

where

L - Collector Length

W - Width of the collector

U_L - Heat Transfer Coefficient

T_a - Ambient Temperature

T_{fi} - Inlet Temperature of the working Fluid.

T_{fo} - Outlet Temperature of the Working Fluid.

S - Absorbed Radiation per unit Area of Unshaded Aperture

$$S = H_b R_b \eta_{opt}$$

$$\eta_{opt} = \rho \gamma (\tau \cdot \alpha)$$

$$U_L = \frac{1}{\frac{h_i D_i}{D_o}} + \left(\frac{\ln \frac{D_o}{D_i}}{\frac{2k}{D_o}} \right)$$

Where,

T_a - Ambient Temperature

T_f - Fluid Temperature

K - Thermal Conductivity of the Tube material

$$A_a = W \cdot L$$

$$A_r = \pi D_o L$$

D_o - Outer Diameter

D_i - Inner Diameter.

Parabolic trough Collector :

In thermal Steady State, the maximum Temperature of Receiver (T_r) in K can be Calculated using the following equation

$$T_r = \sqrt[4]{\frac{\rho \alpha I_D}{\varepsilon \sigma \phi_s}}$$

Where,
ρ - Specular Reflectance of the Reflector Surface
α - Reflector Absorbance
I_D - Direct Solar Radiation in W/m^2
ε - Reflector Emittance.
$\sigma = 5.67 \times 10^{-8} \, W/m^{2\circ}C$ - Stefan-Boltzmann Constant

$$\phi_s = \frac{R_s}{L}$$

R_s - Solar disk Radius $= 0.695 \times 10^9 m$.
L - Mean Distance between the Sun and Earth $= 1.495 \times 10^{11} m$.

Parabolic dish Collector :

The temperature of the Receiver of Parabolic dish collector (T_r) in K Can be Calculated using the following Equation

$$T_r = \sqrt[4]{\frac{3 \rho \alpha I_D}{8 \varepsilon \sigma \phi_s^2}}$$

The notations remain Same as the Case of Parabolic trough collector.

SOLAR THERMAL POWER GENERATION

Solar thermal power generation employs power cycles which are broadly classified as follows

1) Low Temperature Cycles
2) Medium Temperature Cycles
3) High Temperature Cycles.

Low Temperature cycles generally use Flat-plate Collectors so that maximum temperatures are limited to about 100°c

- Medium Temperature Cycles work at Maximum temperature ranging from 150° to 300°c
- While High Temperature Cycles work at temperature above 300°c.

* For Low and Medium Temperature ranges, the thermodynamic cycle prefered is Rankine cycle.

For High Temperature range apart from Rankine Cycle, Brayton and Stirling Cycles are also being considered.

LOW TEMPERATURE THERMAL POWER GENERATION USING FLAT PLATE COLLECTOR :

The Flat plate collector System and Solar Pond are classified as Low Temperature Collectors. because of its temperature range in the order of 60° to 100°c with Collection efficiency of 30 to 50%. Maximum

- In this System, it is not suitable to employ Rankine cycle Solar thermal power production System because the generation of steam using Flat plate collector or Solar Pond is not possible as the boiling Temperature of the water is more than 100°c.

* So it cannot be used directly to run the prime mover. Therefore, Some other organic fluid (Commonly Freon group) is used which evaporates at Low temperature and high pressure by absorbing the heat from the heated water.

The Vapour formed can be used to run a turbine or Engine which may generate power which will be sufficient to Light the group of hours etc for Rural Areas and for irrigation purposes.

A low temperature Solar Engine using heated water from flat-plate Solar Collector and butane as the working fluid is shown in fig.1.

- The System has array of Flat-plate Collectors to heat water up to nearly 70°C. In the heat Exchanger, the heat of water is transferred to butane for boiling it.

* The high Pressure butane Vapour runs a butane Turbine which operates an electric generator. This generator produces electrical power output for further use.

- The exhaust butane Vapour from butane turbine is Condensed in a Condenser with the help of Fresh cold water circulated by a water pump. This Condensate is fed to the heat Exchanger or Butane Boiler.

The System is applied for Small power plants of about 10 KW Capacity. It has the advantage of Simplicity.

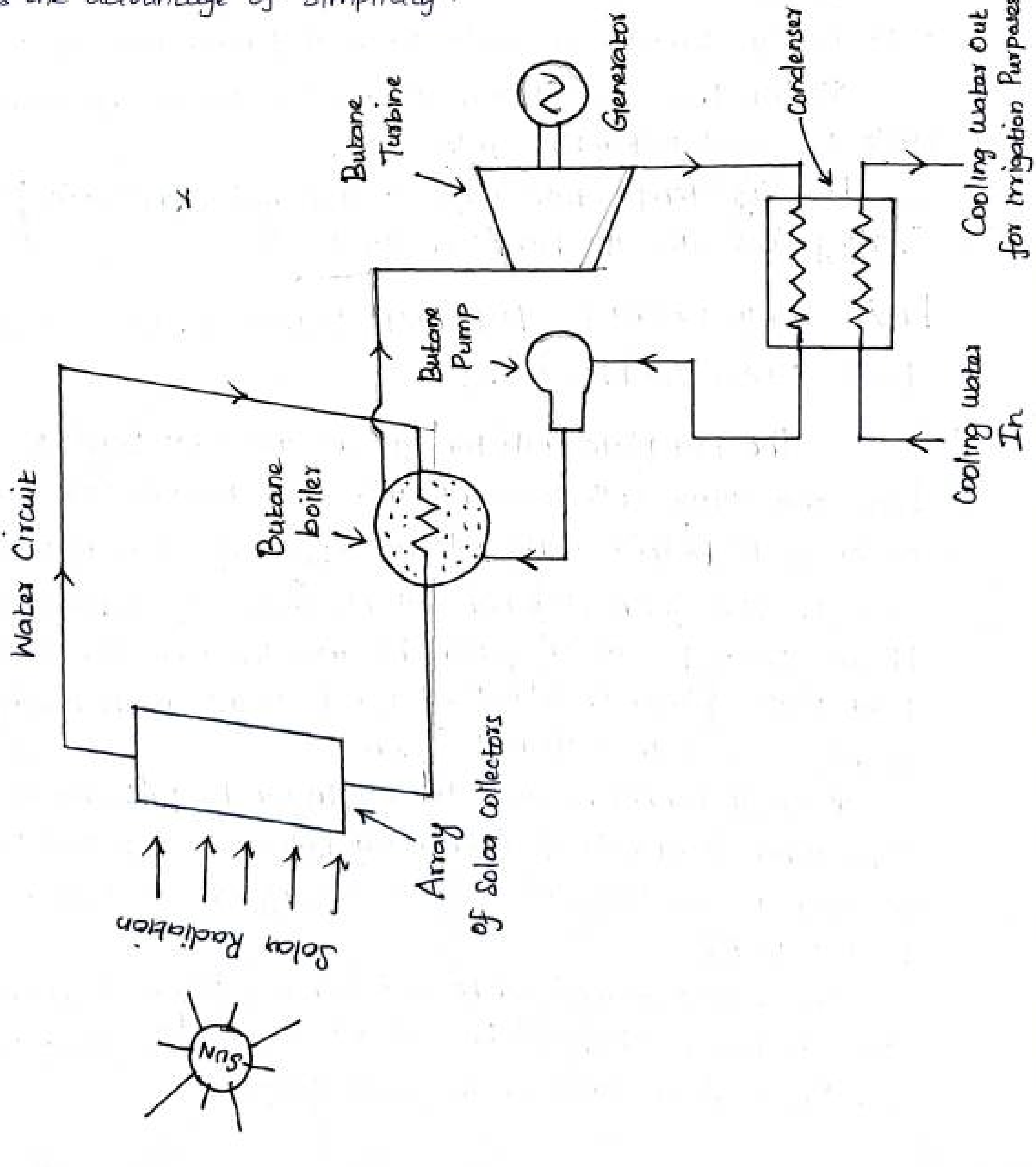


Fig.1. Low Temperature Flat-plate Solar collector.

MEDIUM TEMPERATURE THERMAL POWER GENERATION USING SOLAR DISTRIBUTED COLLECTOR

Medium Temperature thermal power generation systems employ Solar distributed collectors in which parabolic trough Concentrator Collectors with line focus are most commonly used for converting the solar Energy into Heat Energy.

- These Systems can also use paraboloid dish type concentrating collectors. Cylindrical parabolic Concentrating Collectors generate temperature in range of 250° to 700°c with efficiency of 50-70%.

* High Temperature collectors such as paraboloid type concentrators consists of many flat mirrors produce a temperature in range of 600-2000°c with an Efficiency of 60-75%.

this is a modular system consisting of a dish shaped parabolic collector for focusing the solar Radiation on a Receiver to heat a working fluid coupled with a power generation unit (Engine / Alternator) for electricity generation.

- Following types of heat Engines are commonly being used with Parabolic dish / trough systems:

i) Rankine Cycle Engine
ii) Organic-Rankine Cycle Engine
iii) Stirling Cycle Engine
iv) Air-Brayton Cycle Engine

In each of these cycles, hot gas or vapour is expanded through an Engine or turbine to produce work and it is thereby cooled.

the gas or vapour is further cooled to reject heat and it is finally returned to its initial state for getting energised by Solar Radiation and thus completing the cycle.

* In a distributed collector system, the Solar thermal Energy is collected from a large number of sun-tracking solar parabolic trough type or parabolic dish type cylindrical collectors.

Each collector transfers heat to a heat-transfer fluid. This heat transporting fluid available at high temperature from the collectors is pooled at some central power station.

the heat transfer fluid can be water / steam to be used directly in a steam turbine. A simple Parabolic concentrator Solar power generation system using water as working fluid is shown in fig.2.

- It consists of a parabolic cylinder Reflector to concentrate Sunlight on to a collecting pipe within pyrex or Glass Envelop. A proper Sun-tracking arrangement is made so that the maximum sunlight is focused on the reflector for producing optimum Efficiency.

They usually operate in the Lower temperature ranges of about 90° to 315°c. In this system, oil having boiling point higher than the boiling point of water is used to circulate through the absorber tube of the Concentrator Collector.

* The heated oil is then passed through the heat Exchanger where the heat is transferred to the water to produce steam. the hot steam can then be directly used to power a turbine for mechanical work which is coupled to an electric generator to generate electricity.

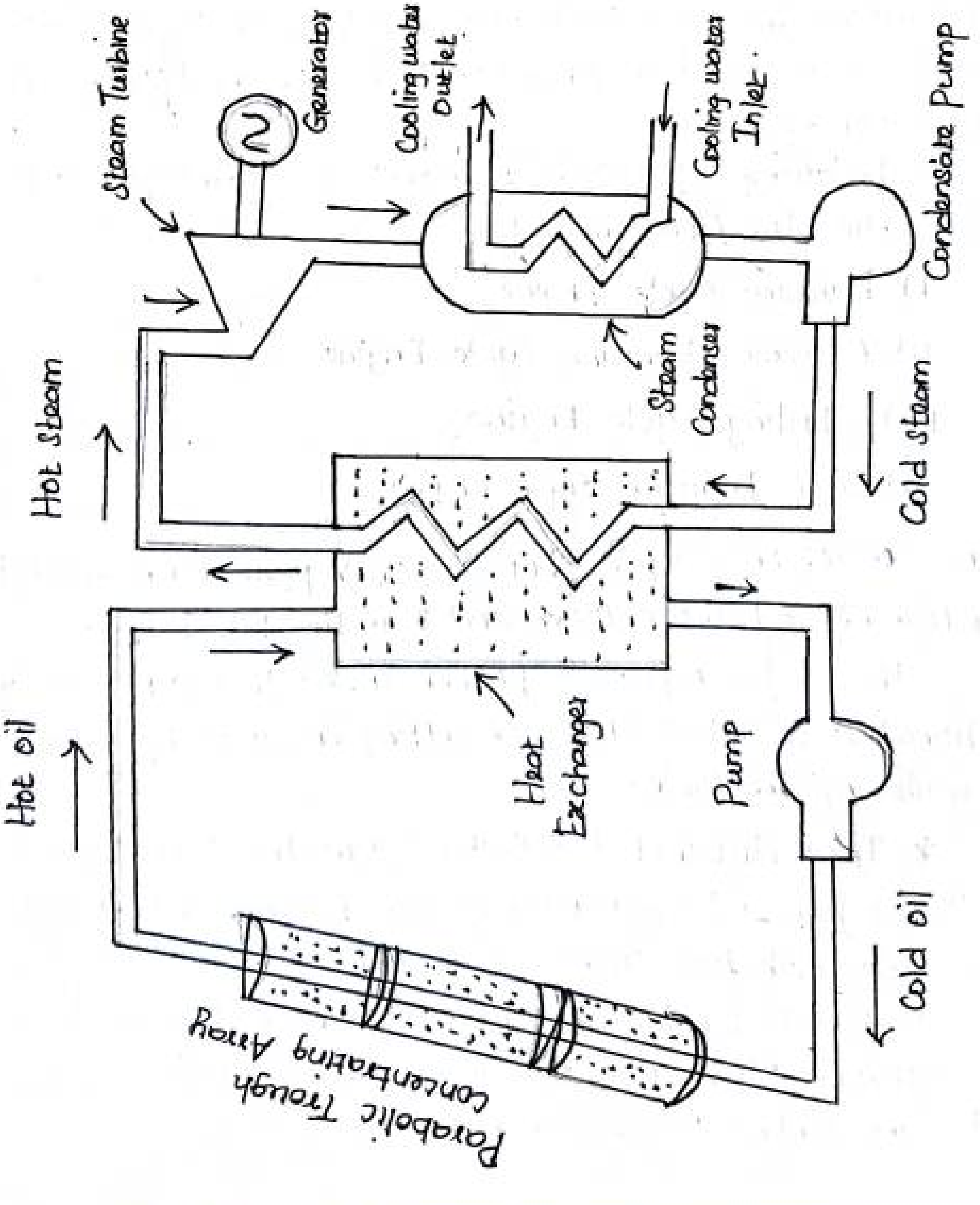


Fig.2. Distributed Collector Solar thermal electric Power plant.

The exhaust Low Temperature Steam from the turbine is Condensed in Condenser with the help of Fresh cold water Circulated by a water pump. This Condensate is fed to the heat Exchanger again using a Condensate pump.

HIGH TEMPERATURE THERMAL POWER PLANT GENERATION USING CENTRAL RECEIVER SYSTEM

A Large Solar thermal power plant in the range of 50 MW to 200 MW Comes under Central Receiver Schemes (CRS). Such Systems are economical in MW range for network Connected plants.

– The high Capacity is possible due to high Temperature Steam in the Central Receiver resulting high Efficiency of plants. In the Central Receiver Scheme, Several helistats are located on the ground Level.

* A helistat is a nearly flat mirror with the provision to track the Sun in two planes. The reflected rays are pointed ~~networ~~ towards a central Receiver mounted on a tall tower as shown in figure. 3

– A large Central Receiver plant is usually build up based on Modular Concepts. Each plant may have 2 modules to 10 modules and rated at 10 MW to 100 MW.

COMPONENTS OF CENTRAL RECEIVER SYSTEM

This System can be Subdivided into the following Subsystems. They are as follows:

1. The Tower with the Central Receiver on top of it
2. The Heat Conversion Sub system
3. The Heat Storage device
4. The Field of Oriented Mirrors

1. CENTRAL RECEIVER :

The Central Receiver at the top of the tower has a heat absorbing Surface by which heat-transport Fluid is heated.

– There are two basic Receiver Configurations as follows

a) Cavity Receiver Type

b) External Receiver Type.

In the Cavity Receiver Type, the Solar Radiation reflected by helistats enters through an aperture at the bottom of the Cavity whereas the absorber Surfaces are on the exterior of a roughly Cylindrical Structure in the External Receiver Type. fig. 4 Shows the cavity Receiver type Central Receiver.

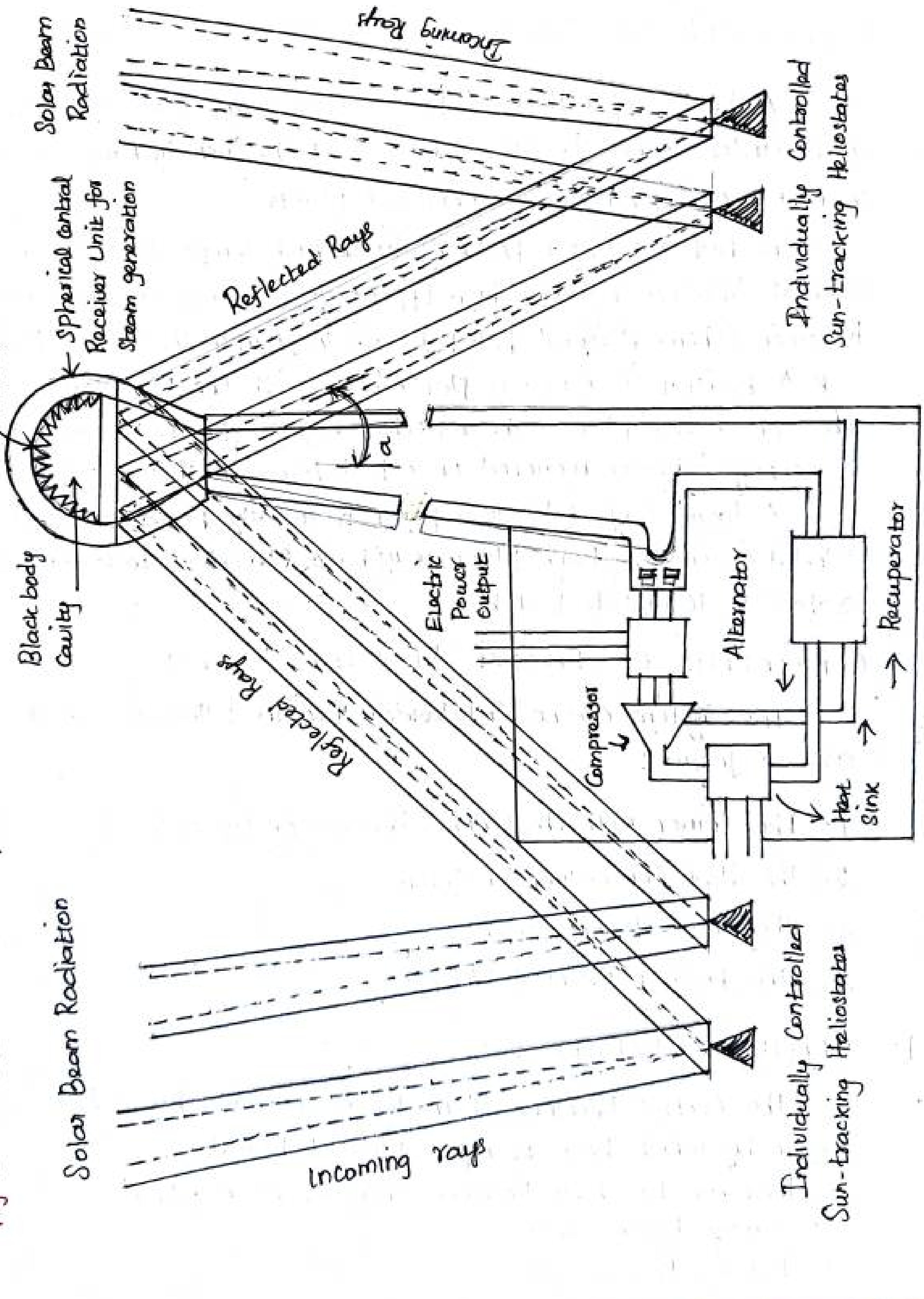


Fig. 3: Solar Central Receiver Power Generation System

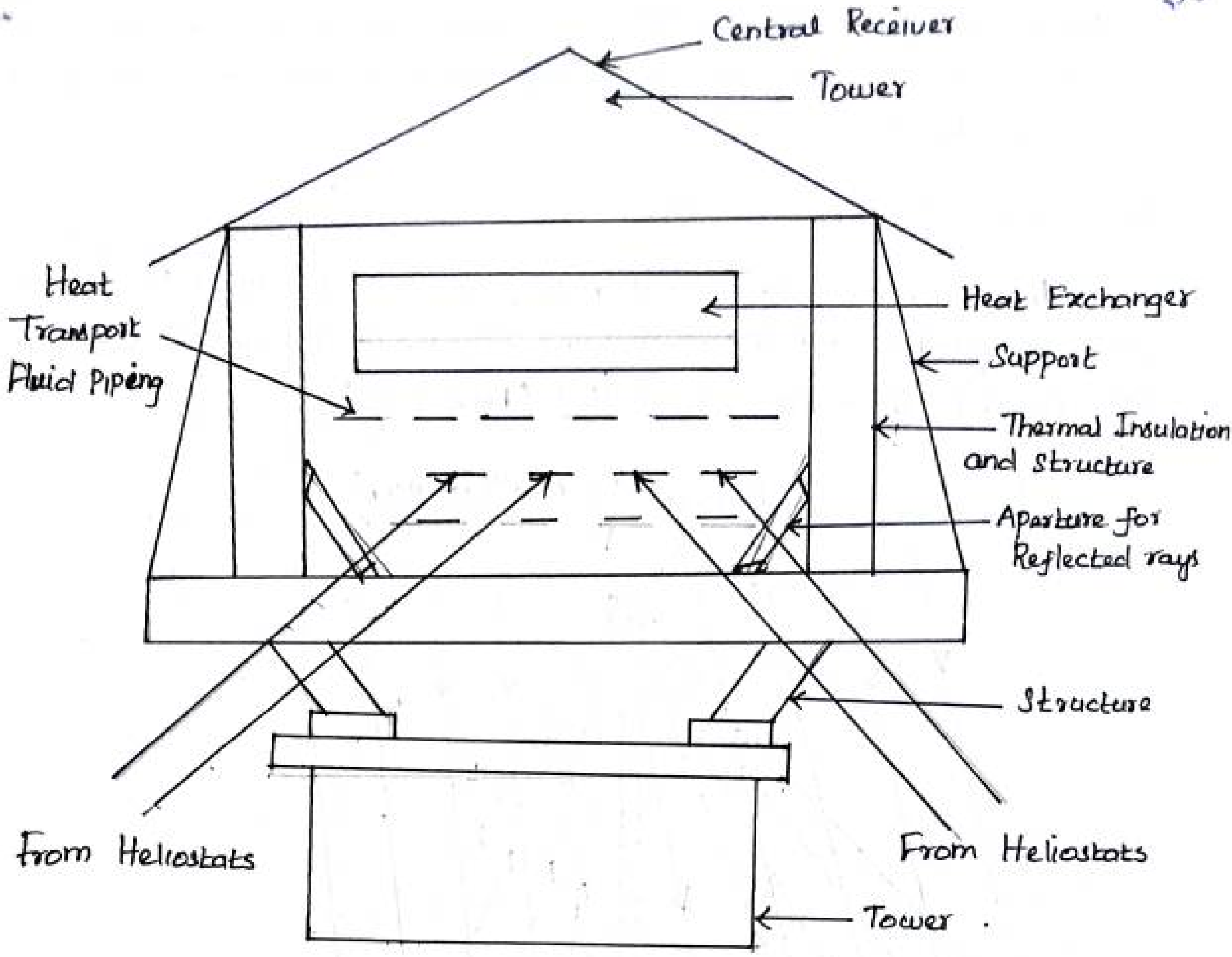


Fig.4. Central Receiver

2. HEAT CONVERSION SUB SYSTEM :

Liquid water under pressure enters the Receiver. Then the heat energy is absorbed by the water and it leaves as super heated steam.

- Typical steam conditions might be a temperature of 500°C and Pressure of 100 atm. The steam is piped to a ground level where it drives Conventional turbine generator system.

3. HEAT STORAGE DEVICE :

Short term storage of heat can be provided by fire bricks, ceramic oxides, fused salts and sulphur.

- The choice of a conventional storage material is determined by its energy density thermal conductivity, corrosion characteristic, cost and convenience of use as well as th by the operating temperature of working fluid.

4. MIRRORS :

The flat mirror surface can be manufactured by metallization of float glass or flexible plastic sheets.

The mirror must be steerable the glass mirrors would not be capable of withstanding the wind load which often occurs in arid lands without any supporting structure.

WORKING OF CENTRAL RECEIVER SYSTEM :

The incoming Solar Radiation is focused to a Central Receiver or a boiler mounted on a tall Tower using thousands of plane Reflectors which are steerable about two axes called 'heliostats'

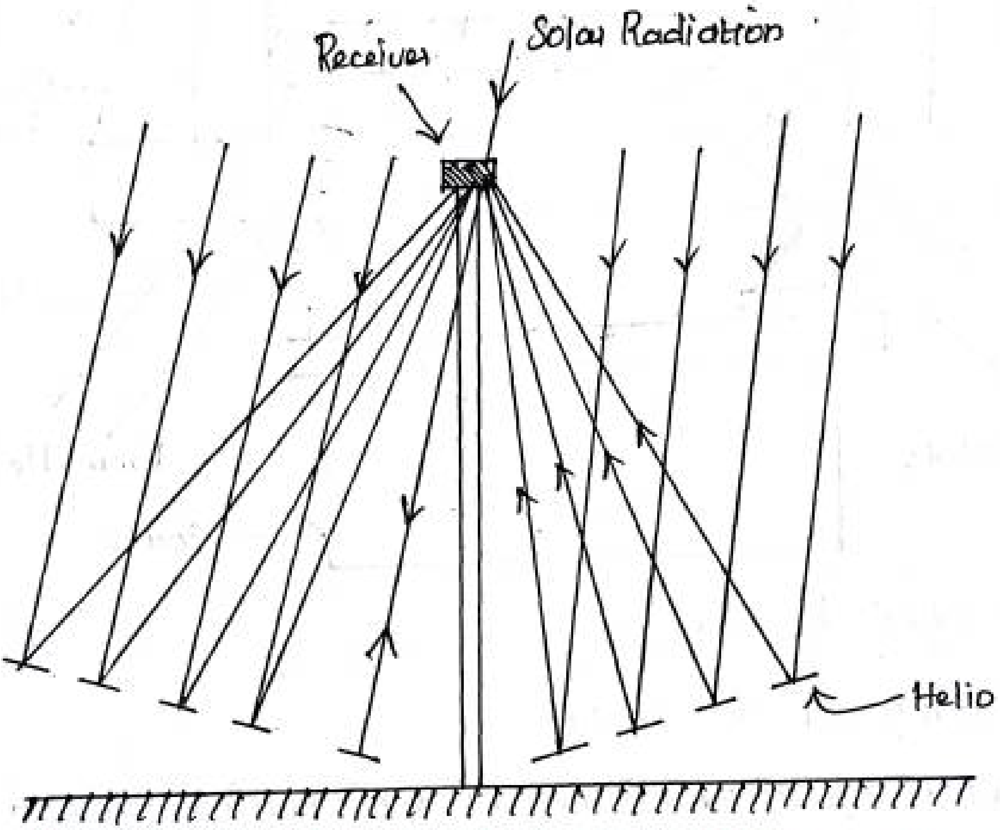


Fig.5. Arrangement of Central Receiver Heliostat Array.

Fig.6 Shows a Schematic View of an electric power generation using a gas turbine power plant working on Brayton cycle.

- the mirrors (heliostats) installed on the ground are oriented so as to reflect the direct Beam Radiation into an absorber or Receiver as shown in fig.5. which is mounted at the top of a tower located near the Center in the field of Mirrors to produce high Temperature.

* Beam Radiation incident in the boiler is absorbed by black pipes in which the working Fluid is circulated and Heated. The working Fluid is allowed to drive a turbine thereby Producing Mechanical Energy.

The turbine which is Coupled to an alternator Produces electrical Energy. A suitable heat storage is also provided to supply the heat Energy during the Period of cloudiness.

Fig.6 Shows the layout of electric power generator using thermal storage.

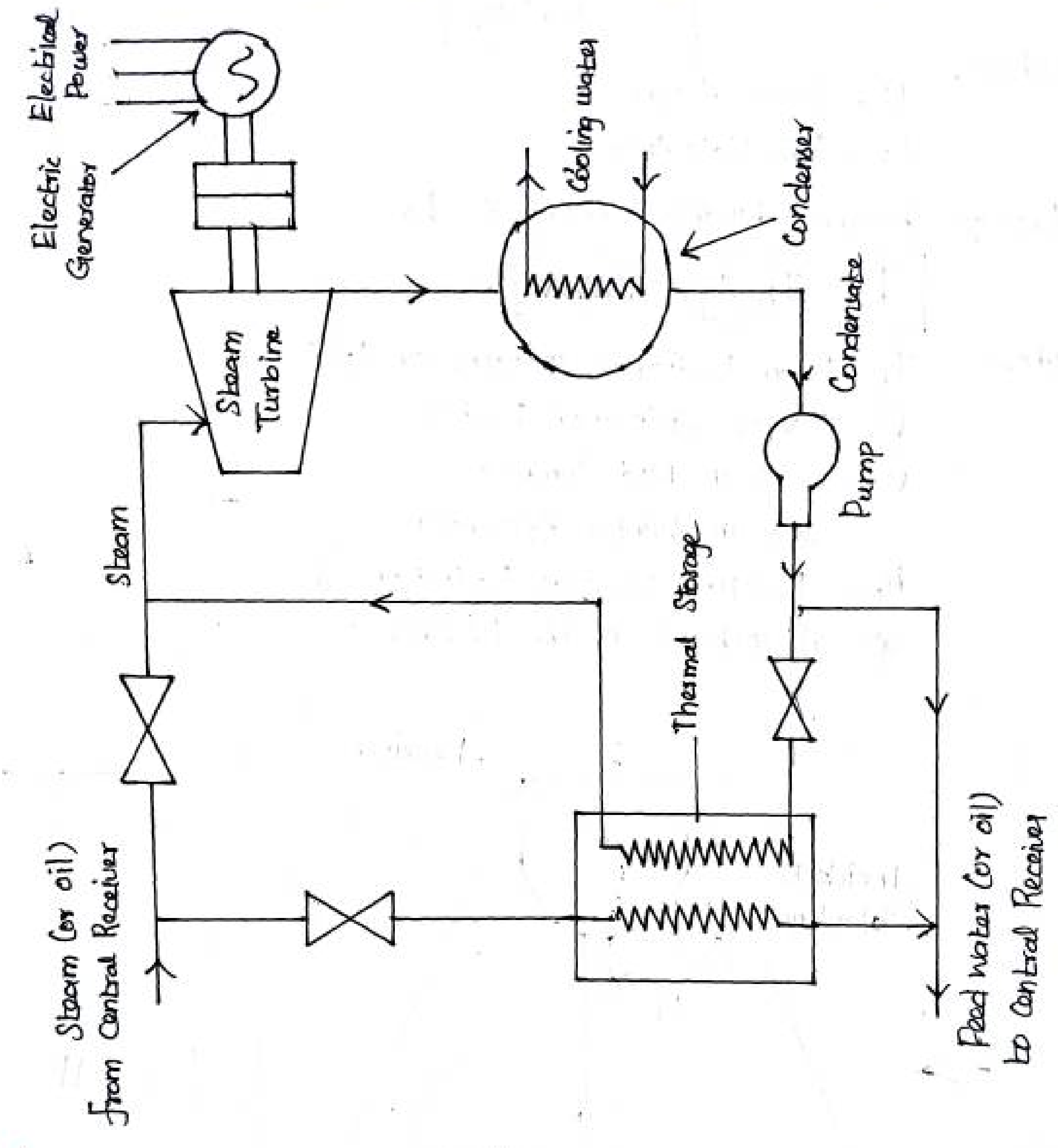


Fig.6. Electric power generation using thermal storage

ANALYSIS OF A CENTRAL RECEIVER SYSTEM

The mirror field in a Central Receiver System is to be laid in such a way to suit for both in winter or summer seasons.

- There is no shade of one mirror on the other mirror. Therefore the heliostats are put apart and a fraction of the ground (ϕ) is only covered.

The value of ϕ is calculated by $$\phi = \frac{N A_m}{A_g}$$

where,

N - Number of Mirrors (Heliostats).

A_m - Area of each Mirror

A_g - Total ground Area used around the tower.

Total ground Area, $A_g = \frac{4H^2}{\tan^2 \theta_r}$

where,

H - Tower Height

θ_r - Rim Half Angle.

Energy absorbed by the Receiver is q_a

$$q_a = I_b A_g \phi \bar{\rho} \eta_0 \alpha$$

where, I_b - Beam Radiation incident on A_R.

$\bar{\rho}$ - Mirror Utilization Factor

$\bar{\rho} = 0.78$ in Mid-Summer

$= 2.0$ in Winter-Afternoon.

η_0 = Fraction of Solar Radiation

α - Absorbance of the Receiver

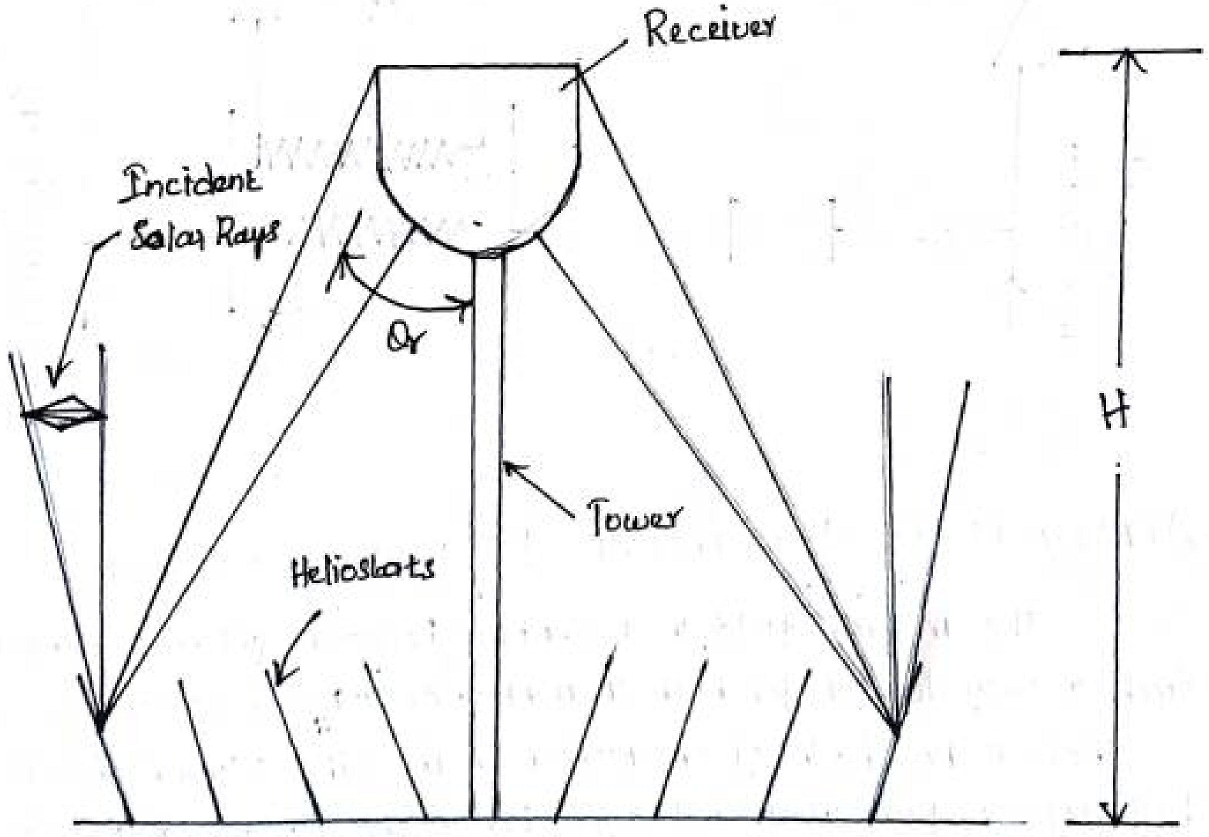


Fig. 7.

The Concentration Ratio is Calculated by the following Equation

$$CR = \frac{N A_m}{A_r} = \frac{\phi A_g}{A_r}$$

where, A_r - Receiver Surface Area.

Now the expression for the useful Energy is given as

$$q_u = q_a - q_1$$

$$q_1 = A_r \varepsilon_r \sigma (T_r^4 - T_a^4)$$

$$q_u = I_b A_g \phi \bar{\rho} \eta_0 \alpha - A_r \varepsilon_r \sigma (T_r^4 - T_a^4).$$

where, ε_r - Emittance of the Receiver Surface at the Radiating Temperature.

ADVANTAGES OF CENTRAL RECEIVER SYSTEM

1. Very High Temperature is obtained. High Temperature is suitable for electricity generation using conventional methods such as Steam Turbine
2. It provides good Efficiency. By concentrating the Sun light, this system can get better efficient than simple Solar cells.
3. A larger Area can be covered by using relatively inexpensive mirrors rather than using expensive Solar cells.
4. Concentrated Light can be redirected to a suitable Location via optical fiber cable. For Example, Illuminating buildings similar to hybrid solar lighting.

DISADVANTAGES :

1. Concentrated collector systems require dual axis Sun tracking to maintain the Sun light focus at the collector
2. Inability to provide power in diffused light Conditions.

UNIT - III

SOLAR ENERGY STORAGE AND APPLICATIONS

1. SOLAR ENERGY STORAGE

One of the Important Characteristics of a Storage System is the Length of time during which energy Can be Kept Stored with acceptable Losses.

* If Solar Energy is Converted Into fuel Such as hydrogen, there will be no Such a time Limit.

• Storage in the form of thermal Energy may Last for Very Short time because of Losses by Radiation, Convection and Conduction.

* Another Important characteristic of a Storage System is its Volumetric Energy Capacity or the Amount of Energy Stored per unit Volume.

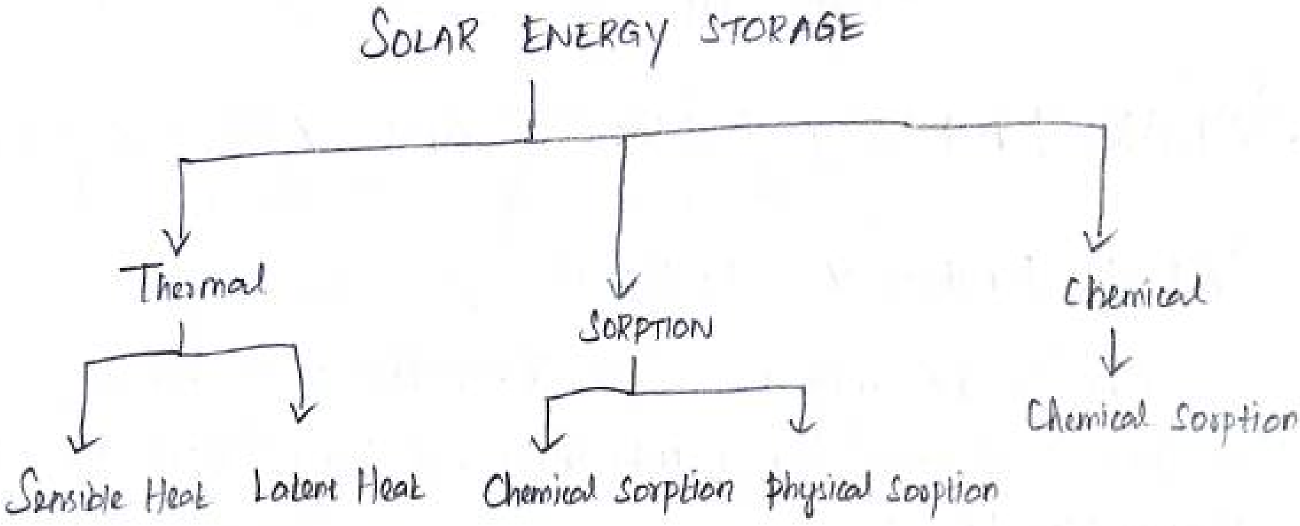
— Therefore, a good System Should have a long Storage time and a Small Volume per unit of Stored Energy.

2. DIFFERENT METHODS OF SOLAR ENERGY STORAGE

* Solar Energy is Stored in a thermal Reservoir for later usage. Solar Energy storage is classified according to the usage.

Thermal Energy Obtained from a Solar Source can be Stored through thermal physical reactions. It means that the temperature difference of materials or (Phase changes) is used to Store the 'thermal Energy'.

* It Can also be Stored through Chemical reactions by Creating new chemical Species ('Solar Fuels')


SOLAR ENERGY STORAGE
Thermal
SORPTION
Chemical
Sensible Heat
Latent Heat
Chemical Sorption
Physical Sorption
Chemical Sorption

1. THERMAL ENERGY STORAGE

Thermal Energy can be directly Stored.

i) Sensible Heat Storage (SHS) :

In SHS, Such as Steam or hot water by changing the temperature of materials (Liquid or Solid) during Peak hour energy, the energy is Stored in the form of 'Sensible Heat'.

ii) Latent Heat Storage (LHS) :

In LHS, Such as phase change materials by changing the Phase of materials (Liquid or Solid) during peak hour energy, the Energy is Stored in the form of 'Latent Heat'.

2. SORPTION STORAGE :

In Sorption Storage, two Chemicals are bonded together under Standard Conditions which are Separated using Peak hour Energy.

* Energy is released when the two chemicals are mixed and exposed to Standard conditions.

- The choice of materials has a great impact on the Performance of the Storage System.

3. CHEMICAL ENERGY STORAGE

Heat generated from Concentrated Solar power is used to Carry out the Endothermic Chemical transformation and produces Storable and Transportable Fuel.

Examples :

Solar Hydrogen, Solar Metal and Solar chemical Heat pipe.

THERMAL ENERGY STORAGE METHODS

Thermal Energy Storage (TES) can be defined as the temporary Storage of thermal Energy at high or Low temperatures.

* TES is not a new Concept and it has been used for centuries. Energy Storage Can reduce the time or rate mismatch between energy Supply and Energy demand, and it plays an Important role in Energy Conservation.

– Energy Storage improves the performance of energy Systems by Smoothing Supply and Increasing Reliability. The higher Efficiency would lead to Energy Conservation and improve the cost effectiveness.

- There are three basic methods for Storing thermal Energy

i) Sensible Heat Storage

ii) Latent Heat Storage

iii) Stratified Storage.

1. SENSIBLE HEAT STORAGE (SHS)

In Sensible Heat Storage (SHS), thermal Energy is Stored by raising the temperature of Solid or Liquid by using its heat Capacity.

* SHS System utilizes the heat capacity and change in Temperature of the material during the Process of charging and discharging.

- The Amount of heat Stored depends on the Specific heat of the medium, Temperature change and the amount of Storage material.

The amount of thermal Energy Stored in the form of "Sensible Heat" Can be Calculated by the following Equation :

$$E = m\,C_p\,\Delta T$$

Where,

E - Amount of Heat Stored in the material (J)

m - Mass of Storage material (Kg)

Cp - Specific Heat of the Storage material (J/Kg.K)

$\Delta T = (T_2 - T_1)$ - Temperature Change (K)

T_1 and T_2 - Lower and Upper temperature Levels of Storage respectively.

* A Variety of Substances have been used as Storage materials in Such Systems.

- These include 'Liquids' like water, Heat transfer oils, and Certain inorganic molten Salts, and 'Solids' like rocks, Pebbles and refractory.

* In the Case of 'Solids', the materials is invariably in Porous form and Heat is Stored or extracted by the flow of a gas or a Liquid through the Pores or Voids

• The Choice of the Substance used depends largely on the temperature level of the application, water being used for temperature below 100°C and Refractory Bricks being used for temperatures around 1000°C

⇒ Sensible Heat Storage Systems (SHSS) are Simpler in design than Latent Heat or 'Bond Storage Systems'

PROPERTIES

The Properties looked at when Selecting a Suitable material are Density, Specific Heat, Thermal Conductivity and diffusivity, Vapour Pressure, Compatibility, Chemical Stability.

Importantly, the materials need to have high thermal capacity and be abundant and cheap.

DISADVANTAGES OF SHS

i) SHS suffers from the disadvantage of being bigger in size

ii) SHS cannot store or deliver Energy at a constant Temperature.

i). LIQUID SENSIBLE HEAT STORAGE

Water is known as one of the best materials that can be used to store thermal Energy in the form of 'Sensible Heat'. because water is abundant, cheap, has a high Specific Heat and has a High density.

* In addition, the use of a Heat-Exchanger is avoided if water is used as the Heat Transfer Fluid in Solar thermal Systems.

➡ Until now, Commerical Applications use water for thermal Energy Storage in 'Liquid based Systems'

* Most Solar water heating and Space-heating Systems use hot water Storage tanks located either inside or outside the buildings or Underground.

➡ The Size of tanks used vary from a few hundred litres to a few thousand cubic meters. An approximate 'thumb rule' followed for fixing the size is to use about 75 to 100 litres of Storage per Square meter of Collector Area.

* Water Storage tanks are made from a Variety of materials such as Steel, Concrete and Fiber glass. The tanks are Suitably insulated with glass wool, Mineral Wool or Polyurethane.

– The thickness of insulation used is large and ranges from 10 cm to 20 cm.

If the water is at Atmospheric Pressure, the temperature is limited to 100°c. It is possible to store water at temperature a little above 100°c by using Pressurized tanks.

* Heat-Transfer oils are used in Sensible Heat Storage Systems (SHS) for intermediate temperatures ranging from 100°c to 300°c.

- Some of the Heat transfer oils used for this purpose are Downtherm and Therminol. The Proplem associated with the use of Heat-Transfer oils is that they tend to degrade with time.

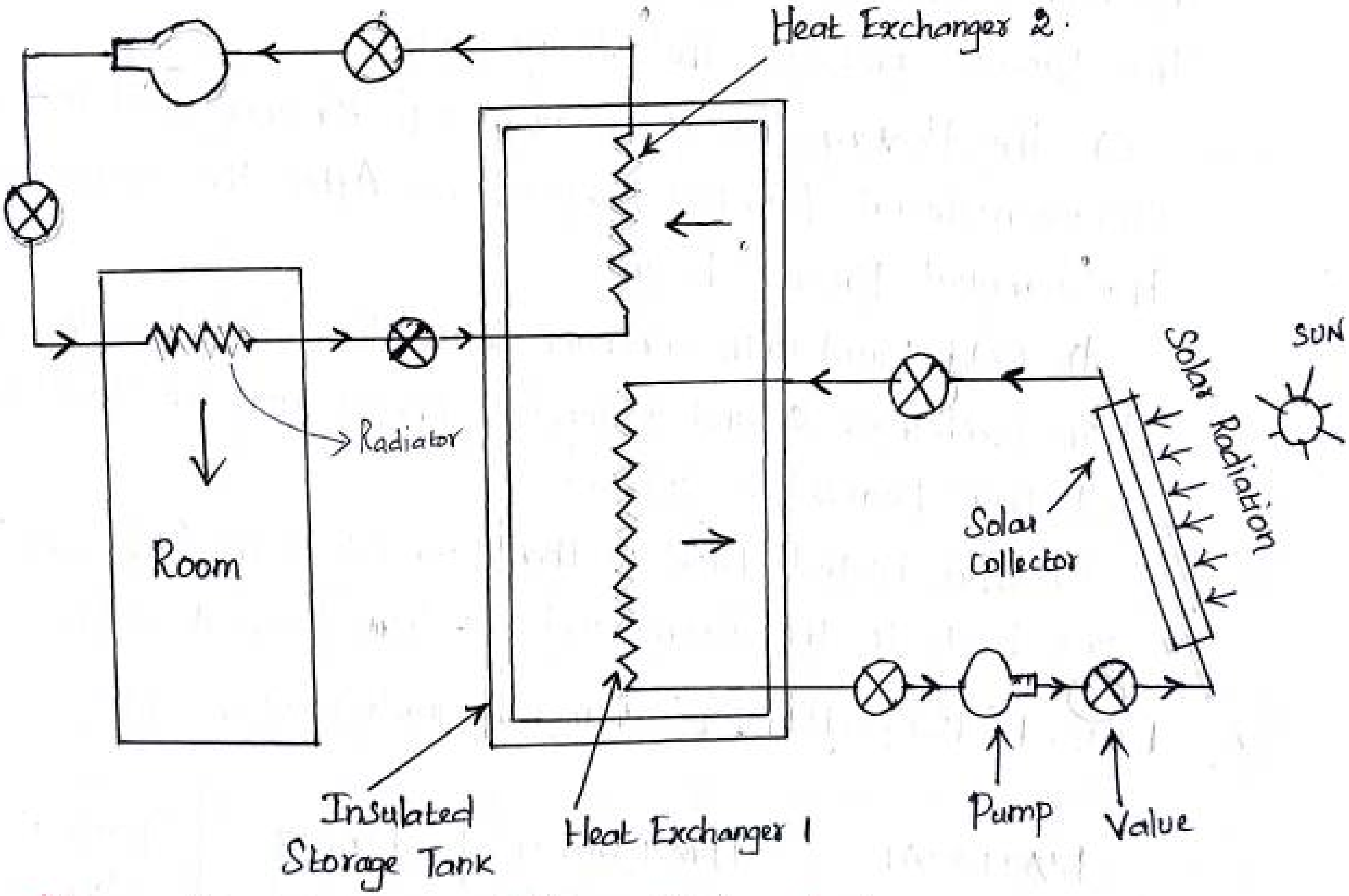


Fig. 1. Liquid Sensible Heat Storage System

Fig. 1. Shows the Schematic arrangement of Liquid Sensible Heat Storage System.

* The System Consist of a Large Liquid bath of mass 'm' and Specific Heat 'Cp' placed in an Insulated Vessel. The System also includes a Solar Collector to give heat Gain to the Collector Fluid and a room in which this Heat Gain is discharged.

The operation of System takes place in three Steps Such as i) Charging ii) Storage and iii) Removal Processes

* The fluid entering the Collector takes the Heat from the Sun and its temperature increases. This Process is 'Charging Process'

a) Hot Fluid from the Solar Collector is passed through the Heat Exchanger 1 which is immersed in the bath of the Storage tank and Leaves at the bottom of the System at Low Temperature.

b) While the hot gas flowing through the Heat Exchanger 1, the bath temperature approaches the hot fluid inlet temperature. This process Completes the 'Storage Cycle'.

c) The Heating Process is allowed to continue up to the desired Storage material (water) temperature. After the Storage Period, the 'removal Process' begins

d) Cold Fluid with constant mass flow rate flows through the Heat Exchanger 2 and it receives Energy from the Liquid bath and then Leaves the System.

e) This heated fluid is then Pumped to the 'Radiator' to give heat to the Room and the ~~Remo~~ Removal cycle is completed.

Table. 1 Properties of Common Liquids Used in SHS

MATERIAL	TEMPERATURE RANGE [°C]	Density Kg/m³	Specific Heat J/kg K.
Water	7-100	1000	4190
Down therms	12 - 260	867	2200
Therminol 66	-9 - 340	750	2100
Engine oil	Upto 157	888	1880

ii) SOLID SENSIBLE HEAT STORAGE

Energy can be stored in rocks or Pebbles Packed in Insulated Vessels. It is simple in design and relatively Inexpensive.

* Typically, the characteristic size of the pieces of rock used varies from 1 cm to 5 cm. An approximate rule of thumb for sizing is to use 300 kg to 500 kg of rock per square meter of collector area for 'Space Heating Applications'.

- Rock or Pebbles-Bed Storages can also be used for much higher temperatures up to 1000°c.

• The difficulties and Limitations relative to 'Liquids' can be avoided by Using 'Solid Materials' for Storing thermal Energy as 'Sensible Heat'

- But Large amount of Solids is needed than using 'Water', due to the fact that Solids exhibit a Lower storing capacity than Water. The cost of the Storage System per Unit energy stored is however, still acceptable for Rocks.

• Direct Contact between the Solid Storage System and Heat Transfer Fluid is necessary to minimize the cost of Heat Exchange in a Solid Storage Medium.

- The Use of Rocks for thermal ~~Ener~~ Storage Provides the following Advantage :

ADVANTAGE OF USE OF ROCKS

a) Rocks are not toxic and Non-flammable.

b) Rocks are inexpensive

c) Rocks act both as Heat transfer Surface and Storage Medium.

d) The Heat transfer between air and a Rock bed is good.

Magnesium oxide (Magnesia), Aluminium Oxide (Alumina) and Silicon Oxide are refractory Materials and they are also Suitable for High temperature Sensible Heat Storage.

* Bricks made of Magnesia have been used in many Countries for Many years for Storing Heat.

Properties of the Common Solids used in SHS are given in Table 2.

Table 2. Properties of Common Solid materials Used in SHS

MATERIAL	TEMPERATURE RANGE (°C)	DENSITY Kg/m^3	SPECIFIC HEAT J/Kg K
Rock	7-27	2560	879
Concrete	7-27	2100	880
Sand	7-27	1550	800
Brick	17-37	1600	840.

2. LATENT HEAT STORAGE (LHS)

Latent Heat Storage (LHS) uses the 'Latent Heat' of the material to Store thermal Energy.

* The Latent Heat is the amount of heat absorbed or released during the Change of material from one phase to another phase.

TYPES OF LATENT HEAT

i) Latent Heat of Fusion

ii) Latent Heat of Vaporization.

i) LATENT HEAT OF FUSION

It is the amount of heat absorbed or released when the material Changes from the Solid phase to the Liquid phase or vice versa.

ii) LATENT HEAT OF VAPORIZATION

It is the amount of thermal energy absorbed or released when the material changes from the Liquid phase to the Vapour phase or Vice-Versa.

* Indeed, Latent heat of Vaporization is not paid attention for Latent Thermal energy Storage Applications, because of the large Change in the Volume accompained by this type of 'Phase change'.

- The amount of thermal Energy stored in the form of 'Latent Heat' in a material is calculated by the following Equation:

$$E = m \Delta h$$

where, E - Amount of Heat Stored in the material (J)

m - Mass of Storage Material (Kg)

Δh - Latent Heat associated with the phase change (J/kg)

* When the Stored Heat is extracted by the Load, the material will again change its phase from Liquid to Solid or from Vapour to Liquid

- Any Latent Heat Thermal Energy Storage System should have atleast the following three Components.

i) Suitable phase change material (PCM) in the desired Temperature range

ii) a Containment for the Storage Substance.

iii) a Suitable Heat Carrying Fluid for transferring the heat effectively from the Heat Source to the Heat Storage.

PHASE CHANGE MATERIALS (PCM)

The Latent Heat materials Store about 5 to 14 times more heat per unit Volume than Sensible Heat Storage materials (SHS) The materials used to Store thermal Energy inform of Latent Heat are called 'Phase Change Materials' (PCM)

Types of Phase Change Materials (PCM)

PCM are classified into three categories

i) Organic PCM (paraffin, fatty acids).

ii) Inorganic PCM (hydrates, Molten Salts, metal) and

iii) Eutectic PCM (organic-organic, Organic-inorganic, Inorganic-Inorganic Compounds)

The Latent heat of 'organic PCM' ranges from 10 KJ/Kg to 300 KJ/Kg. For 'Inorganic PCM' the Latent Heat ranges from 20 KJ/Kg to 250 KJ/Kg. 'Eutectic PCM' ranges from 100 KJ/Kg to 200 KJ/Kg.

* In a typical PCM Storage System, a heat Exchanger is embedded in the Storage material. Fig. 1 Shows a System with direct generation of Steam.

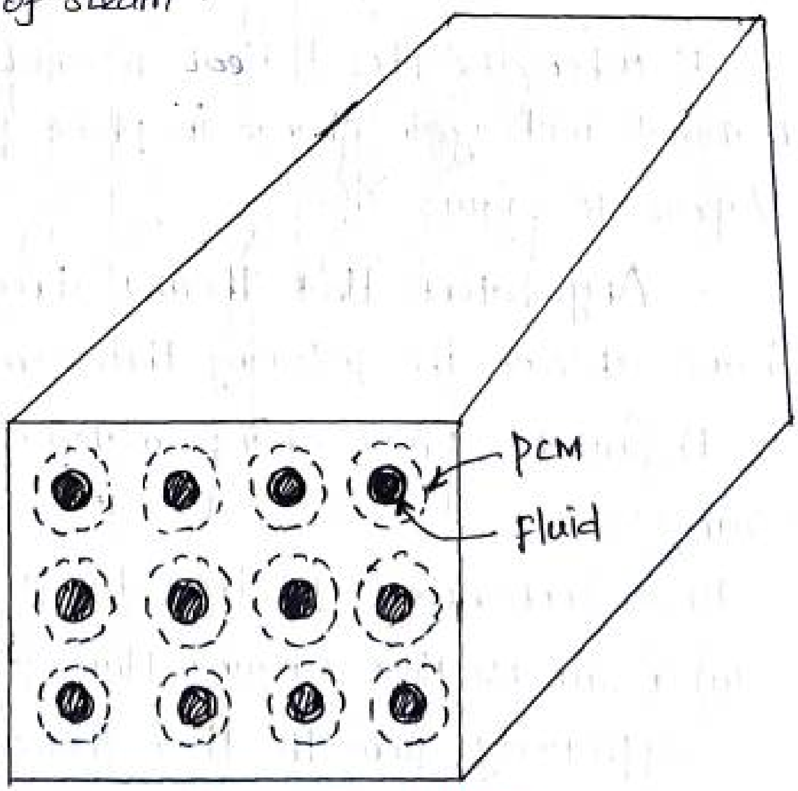


Fig. 1. Schematic of thermal Storage system.

Fig. 2 Illustrates the Schematic arrangement of Latent Heat Storage System used electricity generation.

The energy from the Sun is Collected by melting the PCM Impregnated into the thermal Storage block and then usage of the heat released from the phase change of the material to Produce Steam and generate electric Power.

* Electricity is produced expanding the Steam in a turbine by Coupling a turbo generator with it. The medium used to drive the turbine is pumped back to the heat Exchanger and recirculated within the Loop.

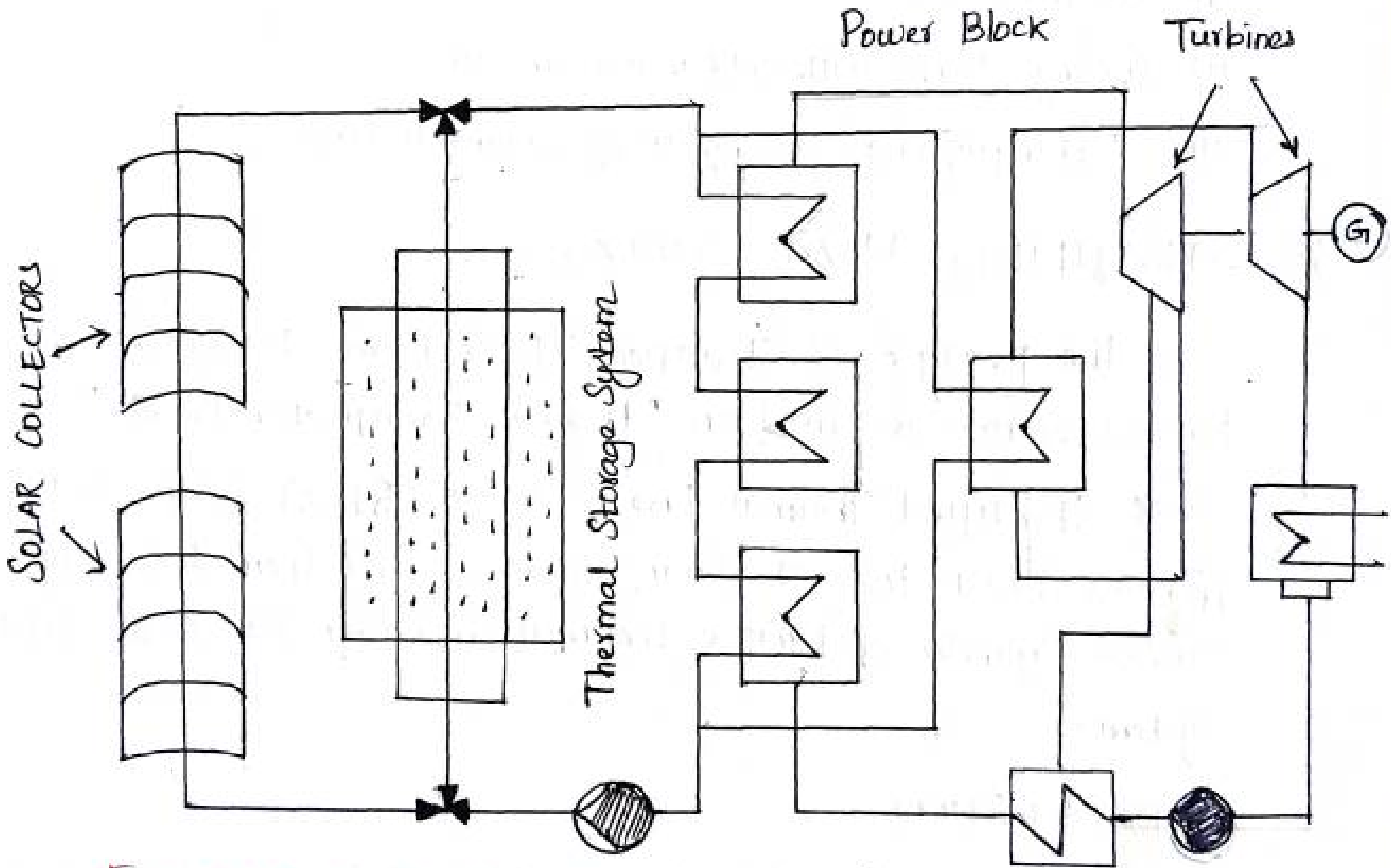


Fig. 2. Electricity generation using Latent Heat Storage.

ADVANTAGE OF LHS

i) It includes a large density of Heat Storage and Constant temperature

ii) The Process is completely reversible and can be repeatedly Utilized without degradation.

DISADVANTAGE OF LHS

i) The PCMs Undergo Solidification and therefore it cannot generally be used Heat transfer media in a Solar Collector or the Load.

ii) Many PCMs have poor thermal conductivity and therefore, they require Large Heat Exchange Area.

iii) Some PCMs are Corrosive and Require Special Containers.

iv) Latent Heat Storage Materials (LHS) are more expensive than the Sensible Heat Storage (SHS)

v) They Increase the System Cost.

APPLICATIONS OF LHS

i) Steaming Food

ii) Cooling drinks with cold water and ice.

iii) Extinguishing fire by using boiling water.

3. STRATIFIED HEAT STORAGE

The principle of Stratified TES (Thermal Energy Storage) tank operation is based on 'thermal Stratification Process'

* Stratified Thermal Energy Storage (STES) Systems gives a massive boost to cost Saving measures. The thermal Energy Storage Cylinder or tank is the most important part of the STES System.

STRATIFICATION:

Stratification is defined as a Natural Process in which both Warmth and density of water are Inversely Proportional Properties.

- The warm water will always Settle on the top of Cold water. The process takes place in a Stratified thermal Energy storage tanks (STES) in terms of two operations such as 'Charging' and 'discharging'

During Charging, Heat Charge Rate is calculated by

$$Q_c = m_c \, C_{pc} \, (T_{ci} - T_{co})$$

Similarly, Heat discharge Rate is Calculated by

$$Q_d = m_d C_{pd} (T_{do} - T_{di})$$

where, Q_c - Heat charge Rate in Watts.

m_c - Mass of water during Charging in Kg.

C_{pc} - Specific Heat of water during Charging in KJ/Kg K

T_{ci} - Inlet Temperature of water during Charging in K.

T_{co} - Outlet Temperature of water during Charging in K.

Similarly, Q_d, m_d, C_{pd}, T_{di}, & T_{do} are Corresponding Parameters during discharging Heat.

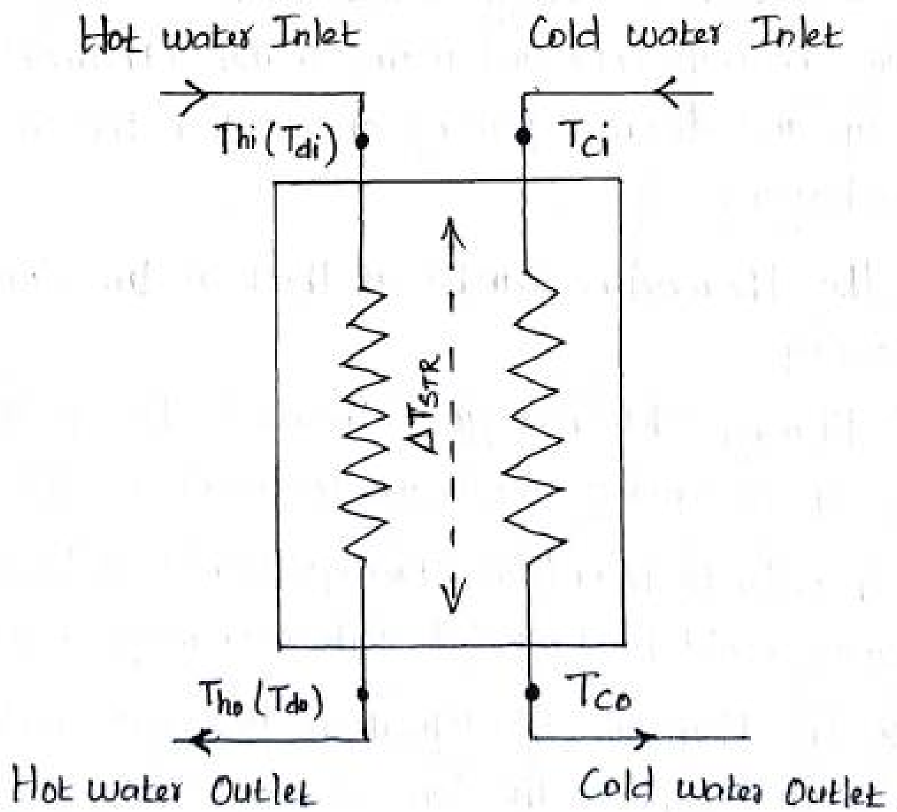


Fig.1. Principles of Stratified Heat Storage.

i) CHARGING OPERATION

Charging operation Starts when the tank is full of warm water. The water is replaced by 'Chilled water' slowly and regularly. The chilled water is supplied from a Separater Chiller Unit.

- This replacement is carried out for several hours upto a point where there is no longer 'warm water' in the tank. and only the 'colder water' is left.

ii) DISCHARGING OPERATION

This process is just opposite to the charging process. 'Cold water' is removed from the tank through 'diffusers' located at the bottom for several hours.

* 'Warm water' enters the tank through diffusers placed at the top of the tank to replace the 'Cold water' as shown in fig.1.

- Diffusers are critical in both processes because they minimize the mixing of different layers of water.

• The thermal Energy Storage tank is always full but the Interface between cold and warm water (thermocline) ~~can be~~ moves up and down, depending on whether the system is 'charging' or discharging

- The thermocline can be as thick as 1m during charging and discharging

* Having obtained good thermal stratification by eliminating mixing, it is equally important to maintaing the temperature layers.

- In order to maintain stratification over long time intervals, the tank should be provided with extremely good 'thermal Insulation'.

* In Thermal Stratification is for example, the use of a thin plastic tube of the same density as the water as illustrated in fig.2.

- the tube moves up and down according to the density of hot water, placing the warm water in the right part of the tank.

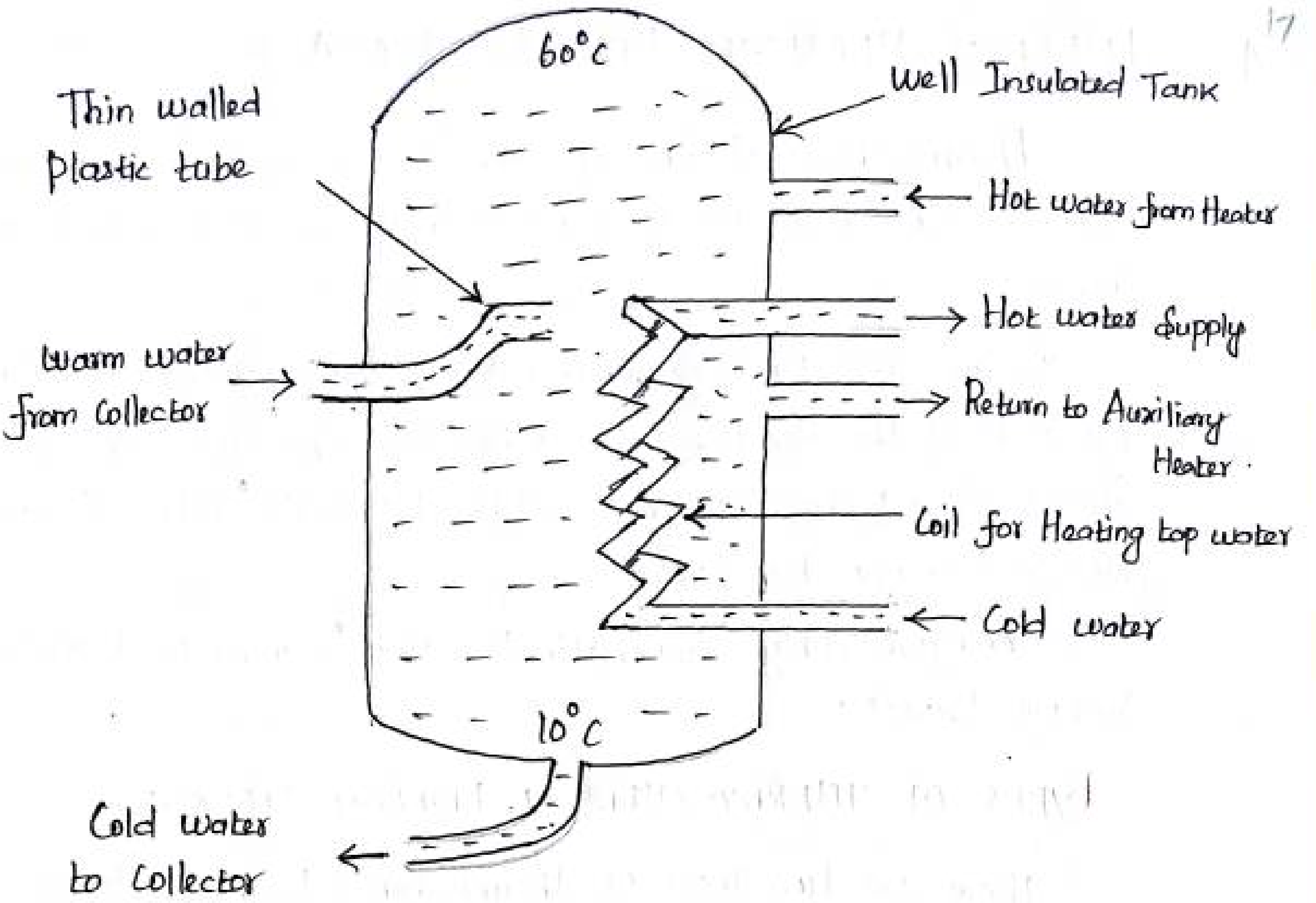


fig. 2. Thermally Stratified Hot Liquid Tank

ADVANTAGES OF STRATIFIED HEAT STORAGE

1. ENERGY EFFICIENCY :

TES tanks are able to minimize the energy loss and save the Peak Energy capacity.

2. OPTIMUM PROCESS :

It has a Unique Load Curve that determines the Charge and discharge Rates.

- To Serve a wide range of applications, ARANER tanks are available in different shapes and sizes.

3. RELIABLE MATERIAL

The tanks are made with Corrosion Resistant material.

- Thermal Insulation properties are Excellent.

4. THERMOCHEMICAL ENERGY STORAGE

Thermo Chemical Energy ~~Stor~~ is produced when a chemical reaction with high energy involved in the reaction is used to store energy.

* the important requirements of these systems are that the products of the Reaction should be able to be 'stored' and the Heat Stored during the reaction should be able to be 'retrived' when the reverse Reaction takes place.

Therefore, only 'Reversible Reactions' can be used for this storage process.

TYPES OF THERMO CHEMICAL ENERGY STORAGE

There are two types of thermo chemical Energy storage such as

i) Chemical Reaction Systems.

ii) Sorption Systems.

i) CHEMICAL REACTION SYSTEMS :

In Chemical Reaction Systems, high Energy Storage density and Reversibility are required of the materials.

- Usually, Chemical Energy conversion has better Energy storage performance Efficiency than physical methods such as Sensible Heat (SHS) and Latent Heat Storage (LHS).

* The most important challenge is to find the appropriate Reversible Chemical Reaction for the Energy Source used.

ii) SORPTION SYSTEMS :

Sorption is the fixation or capture of a gas or a vapor (Sorpate) by a Solid or Liquid Substance (Sorbent).

- the Sorption of gas by Liquid is called "absorption" while the Sorption of gas by Solid is called "adsorption"

Adsorption includes two mechanisms

i) Thermo-physical Reaction by Van der Waals forces (Physisorption)

ii) Thermo-chemical Reaction by Valence forces (Chemisorption)

* Chemisorption Processes typically store more heat per unit mass than "physisorption" but it may be irreversible.

- The principle of using sorption (also for thermo chemical storage) to store energy is based on a Reversible physic-chemical Reaction.

* In this process A/B is working Sorbate / Sorbent couple. When heat is introduced to the system, AB will be split into compounds A and B during Regeneration or Charging phase.

$$AB \xrightarrow{\text{Heat}} \text{Sorbate } A + \text{Sorbent } B$$

The Compounds A and B have to be stored separately. In the same method, Solar thermal Energy is stored as the chemical potential ~~for Long-term Storage~~ of A and B with negligible Loss ~~* when~~ which gives Sorption the potential for Long-term Storage

- When A and B are mixed, A is fixed into B to form 'AB', releasing heat called "discharging phase". The Reversible reaction can be used to store and release energy as needed.

TYPES OF SORPTION SYSTEMS :

i) Closed Sorption System

ii) Open Sorption System.

i) CLOSED SORPTION STORAGE SYSTEM

In a closed Sorption Storage System, the heat is transferred to and from the adsorbent by a Heat Exchanger, usually called Condenser / Evaporator.

The heat has to be transported to the absorber at the same time as it is extracted from the Condenser to Keep the high temperature Fluid, usually 'water' flowing from the adsorber to the Condenser.

* The Energy density is lower than in "open Sorption Systems" because the adsorptive Fluid is the part of the Storage System and also has to be Stored.

- In the Case of using Zeolite or Silica gel as adsorbent, it Can be upto 30-40 % of the weight of the Storage material.

ii) OPEN SORPTION STORAGE SYSTEM

In an Open Sorption Storage system, air transports water Vapour and heat in and out of the absorbents.

* In the 'desorption process' hot air desorbs the water from the adsorbent, Leaving the System Cooler and Saturated.

- In the 'Adsorption Process' humidified Cool airs enters the adsorbent which adsorps the water Vapour and Releases heat and also the air leaves the storage warm and dry.

ADVANTAGE OF CLOSED SYSTEMS :

i) Being able to reach higher Output temperature for heating Operations when Compared to open Systems.

ii) Being able to supply Lower temperature for cooling

iii) Being able to produce ice in the Evaporator.

SOLAR FUELS

The principle of Solar Fuels is shown in figure 1.

- Using optical devices, scattered Sunlight can be captured and the heat generated from Concentrated Solar power can be used to Carry out Endothermic Chemical Transformation to produce Storable and Transportable Fuels.

EXAMPLES : Solar Hydrogen, Solar Metal and Solar Chemical Heat Pipe

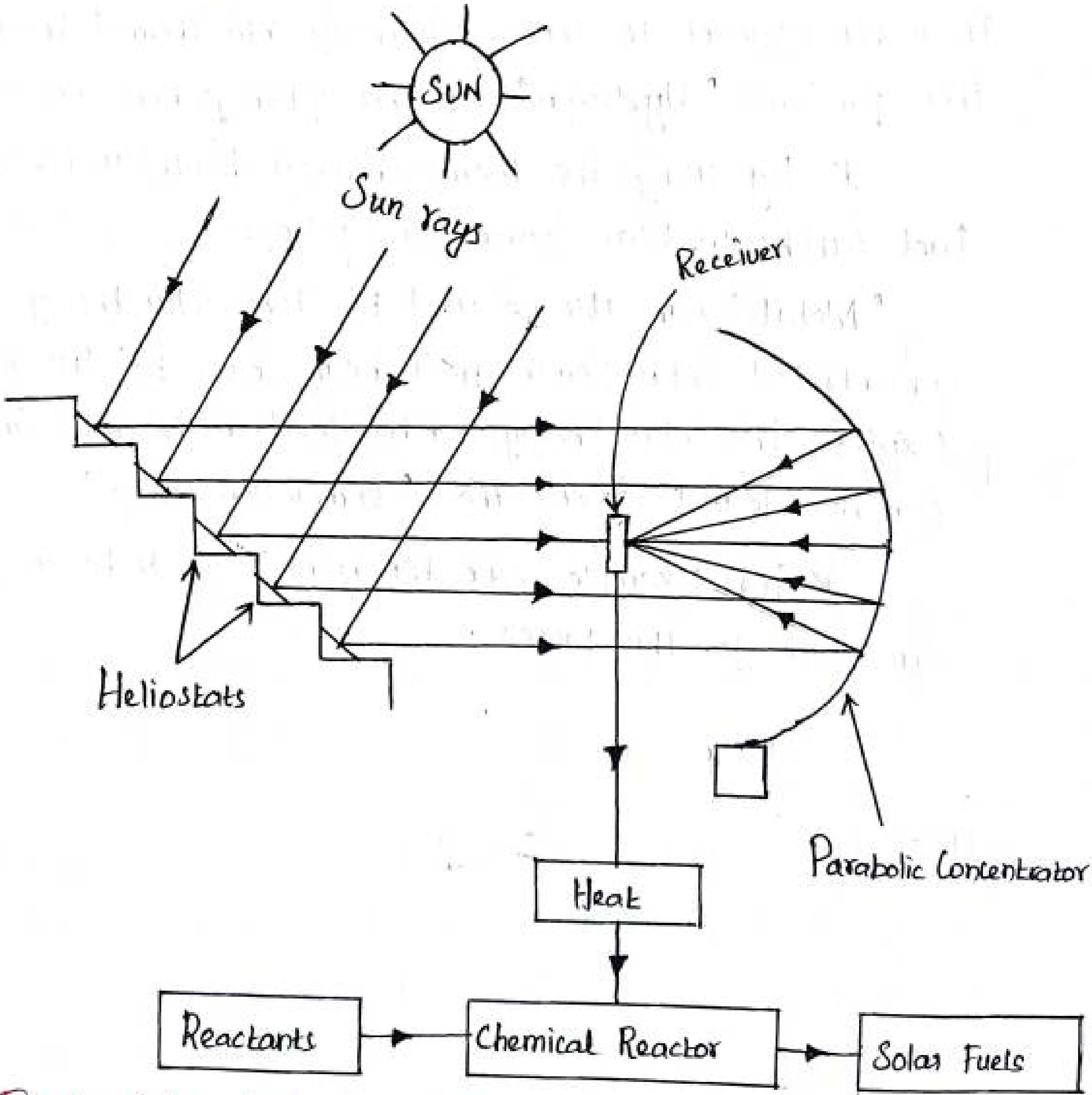


Fig. 1- Solar Fuel Generation

The engine which combusts hydrogen to generate power is called 'hydrogen Engine'

* There are three different ways to generate hydrogen with Solar Power Such as

i) Electro chemical

ii) Photo chemical

iii) thermo chemical.

Electrical Energy can be also directly stored as 'Solar Fuels'. It is not efficient to convert electricity into thermal Energy and then produces 'Hydrogen'. So this option is not considered.

* By using the thermo chemical Route, water and Fossil Fuel can be used as Source for Hydrogen.

'Metals' can also be used to store Solar Energy. Using the Concentrated Solar Power as a heat source to dissociate metal Oxides, the Solar Energy can be stored in the metal and energy can be released during the 'Combustion Process'.

* For Example, Zinc has been shown to be an attractive candidate for this process.

SOLAR POND

INTRODUCTION :

A Natural or Artificial body of water for collecting and absorbing Solar Radiation Energy and Storing it as 'Heat'.

- Thus a Solar pond Combines Solar Energy collection and Sensible Heat Storage.

PRINCIPLE OF OPERATION & DESCRIPTION OF NON-CONVECTIVE SOLAR POND

A Solar Pond is a mass of Shallow water about 1 or 2 metres deep with a Large Collection Area, which act 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'

- On the other hand, Convection Can be eliminated by initially Creating a Sufficiently Strong 'Salt Concentration gradient'

* At the bottom of the Pond, a thick durable plastic Liner is Laid. Materials used for the Liner Include butyl Rubber, Black Poly ethylene 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'

- In the Salt-gradient Solar ponds, dissolved Salt is used to Create Layer of water with different densities.

~~Solar~~ Salt Gradient Solar Pond normally consists of the following three zones as shown in fig. 1

i) Surface Convective Zone or Upper Convective Zone (Fresh water)
(0.3m - 0.5m), Salinity < 5%.

ii) Non-Convective Zone (Gradient Zone)
(1m - 1.5m), Salinity increases with depth.

iii) Lower Convective Zone (Storage Zone or Salt Saturated)
(1.5m - 2m), Salinity ≃ 20%.

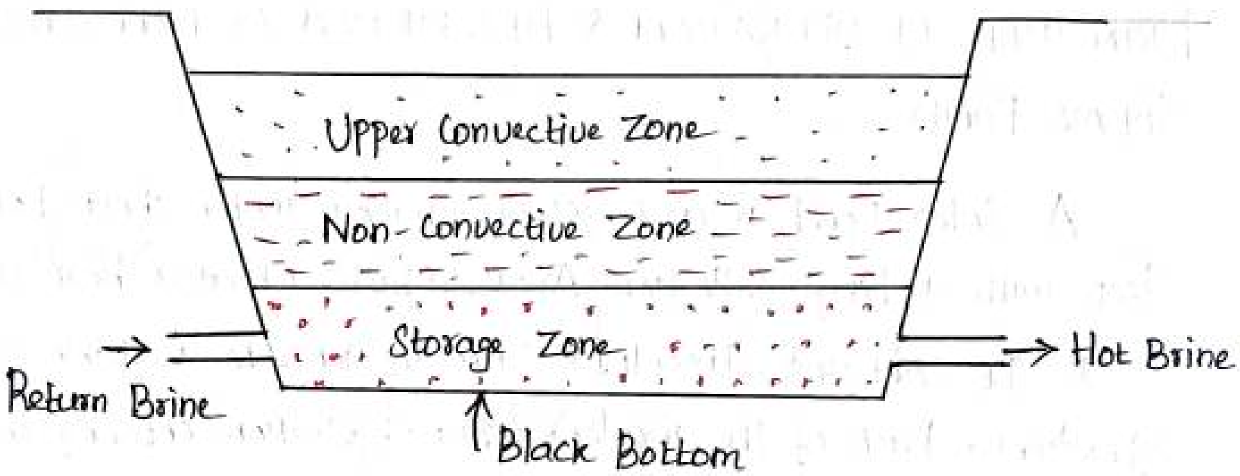


Fig. 1. Convective Zones in Solar Pond.

i) SURFACE CONVECTIVE ZONE

The Surface Convective Zone usually has a small thickness, around 10 to 20 cm. It has a low, uniform concentration which is close to zero as well as fairly uniform temperature which is close to the Ambient Air temperature.

ii) NON-CONVECTIVE ZONE

The Non-Convective Zone is much thicker and occupies more than half the depth of the Pond.

* Both Concentration and Temperature increase with depth in it. It serves mainly as an insulating layer and reduces the heat loss in the upward direction.

This part acts as a thermal Storage as Some of the heat Collection also takes place in this Zone.

iii) LOWER CONVECTIVE ZONE

The Lower Convective Zone or Storage Zone is Comparable in thickness to the Non-Convective Zone

* Both the Concentration and Temperature are nearly Constant in this Zone. It Serves as the main Heat Collection as well as thermal Storage Medium.

– The deeper the Zone, the more heat is Stored. The Lowest Zone traps heats for the long periods

CHARACTERISTICS

The Salt used in a Solar pond for creating density gradient Should have the following Characteristics:

i) It must have a high Value of Solubility to allow high Solution densities

ii) The Solubility Should not Vary appreciably with temperature.

iii) Its Solution must be adequately transparent to Solar Radiation.

iv) It must be inexpensive

v) It must be available in abundance near Site so that its total delivered cost is Low

vi) It must be environmentally benign, Safe to handle the ground water.

EXTRACTION OF THERMAL ENERGY USING SOLAR POND

Energy is Stored in Low grade thermal form of the 'Lower Convective Zone'

– Convection in the Zone is due to the Process of heat Extraction accomplished by hot brine withdrawl and Cool Brine Return.

Extraction of thermal Energy Stored in the Lower layer of the Pond can be easily accomplished without disturbing the Non-convective Salt gradient Zone above.

* Hot water can be extracted from a Solar pond without disturbing the Concentration gradient. This is achieved by installing the 'water outlet' at the same height as the 'water Inlet'

– Hot Brine can be withdrawn and Cool Brine returned in a Laminar Flow pattern because of the presence of density gradient.

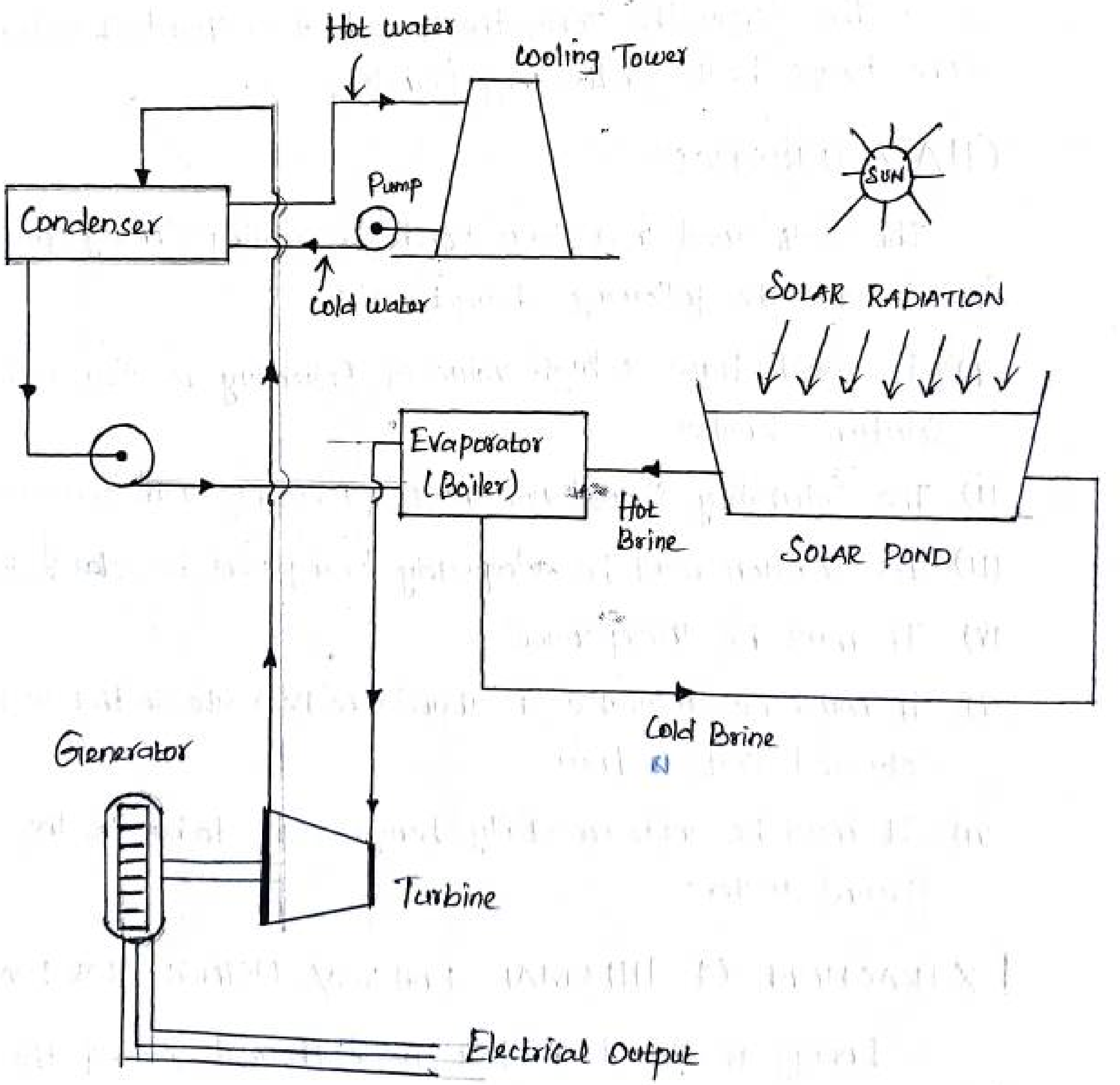


Fig: 2. Solar Pond electric power plant with Cooling tower.

Thermal Energy from Solar Pond is used to drive a 'Rankine Cycle' Heat Engine

– Hot water from the bottom level of the pond is pumped to the 'Evaporator', where the Organic working fluid to Vaporized. The Vapour flows under high pressure to the turbine and thereby expanding through the turbine wheel and the electric Generator linked to it.

* The Vapour then travels to the 'Condenser' where cold water from the 'Cooling Tower' Condenses the Vapour back it to a Liquid

– The Liquid is pumped back to the 'Evaporator' where the cycle is repeated.

APPLICATIONS OF SOLAR POND

i) Heating and Cooling of Buildings
ii) Production of Power
iii) Industrial Process Heat
iv) Desalination
v) Heat for Biomass Conversion

ADVANTAGES OF SOLAR PONDS

i) It provides low investment costs per installed collection Area
ii) Thermal storage is incorporated into the collector and it is very low cost
iii) Separate Collector is not needed
iv) Environmental Friendly
v) This technology is attractive for rural areas in developing countries.

LIMITATIONS OF SOLAR PONDS

i) Need Large land Area to function Properly.
ii) It can be operated only in Sunny days
iii) Large quantity of Salt is required for operating the Solar Pond.
iv) A proper algae and dust removal are needed as the thermal Efficiency of Solar Pond

SOLAR CELL

SOLAR CELL INTRODUCTION

The direct conversion of Solar Energy into electrical Energy by means of 'photovoltaic Effect', that is the conversion of Light into electricity.

PHOTOVOLTAIC EFFECT :

The photovoltaic Effect is defined as the generation of an Electromotive force as a result of the absorption of Ionization Radiation.

- Energy conversion devices which are used to convert Sunlight to electricity by the use of the photo Voltaic Effect are called 'SOLAR CELLS'. A Single Converter cell is called a Solar cell or 'Photovoltaic cells' a Combination of Such cells, designed to increase the electric Power Output is called a 'Solar Module' or 'Solar Array'

PHOTOVOLTAIC CELLS :

Photovoltaic cells 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 Surfaces of the Semiconductors.

* The Silicon Cell Consists of a Single Crystal of Silicon into which a doping material is diffused to form a Semi-conductor.

- The silicon is one of the earth's most abundant materials, it is expensive to extract (from Sand, where it occurs mostly in the form SiO_2 and refine to the purity required for 'Solar cells'

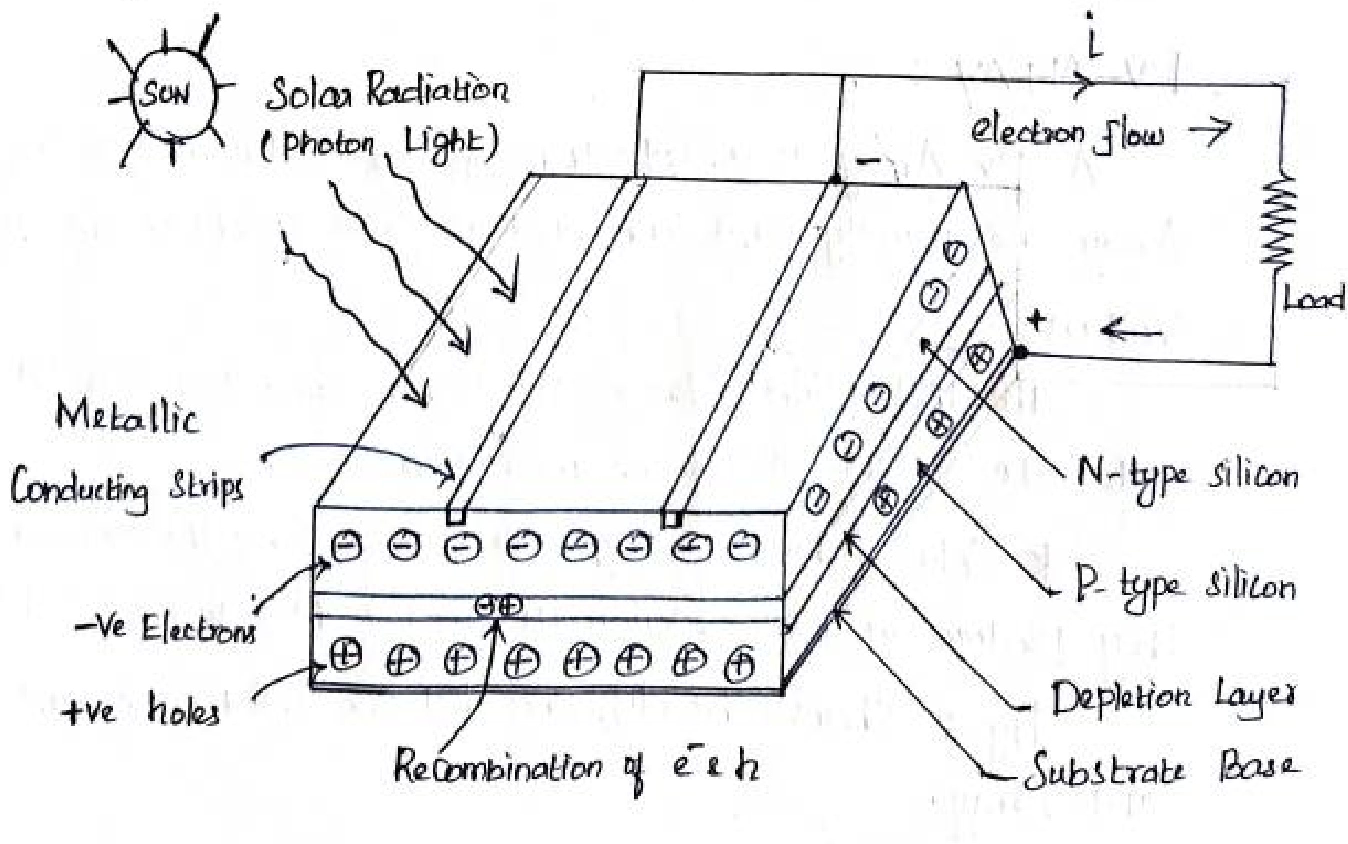
SOLAR CELL PRINCIPLE

The piece of Semiconductor with one side of the P-Type and the other of the N-type is called a 'PN Junction'.

- In this junction after the photons are absorbed, the free electrons of the N-Side will tend to flow to the P-Side, and the holes of the P-Side will tend to flow to the N-Side to compensate for their respective deficiencies

* This diffusion will create an electric field 'E_f' from the N-Region to the P-Region. This field will increase until it reaches equilibrium for 'V_e', the Sum of the diffusion potentials for holes and Electrons.

- The free electrons will flow from the N-type material through the Conductor to the P-type material. The flow of electrons through the external conductor constitutes an electric current (I) which will continue as long as more free electrons and holes are being formed by the Solar Radiation.



This is the basis of photovoltaic Conversion, that is the Conversion of Solar Energy into electrical energy.

* The Combination of ~~Conversion~~ N-type and P-type Semiconductor thus constitutes a photovoltaic Cell or 'Solar Cell'. All such cells generate direct Current (DC) which can be Converted into alternating Current (AC) If needed.

CONFIGURATION OF A SOLAR PV PANEL

A 'PhotoVoltaic module' is made of multiple interconnected Solar cells

* A Solar PV panel is a collection of modules physically and electrically grouped together on a Support Structure.

- These modules are Connected in Series / Parallel to increase the Voltage / current ratings.

* When modules are Connected in Series, it is desirable to have each module's Maximum Power production occuring with the Same Current.

PV ARRAY :

A PV Array is a Collection of Panels. The modules in a PV Array are usually first Connected in Series to obtain the desired Voltage.

- The Individual Strings are then Connected in Parallel to allow the System to produce more Current.

* Solar Arrays are typically measured by the electrical power they Produce in Watts, Kilowatts or even Mega Watts.

Fig. 2 Shows the difference between Cell module and panel and Array.

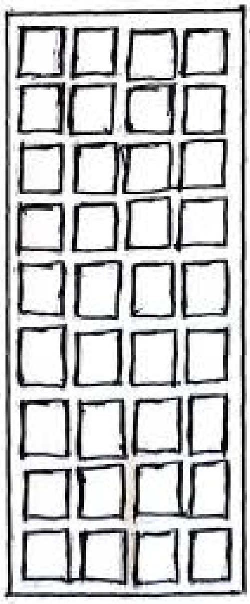
Most Solar PV Panels have 30 to 36 cells Connected in Series. Each Cell produces about 0.5V in Sun light. So a panel produces 15 V to 18 V.

- These panels are designed to charge 12V Batteries. The Current depends on the Size of each Cell and the Solar Radiation Intensity. Most cells produce a Current of 2A to 3A in bright Sun light

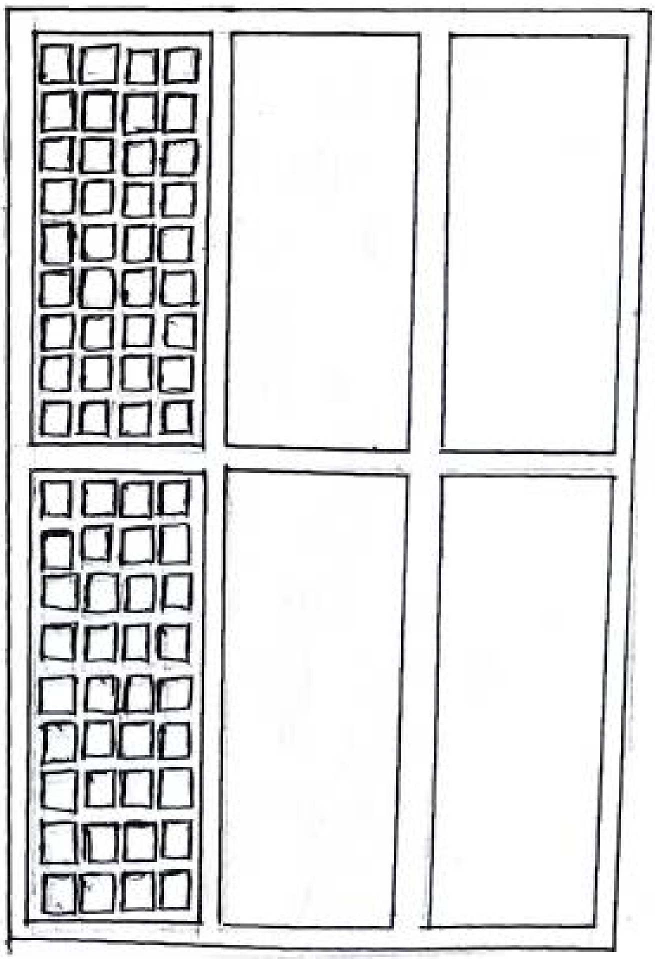
The Current is Same in every cell because cells are connected in Series.

* So the modules are linked together to form an "Array" Most PV arrays use an Inverter to Convert the DC Power (DC) Produced by the modules into Alternating Current (AC) that can plug into the existing Infrastructure to power lights, motors and other loads.

a) SOLAR CELL



b) SOLAR MODULE



c) SOLAR ARRAY

SOLAR HEATING TECHNIQUES

There are many uses of Solar Energy. Direct thermal Applications Involve the direct use of heat thereby resulting the absorption of Solar Radiation for

- Space Heating and cooling of Residences and other buildings
- to provide hot water for Such buildings
- to provide heat for agricultural, Industrial and other Processes that require only moderate temperatures

* Various Solar direct thermal application System are discussed briefly here.

1. SOLAR WATER HEATER

It is a device to heat water using Solar Energy. Solar water heaters are one of the best options to be adapted in the developing country.

- Solar Water heating Systems are Commerically produced in the Country. Most of the Systems available in India are designed to give water temperature from 60°c to 90°c.

* These are suitable for preheating the feed water of boiler and Processing industries and hot water application in hotels, Bakeries Industries etc,

The term Solar water Heater Includes a Conventional Flat Plate Collector with either 'thermosyphon or forced circulation flow System'

* A Solar water heater normally Consists of the following Components.

a) A Flat plate Collector to absorbs Solar Radiation and Convert it into thermal Energy

b) Storage Tank to hold water for use and Cold water feeding the 'Flat-plate Collector'

c) Connecting pipes inlet and outlet for feeding cold water from the storage tank and taking hot water to the storage tank or point of use.

i) THERMOSYPHON OR NATURAL CIRCULATION SYSTEM :

The schematic diagram of a solar water heater with natural circulation mode is shown in fig. 1.

* In this system, the circulation of heated water is accomplished by the natural convection. A simple small capacity natural circulation system is suitable for domestic purpose.

- The storage tank is an insulated vessel and contains 'two inlets'. One is to allow the hot water from the collector and the other one is to allow the cold water from the main to reach the bottom of the tank without mixing with hot water.

* There are 'two outlets'. One is for the withdrawl of hot water and the other one is used to feed cold water to the collector inlet.

- The tank is located above the level of the collector. The entire length of the connecting pipes is covered with glass-wool insulation to reduce the heat loss.

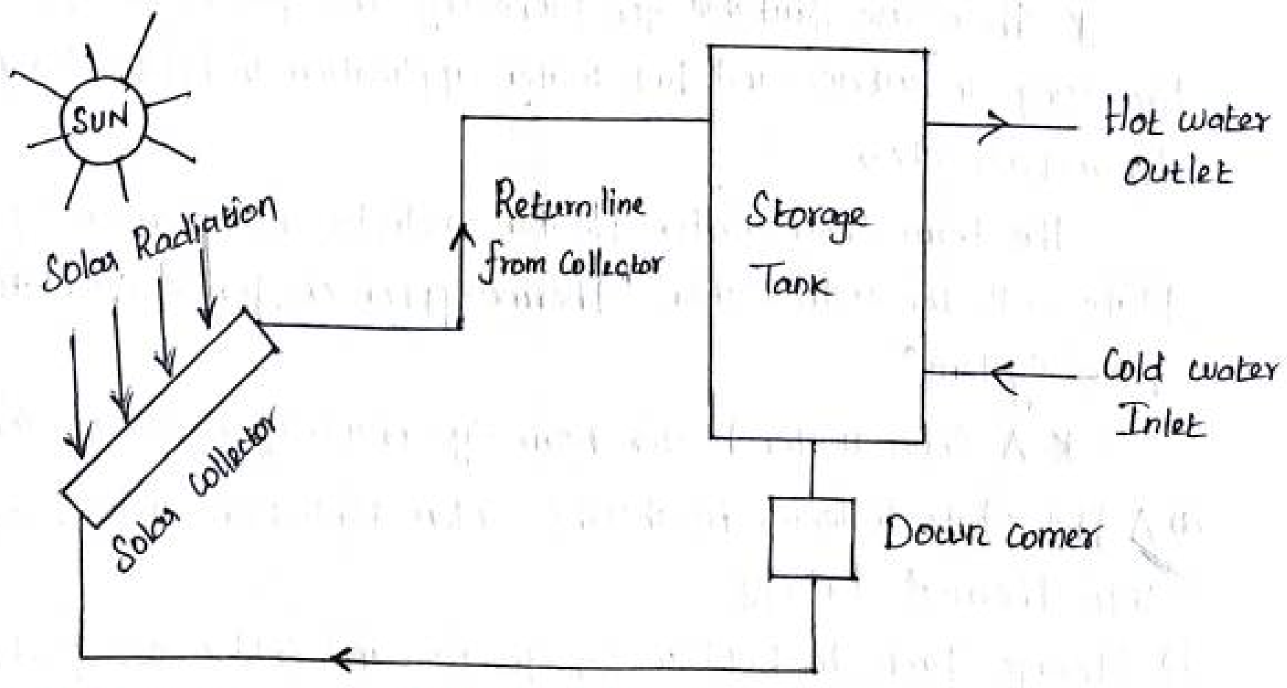


Fig. 1. Thermosyphon or Natural Circulation Water Heater

As water in the flat-plate collector is heated by "Solar Energy", it flows automatically to the top of the water tank due to low density.

– The vacuum created by this flow is filled up by the cold water from top of the storage tank. Whenever it is done, cold water automatically enters at the bottom.

* An auxiliary heating system is provided for use on cloudy or rainy days. Typically, such systems have capacities ranging from 100 litres to 200 litres and adequately supply the needs of a family of four or five persons.

ii) FORCED CIRCULATION SYSTEM :

The schematic diagram of a solar water heater with forced circulation mode is shown in fig. 2.

– In this system, a small water pump is required for the flow of water between flat-plate collector and storage tank.

* The collectors can also be connected in series for high water temperature if required.

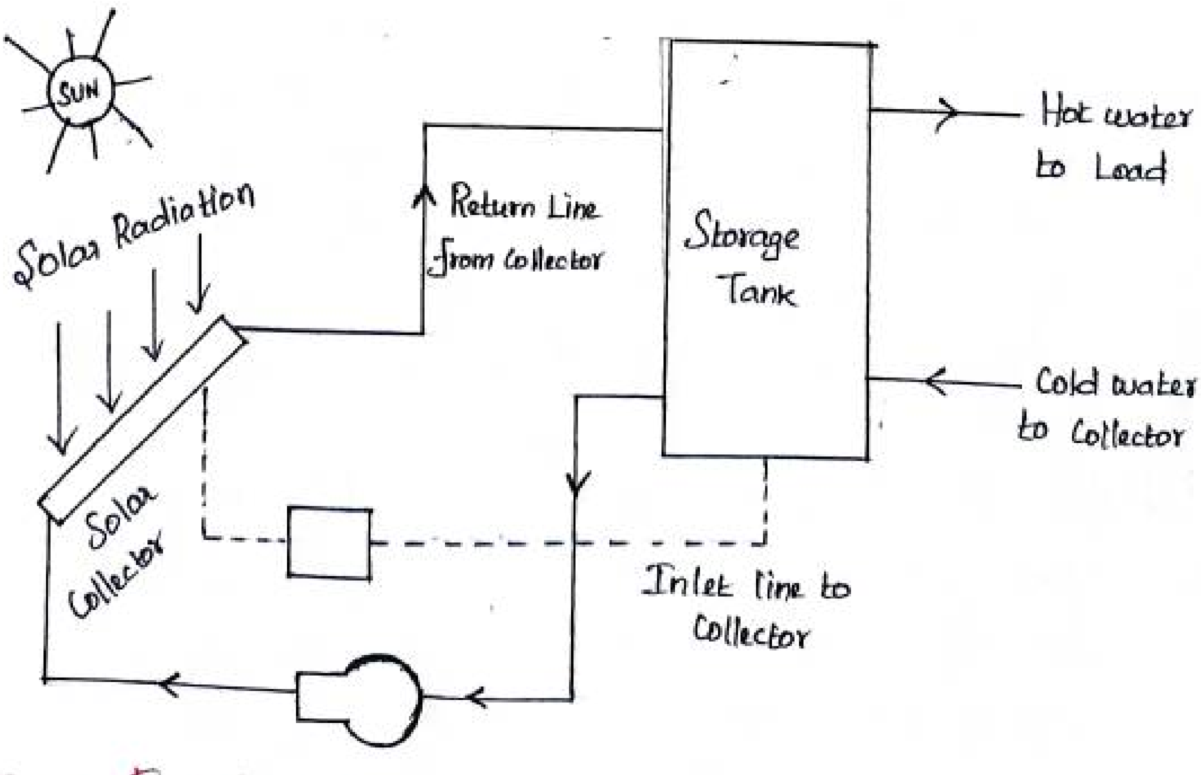


Fig. 2. Forced Circulation System.

UNIT-4 WIND ENERGY AND BIO-MASS ENERGY

INTRODUCTION TO WIND ENERGY

Wind Power is the Conversion of wind Energy into a useful form of Energy Such as using wind turbines to make electricity, wind Mills for Mechanical power, wind pumps for water pumping or drainage or Sails to propel ships.

SOURCE OR ORGIN OF WIND

Wind is produced by the uneven heating of the Earth's Surface by Energy from the Sun

* The poles of the Earth receive less energy from the Sun than the equator. Among these two, the dry land heats up (and cools down) more quickly than Sea.

- The differential heating drives a global Atmospheric Convection System reaching from earth's Surface to the Stratosphere which acts as a Virtual ceiling.

* Since the Earth's Surface is made of different types of land and water, it absorbs Sun's Radiant Energy at different rates. Much of this energy is Converted into heat as it is absorbed by land areas, bodies of water and the air over these formations.

- On a global Scale, the Non-uniform thermal effects Combine with the dynamic efforts from the Earth's rotation to produce Prevailing wind patterns.

* There are also minor Changes in the flow of the air as a result of the differential heating of Sea and Land. The nature of terrain ranging from mountain and Valleys to more local obstacles Such as buildings and trees also has an Important effect on the "Orgin of Wind".

Generally, 'during day time', the air above land Mass tends to heat up more rapidly than the air above water.

* In Coastal Region, it manifests itself in a strong on shore wind. In 'Night time', the Process is reversed because of the air Cools down more rapidly over the Land and the breeze, therefore blows Off-Shore similar Process occurred in mountains and Valleys. Thus it Creates 'Local wind'.

* The Speed of wind is affected by the Surface over which it blows. Rough Surfaces Such as areas with trees and buildings Produce more friction and Turbulence than Smooth Surface Such as lakes or open Crop land.

– The greater friction means that the wind speed near the ground is reduced. Most of the energy stored in these ~~m~~ wind movements can be found at high Altitude where the Continuous wind Speed of over 160 Km/h occurs.

* Eventually, the wind energy is Converted through friction into diffuse heat throughout earth's Surface and Atmosphere.

CHARACTERISTICS OF WIND ENERGY

1. Wind-power Systems do not pollute the Atmosphere.
2. Fuel Provision and Transport are not required in wind-power Systems
3. Wind Energy is a Renewable Source of Energy.
4. Wind Energy when produced on Small Scale is Cheap. but it is Competitive with Conventional power generating System when Produced on a Large Scale.

WIND SPEED

Power in the wind is Proportional to the Cube of the wind speed. The highest wind Velocities are generally found on Hill tops, Exposed coasts and out at

WIND DATA.

The wind is measured on the basis of many factors such as Time availability, budget allocated for the measurement and Accuracy needed for the estimation.

- It is better to use metrological data or civil aviation data. Basically, the measurements are wind speed and wind direction.

* The Standardized wind data should be used similar to a metrological department. The metrological department collects data continuously about wind from many airports and from anemometers located at 10 m height inorder to follow the world standard.

Types of Wind Mills

Based on the axis of Rotation of the rotor, wind turbines are further classified as follows :

1. Horizontal -axis wind Machines
2. Vertical-axis Wind Machines

1. Horizontal Axis Wind Mills

In horizontal axis wind mills or turbines, the axis of Rotation is horizontal with respect to the ground.

- In this Case, the rotating Shaft is parallel to the ground and the Blades are perpendicular to the Ground.

* Horizontal-axis or Propeller-type turbines are more Common and highly developed than "Vertical-axis turbines".

Figure. 1 Shows a Schematic arrangement of a horizontal axis wind turbine. Although the Common wind turbine with a horizontal axis is Simple in principle yet the design of a Complete System especially a large one that would produce electric power economically is Complex.

* It is of prime Importance that the Components Such as Rotor, Transmission, Generator and Tower Should not only be as efficient as possible but also they must function effectively in Combination.

- Horizontal Axis Wind Turbines (HAWT) have the main Rotor Shaft and electrical Generator at the top of the tower and it must be pointed Into the wind

* Small turbines are pointed by a Simple wind Vane while Large turbines generally use a 'wind Sensor' Coupled with a 'Servomotor'

Most of them have a gear box which turns the blades slowly into a quick Rotation which is more Suitable to drive an Electrical Generator.

* Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Turbine Blades are made stiff to prevent blades from being pushed into a tower by high winds

- Additionally, the blades are placed at a Considerable distance in front of the tower and they are Sometimes tilted up a Small Amount.

* 'Down wind Machines' have been built despite the Problem of turbulence because they do not need an additional mechanism for Keeping them in line with the wind and high winds

- The blades Can be allowed to bend which reduces their Swept area and thus it reduces their wind Resistance

* Since the Cyclic turbulence may lead to fatigue failures, most HAWTs are of 'Upwind Machines'

ADVANTAGES :

1. Variable blade pitch which gives the turbine blades the optimum angle of attack
2. The tall tower Base allows an access to Stronger wind in Sites with wind Shear
3. Efficiency is high
4. The face of a horizontal axis blade is Struck by the wind at a Consistent Angle regardless of the position in its direction.

DISADVANTAGES :

1. HAWTs have difficulties in operating in near ground and turbulent winds. Therefore, Tall Towers are Required.
2. The tall towers and blades upto 90m long are difficult to transport

3. Tall HAWTs are difficult to install and they need very tall and expensive cranes and skilled operators.

4. Massive tower construction is required to support heavy blades, gear box and generator.

5. HAWTs require an additional yaw control mechanism to turn the blades towards wind.

6. Down wind variants suffer from fatigue and structural failures caused by Turbulence.

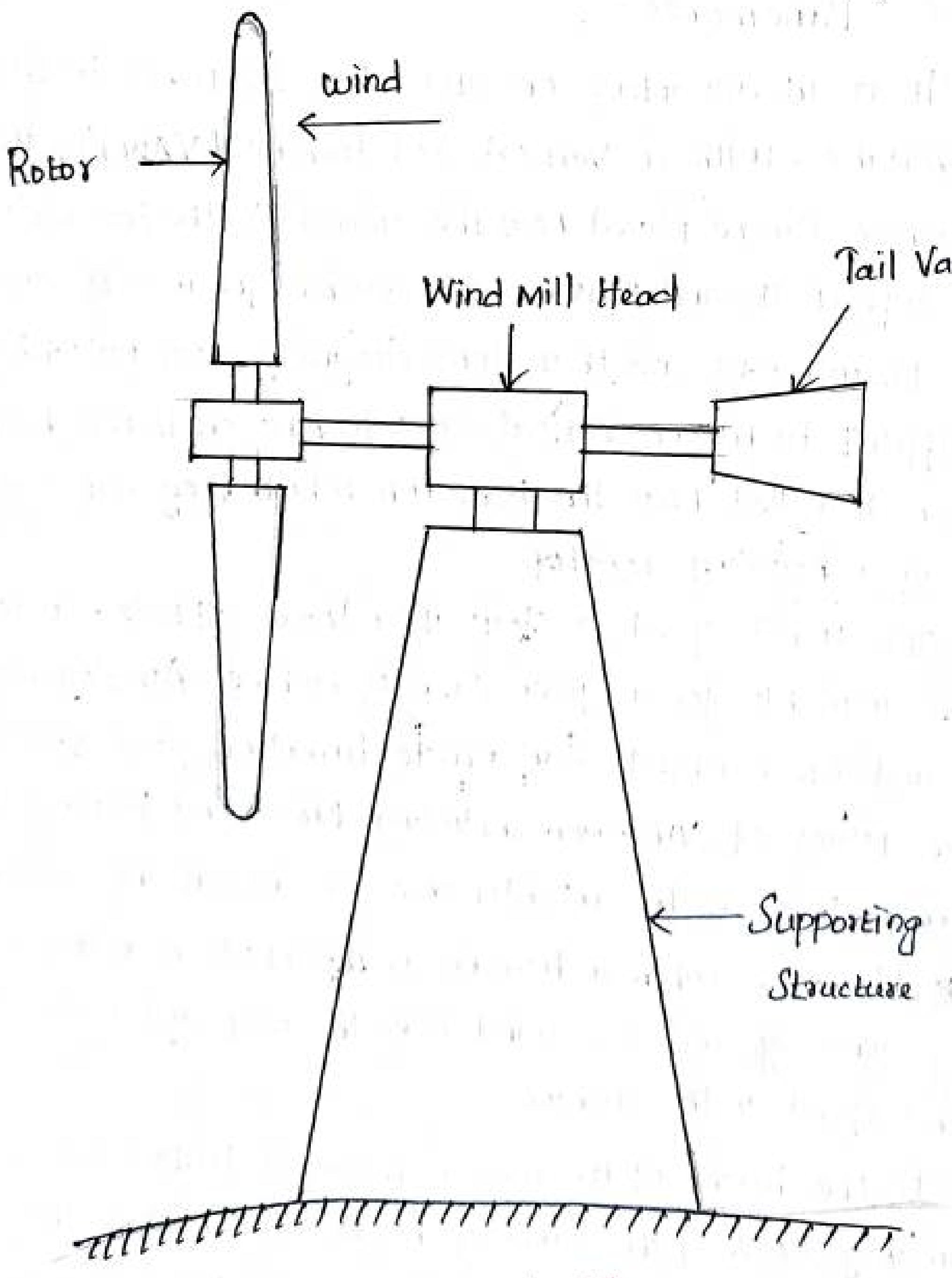


Fig. 1. Horizontal Axis Wind Mill.

2. VERTICAL AXIS WIND MILLS

In Vertical - Axis Wind turbines (VAWT), the main Rotor 'Shaft arranged Vertically and the axis of rotation is Vertical with respect to the Ground.

Fig. 2 Shows a Vertical axis type wind Machine. The key advantage of this arrangement is that the turbine does not need to be pointed Into the wind Streams to be effective because their operation is independent of wind direction and these Vertical axis machines are called 'Panemones'.

- It is an advantage on sites where the wind direction is highly Variable. with a Vertical axis turbine (VAWT), the generator and Gear box can be placed near the ground So the tower does not need to Support it and it is more accessible for maintenance.

* Drawbacks are that Some designs produce pulsating Torque. It is difficult to mount Vertical-axis turbines on towers because they are often installed near the Base on which they rest Such as ground or a building rooftop

- The wind speed is slow at a lower altitude. So less wind energy is available for a given Size of turbine. Air flow near the ground and other objects can create turbulent flow which can introduce issues of Vibration Including Noise and Bearing wear Which may increase the maintenance or Shorten the Service Life.

* However, when a turbine is mounted on a roof top, the building generally redirects wind over the roof and it can double the wind speed at the turbine

- If the height of the rooftop mounted turbine tower is approximately 50% of the Building height, it is near to the optimum point for maximum wind Energy and Minimum Wind Turbulence.

Various types of Vertical - axis wind turbines are as follows

1. Darrieus Rotor
2. Savonius Rotor
3. Multiple Blade Rotor
4. Musgrove Rotor
5. Evans Rotor

a) DARRIEUS ROTOR :

This rotator is shaped such as an Egg Beater and it consists of two or three Curved Blades shaped such as 'Aero foils'

– The driving forces are lifting Forces. This ~~will~~ wind mill needs much less Surface Area. The maximum torque occurs when a blade is moving across the wind of a speed much high than the wind speed.

* Initial movement may be initiated with the electrical Generator used as a motor.

b) SAVONIUS ROTOR :

This type of windmill has hollow ~~cylin~~ circular cylinder Sliced in half and the halves are mounted on a Vertical shaft with a gap in between them.

– There is a Complicated motion of wind through and around the two curved Sheet Aero foils rotates by drag force.

* Torque is Produced by the Pressure difference between the two sides of the half facing the wind. It is quite Efficient but it needs a large Surface Area. It is simple in Construction and it is in Expensive.

c) MULTIPLE BLADE TYPE

It is the most widely used type of wind mill. It has 15 to 20 Blades made from metal sheets.

* The Sail type has three Blades made by stitching out triangular pieces of Canvas cloth. Both these types run at Low speed of 60rpm to 80 rpm.

d) MUSGIROVE ROTOR :

In this Rotor, the Blades are Vertical for normal power Generation. This Rotor has an advantage of Fail-Safe Shunt down in strong winds.

e) EVANS ROTOR :

Vertical Blades twist about a Vertical axis speed for control and a Fail-Safe Shut down.

* Other types of wind mills available for the power Generation are: Four-Blade Dutch wind mill and Propeller type

Fig.3 Shows Various types of Vertical-axis wind turbines (VAWTs). Rotor can also be classified on the basis of their movement at Variable Speed rotor or Constant Speed Rotor

* For water pumping and Small-battery operation, it is desirable to allow the rotor speed to Vary. However, for the Large Scale Generation of electricity, it is Common to operate 'wind turbines at Constant Speed.'

'Variable speed wind turbines' are sometimes used for electricity generation but a power electronic frequency Converter is then required to Connect the Variable frequency Output of the wind turbine to the fixed frequency of the electrical system.

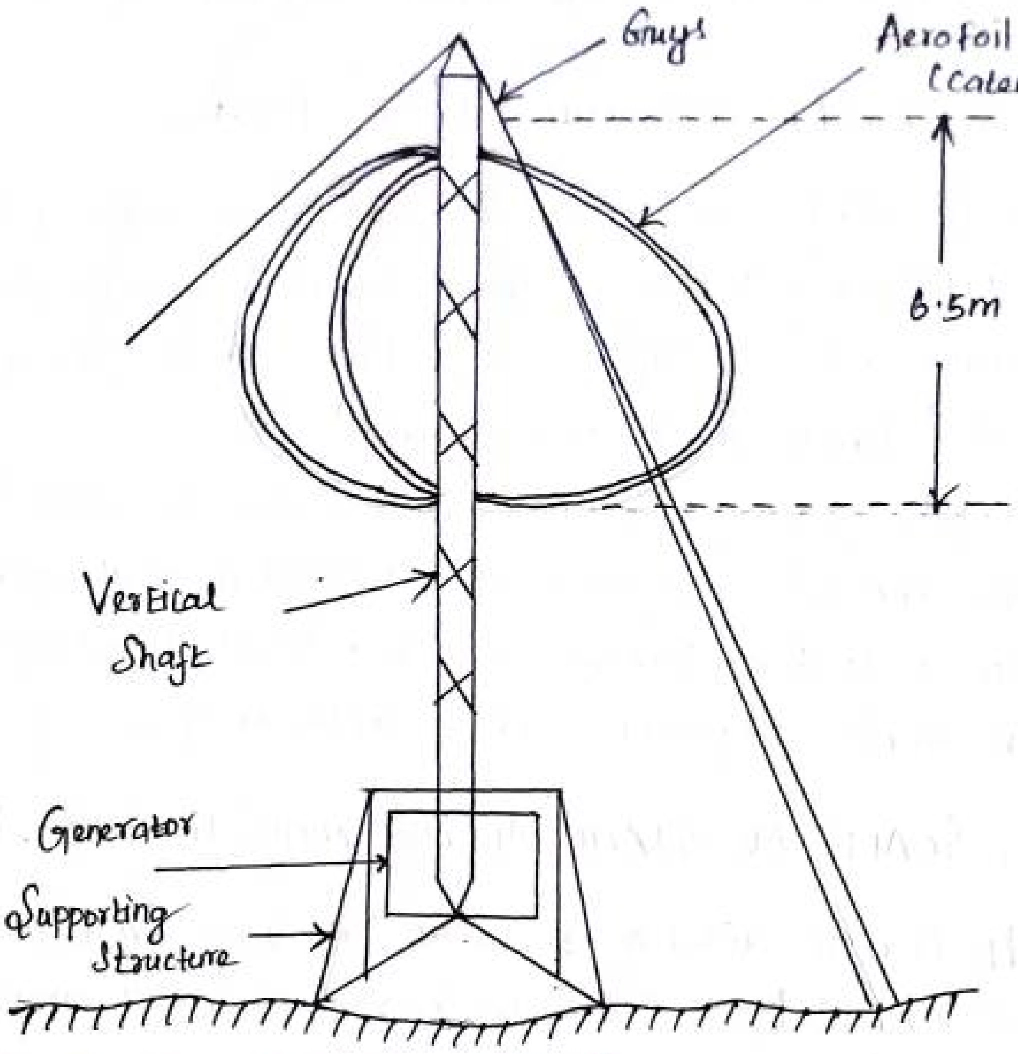


Fig. 2. Vertical axis wind mill.

ADVANTAGES

1. Designs without yaw mechanisms are possible with fixed pitch Rotor designs
2. VAWTs may have a Lower Noise signature
3. VAWTs situated close to the ground can increase the wind velocity.
4. VAWTs have Lower wind start up speeds than HAWTs. Typically they start to generate electricity at 10 km/h.
5. VAWTs may be built at locations where tall structures are prohibited

DISADVANTAGE

1. VAWT which uses Guy wires to hold it, whole weight of the rotor is on Bearing
2. The reversal of stress increases, the chance of failure by fatigue.
3. Changing of VAWTs Parts nearly impossible without dismantling the structure If it is not designed Properly.

TYPES OF WIND POWER PLANTS

1. REMOTE OR OFF-GRID WIND POWER PLANTS :

Areas which are remote but are blessed with good wind speed and frequency need a wind Turbine which is maintenance free or Low-maintenance for long period of time. These types of turbines are Known as 'remote wind power turbines'

* These power plants are used in situations in which remote or Non-Grid connected power is needed but power must always be available, for example, to Keep Vaccines cold or a Rural clinic's Lights on or communications equipment running continuously.

2. SMALL SCALE OR STAND-ALONE WIND TURBINES PLANTS :

It is more suitable for small scale wind power such as domestic systems. Fig. 1 Shows the components and its arrangement for Small Scale domestic wind power system.

* One choice is to have little control so that the output is of Variable Voltage for use as Heat or Rectified power. Such a type of power supply is very useful.

The relatively Small amount of power that usually has to be Controlled at Say 240V / 50 Hz or 110V / 60 Hz Can be obtained from batteries by Inverters

– However it is preferred to have electricity at constant Frequency. Mechanical Control and pitch power Control of wind turbines are generally used for 'Constant Frequency Generation'

iii) MEDIUM SCALE WIND TURBINES PLANTS :

Medium Scale wind power plants are used in Variety of places Such as community Center, Health Clinic or School.

* The Basic aim of the wind turbine is to be a diesel Saver. The diesel generator Supplies power in windless periods.

– A reasonable amount of diesel fuel could be saved with a Control Strategy and System architecture which allows to Shutting down to diesel Generator when the wind is Sufficient to Carry the Load.

In this case, there are two extreme modes of operation.

a) SINGLE MODE ELECTRICITY SUPPLY DISTRIBUTION

It is usually a three-phase Supply that takes Single phase to domestic dwellings with Single Set of distribution cables and the System operates in a Single mode at fixed Voltage 24 hr maintained Supply without Load-management Control depends usually on generation due to non-availability of wind.

The diesel is either left on Continuously Switch-off when excessive wind blows.

- Generally, a large amount (over 70%) of the wind generated power is to be dumped into a Outside Resistor banks owing to the mismatch Supply and demand in windy conditions Shown in fig. 2.

b) MULTIPLE - MODE DISTRIBUTION :

Only the Loads on the Expensive Supply are enabled to Supply Power by a diesel Generator without availability of wind.

* The Economic advantage of multiple mode operation is used at all times. Fig. 3 Shows Schematic arrangement of multiple-mode Supply of Wind / Diesel Supply.

— Large and more costly turbines generally have geared with Power trains for AC output. Also, they are actively focused into the wind.

* Direct drive Generators and Aero elastic blades for large wind turbines are being researched.

IV) HYBRID WIND POWER PLANTS

Wind is not fully Reliable. So, we cannot depend on wind Alone for generating power.

* A wind power plant is combined with some other Renewable Source of Energy such as the SUN or Solar Energy to get more Efficiency. Such an arrangement is known as 'Hybrid Arrangement'

During wind Resource available period, the system might work as single system to produce Electricity. During peak period power demand, the Hybrid system is mainly used in order to meet the demand.

* In addition, Some times, the power system might add 'Biomass' bu hydro or other generating ~~syst~~ Sources in the hybrid system based on the Local Resource Availability.

V) GRID CONNECTED WIND POWER PLANTS :

This concept is similar to a hybrid system and the wind power plant is used in conjunction with a main grid which supplies the most of the power.

*

The main purpose of the wind turbines is to Supplement the energy Supply for the Grid whereas the main function in the hybrid system is to Complement the energy Supply.

– The fig.4 Shows Schematic arrangement of Grid-linked wind Power plant.

VI) WIND FARMS :

Wind Farm is a Collection of wind turbines for generating power in a given area or Utility and hence, the harness of wind force in a collective manner amplifies the Effect of a Single Unit.

* These Configurations are used at Various locations depending on the Conditions of Region and the presence of other Sources for electrical Supply.

– An optimum mix would Consist of an Ingenious combination of Various Sources in the best Fesible manner.

SITE SELECTION FOR WIND ENERGY SYSTEMS

Mainly, four Sites are Selected to install wind mills for the extract of wind Energy. They are as follows

i) Plane Site

ii) Hill top Site

iii) Sea-Shore Site

iv) Off-Shore Shallow water Site

The main Considerations for Selecting a site for wind turbine Installations are as follows

1. Wind Farms are located away from main cities to avoid Resistance to the air movement Created by buildings
2. Wind Power is based on the wind Velocity as the wind power is proportional to the Cubic power of wind Speed.

3. The Selected site should provide good average of wind velocity throughout the year continuous generation of Energy.

4. The proposed site should be checked for high altitude due to strong winds

5. A Stable Ground is Selected

6. Small trees and Grass are avoided under wind mill Inorder to minimise the Installation cost

7. The Site should be near the consumer for reducing the cost and transmission losses of the generated power.

8. Wind direction is also considered for the site selection.

9. The Land cost should be favourable so that the total project cost is minimal

10. Togography such as mountain gap helps to channelise and speed up winds.

11. The Selection of coastal Area or Lake Area for wind mill installation is favourable because land generates wind of sufficient speed.

12. The selected site should be easily accessible to provide a transport facility for the erection of equipment and structures as well as for maintenance.

PERFORMANCE CHARACTERISTICS OF WIND TURBINE ROTORS

1. SOLIDITY :

Solidity is defined as the percentage of circumference of the rotor which contains the material instead of air

* Solidity is calculated by

Percentage of Solidity = 31.8 × No. of Blades × Blade Width × Rotor Diameter

2. TIP-SPEED RATIO :

It is defined as the ratio of speed of the blade Tip of a Wind Mill Rotor to the speed of free wind.

* It is a measure to know the 'gearing Ratio' of the Rotor.

$$\text{Tip-speed Ratio} = \frac{\text{Blade Tip speed}}{\text{Wind Speed}}$$

3. PERFORMANCE COEFFICIENT :

The proportion of power in the wind that the rotor can extract is termed as 'performance Co-efficient (Cp)'

-* It is a function of Tip Speed Ratio which is normally used to classify the type of Rotor.

$$C_p = \frac{\text{Power delivered by the Rotor}}{\text{Maximum Power available in the wind}}$$

4. TORQUE

It is the turning moment produced by the Rotor. It does mainly depend on Solidity and Tip speed Ratio of the Rotor.

PERFORMANCE CHARACTERISTICS OF WIND MILL

The following are the four important characteristics of the wind speeds.

1. CUT-IN WIND SPEED :

It is the wind speed when the machine begins to produce power. It is typically between 3 m/s and 4 m/s (10 km/hr and 14 km/hr).

2. DESIGN WIND SPEED :

It is the wind speed when the windmill reaches its maximum Efficiency.

3. RATED WIND SPEED :

It is also called 'Name plate Capacity'. It is the wind speed when the machine reaches its maximum output power.

* The rated wind speed is typically about 15 m/s (54 Km/hr)

4. CUT-OUT WIND SPEED

It is the maximum safe working wind speed and the speed at which the wind turbine is designed to be shut down by applying brakes to prevent damage to the system.

i) STALLING :

It is the self-correcting or passive strategy which can be used with fixed speed wind turbines.

- As the wind speed increases, the wind angle of attack is increased until it reaches its stalling angle.

ii) FURLING OR FEATHERING :

It is a technique derived from sailing in which the pitch control of the blades is used to decrease the angle of attack which in turn reduces the 'lift' on blades

iii) SURVIVAL WIND SPEED :

This is the maximum speed that a given wind turbine is designed to withstand above which it cannot survive.

* The survival speed of commerical wind turbines is in the range of 50 m/s (180 Km/hr) to 72 m/s (259 Km/hr)

BIOMASS ENERGY

The energy obtained from organic matter derived from Biological Organisms (plants and Animals) is Known as 'Bio energy' Or 'Biomass Energy'

– Animals feed on plants and plants grow through the photo-Synthesis process using Solar Energy.

* ~~Phy~~ Photosynthesis Process is primarily responsible for the generation of Biomass energy. Biomass Energy Resources are available from botanical plants, Vegetation, Algae, Animals and Organisms living on land or in Water.

– Biomass Resources are mainly classified into two categories.

1. Biomass from Cultivated Fields, Crops and Forests.
2. Biomass from Municipal Waste, Animal Dung, Forest Waste, Agricultural waste, Bioprocess waste and Fishery waste.

* Biomass Energy may be transformed either by chemical or Biological Processes to produce Intermediate Bio-fuels such as Methane, Producer Gas, Ethanol and charcoal etc,

– Biomass cycle maintains the environmental balance of Oxygen, CO_2, rain etc, Biomass is used for producing the Process heat and Electricity, Gaseous and Solid Fuels, Liquid and Chemicals.

BIOMASS RESOURCES

Biomass Resources for Energy Production encompass a wide spectrum of materials ranging from Forest, Agriculture, Aquaculture, (fresh and Sea water) and Industrial and Social activities such as food Processing, Urban Refuse etc.,

i) FORESTS :

Forests, Natural or Cultivated, Serve as Sources of Fuel wood, Charcoal and Producer Gas.

- Some fast growing Intensive trees such as Eucalyptus, Poplar and Pine are Specially cultivated for the purpose of Energy.

ii) AGRICULTURAL RESIDUES :

Crop Residues Such as Straw, Rice husk, Coconut shell, Groundnut Shell, Sugar cane, Baggage etc, are gasified to obtain Producer Gas.

iii) ENERGY CROPS :

Certain Cultivated plants produce Raw material for 'Bio-fuels'. They are as follows :

a) SUGARCANE :

It is a Raw material Source for 'Bio-ethanol'. The Sugar cane Stems are milled to obtain the Cane juice which is Subsequent used for Sugar (Sucrose) or Alcohol (ethanol) production.

* The Residual Fraction from the Sugar cane stem milling is named as 'bagasse'. One-third of the total energy is available in Sugar cane and another Similar amount is available in Bagasse, leaves and cane tops.

b) OIL PRODUCING PLANTS :

Oil producing plants Such as Sun flower, Rapeseed, Palm oil, Castor oil, Soybean, Ground nut and Cotton Seed have the Capabilities of Producing Energy.

iv) AQUATIC PLANTS :

Some Water plants grow very fast and provide Raw materials for Producing Biogas or Ethanol.

- These are Water Kelp, Seaweed and Algae, etc,

v) URBAN WASTE :

Urban waste is of two types. They are given below.

a) Muncipal Solid Waste (MSW)

b) Sewage (Liquid waste).

ADVANTAGES AND DISADVANTAGES OF BIO ENERGY

ADVANTAGES OF BIO ENERGY

1. It is a Renewable Source
2. The pollutant Emissions from Combustion of bio mass are usually lesser than Fossiel Fuels.
3. Commerical use of Bio mass may avoid or Reduce the Problems of waste disposal in other Industries.
4. Use of Bio gas plants apart from Supplying Clean Gas also leads to Improved and Stabilized Sanitation.
5. the forestry and Agricultural Industries which Supply feed stocks are also provide Substantial Economic development opportunities in Rural Areas

DISADVANTAGES OF BIO ENERGY

1. It is dispersed and Land Intensive Source
2. It is often of Low Energy density.
3. It is also labour Intensive and the cost of collecting Large quantities of Bio mass for Commerical application is Significant.

APPLICATIONS OF BIO ENERGY :

Biomass is an Important Source of Energy and the most important Fuel world wide after coal, oil and Natural Gas.

* Bio-Energy in the form of Bio gas which is derived from Biomass Gasifier is expected to become one of the Key Energy Resources for Global Sustainable Development.

Biomass Offers higher Energy Efficiency through form of Bio gas than by direct Burning.

* Some of the potential applications of Bio energy are : Cooking, Mechanical applications, Pumping and Power Generation.

Biomass Gasifiers Convert the Solid Biomass (Basically wood waste, Agriculteral Residues etc) Into a Combustible Gas mixture normally called 'Producer Gas'

APPLICATIONS

1. WATER PUMPING AND ELECTRICITY GENERATION :

Using Biomass Gas, It is possible to operate a diesel Engine on Dual fuel mode. Part diesel and Part Biomass Gas.

* Diesel Substitution of the order of 75 % to 80 % can be obtained at Nominal Loads

– The Mechanical Energy thus derived can be used either for energizing a water pump set for Irrigational purpose or for Coupling with an Alternator for electrical power generation of 3.5 KW – 10 MW.

2. HEAT GENERATION :

A few of the devices to which gasifier could be retrofitted are dryers for drying Tea, Flower, Spices, Kilns for Baking tiles or potteries, Furnaces for melting Non-ferrous Metals, Boilers for Process Steam etc.

* Direct Combustion of Biomass has been recognized as an Important Route for generation of power by Utilization of vast amount of Agricultural Residues, Agro-Industrial Residues and forest wastes.

– Gasifiers can be used for Power Generation and available upto a capacity 500 KW.

3 HIGH EFFICIENCY WOOD BURNING STOVES :

These Stoves Save more than 50 %. Fuel wood Consumption.

They also reduce drudgery of women Saving time in Cooking and Fuel Collection and Consequent Health Hazards.

* They also help in Saving firewood leading to conservation of Forests. They also Create employment opportunities for People in the Rural Areas.

4. BIO FUELS :

Unlike Other Renewable Energy Sources, Biomass can be Converted directly into Liquid Fuels and Bio fuels for our transportation needs (Cars, Trucks, Buses, Air planes and Trains).

* The two most Common types of Bio fuels are 'Ethanol' and 'Biodiesel'. Bio diesel produced by plants Such as rapeseed (Canola), Sun Flowers and Soy beans can be extracted and refined into fuel which can be burned in diesel Engines and Buses.

— Bio diesel can also be made by Combining alcohol with Vegetable oil or Recycled Cooking greases.

* It can be used as an Additive, to reduce Vehicle Emissions (typically 20%) or in its pure form as a Renewable Alternative Fuel for diesel Engines.

BIOMASS FUELS

Biomass is an organic Carbon based material that reacts with oxygen in Combustion and Natural Metabolic Process to release heat.

* Some of its forms available to users are given below:

1. Fuel wood
2. Charcoal
3. Fuel Pellets
4. Bio-Ethanol
5. Biogas
6. Producer Gas
7. Vegetable oils (Bio-diesel).

1. FULL WOOD :

Wood is the most obvious and oldest Source of Biomass Energy. Direct Combustion is the Simplest way to obtain Heat Energy.

* Its Energy density is '16-20 MJ/Kg'. It can also be Converted into more useful forms Such as Charcoal or Producer Gas

2. CHARCOAL :

Charcoal is a Clean, dry, Solid Fuel of Black Colour. It has 75-80 % Carbon Content and has energy density of about '30 MJ/kg'

* It is obtained by Carbonization Process of woody Biomass to achieve higher Energy density per unit Mass. It is also used for making high quality Steel.

3. FUEL PELLETS :

Crop Residues Such as Straw, Rice husk, Cow dung etc., are Pressed to form lumps Known as 'Fuel pellets' and used as Solid Fuel.

4. BIO-ETHANOL :

Ethanol (C_2H_5OH) is a Colourless Liquid Bio fuel. Its Boiling point is 78°C and Energy density is 26.9 MJ/kg

- It Can be derived from wet Biomass Containing Sugar Starches or cellulose. Commerical Ethanol is used in specially designed IC Engines

5. BIOGAS :

Organic wastes from plants, Animals and humans Contain enough energy to Contribute Significantly to energy Supply in many Areas.

* Biogas is Produced in a Biogas Fermenter or digesters. If a Raw material is Cow manure, the output biogas will contain about 50 % to 60 % CH_4, 30 % to 40 % CO_2, 5 % to 10 % H_2, 0.5 % to 0.7 % N_2 with trace amounts of O_2 and H_2S.

- It energy density is about 23 MJ/m^3. It is used for Cooking, Lighting, Heating and Operating Small IC Engines etc.,

6. PRODUCER GAS

Woody matter Such as crop Residue, Wood Clips, Bagasse, Rice husk, coconut shell etc, can be transformed to Producer Gas (Wood Gas, Water Gas or Blue Gas) by a method known as 'Gasification' of Solid Fuel.

* The gas production depends upon the type of biomass and the design of Gasifier.

7. VEGETABLE OILS (BIO-DIESELS)

It can be used as Such or Blended with diesel as a Diesel Engine Fuel.

BIOMASS GASIFICATION

The word gasification implies the conversion of Solid Fuel into a Gaseous Fuel by a thermo-chemical method without leaving any Solid Carbonaceous Residue.

* Gasifier is equipment which converts Biomass into Producer gas. Most common Raw materials are given below:

1. Wood chips
2. Coconut shells.
3. Straw
4. Rice Husk.

Gasification involves the partial combustion and Reduction operations of Biomass.

* In a typical combustion Process, the combustion products mainly Carbon dioxide, Water Vapour, Nitrogen, Carbon Monoxide and Hydrogen Pass through glowing Layer of Charcoal for the reduction process to occur.

– The Composition of gas Production depends on the degree of equilibrium among Various Reactions.

UNIT - V

GEOTHERMAL AND OTHER RENEWABLE ENERGY SOURCES.

The thermal Energy Contained in the Interior of the earth is Called " Geo thermal energy ". The Geo thermal energy is enormous and last for Several milions of years. Hence It is called "Renewable Energy"

* Energy Present as heat (Thermal Energy) in the earth's Crust. The more readily accessible heat is in the upper most (10 km) This heat is apparent from the increase in temperature of the earth with increase in depth below the Surface.

Although higher and Lower temperature occur, the average temperature at a depth of 10 km is 200°C. The molten rock within the earth is Called " Magma "

* It is Commonly present at a depth of about 32 km on an average with the temperature of about 3000°C. In Some places anomalous geologic Conditions cause the Magma to be pushed up towards the Surface where the heat of the magma is being Conducted upward through an overlying Rock Layer.

– Fig. 1 Shows a typical Geo thermal Field. The hot magma near the bottom Surface Solidifies into igneous Solid Rock (B). The heat of Magma is Conducted upward to this igneous Rock.

* Ground Water which finds its way down to this Rock through Cracks is heated by the heat of Rock or by mixing with hot Gases and Steam Coming from magma. The heat is transported from hot rocks by Circulating movement. Then the heated water Convectively rises upward into a Porous and Permeable Reservoir above the Solid Rock.

OCEAN THERMAL ENERGY CONVERSION (OTEC)

Energy is available from the ocean by

i) Tapping Ocean Currents

ii) Using the Ocean as a heat Engine

iii) Tidal Energy

iv) Wave Energy.

Rivers, Oceans, Large lakes and bays are in the form of huge Reservoirs Considered as Renewable Energy Sources which are useful to generate Electrical Energy.

* In the world, the energy available through ocean is around 130×10^6 MW. Due to Various reasons, only less amount of energy can be economically recovered. 70% of the earth's Surface is occupied by Salt water.

- There are five principal oceans as follows:

i) Indian Ocean

ii) Atlantic Ocean

iii) Antartic Ocean

iv) Pacific Ocean

v) Arctic Ocean

Ocean TEC is an Energy technology that Converts Solar Radiation falling on the ocean Surface into electric power. The use of Stored thermal Energy by Solar Radiation from Oceans was first Proposed by a French physicist d'Arsonval in 1881.

* OTEC Systems use the ocean's Natural thermal Gradient. The temperature difference between warm Surface water on the upper Layer of ocean and cold deep water below 600m is about 20°C.

An OTEC System can produce a Significant amount of power using thermal Gradient. The oceans are vast Renewable resources with the potential to help in producing billions of watt of electric Power.

* The cold Sea water used in OTEC process is also rich in Nutrients and it can be used to Culture both Marine Organisms and Plant life near the Shore or on Land.

Lambert's Law States that each layer of equal thickness absorbs the fraction of Light that passes through it. Solar Energy absorption by Sea water according to Lambert's Law of Absorption is given by

$$-\frac{dI(x)}{dx} = KI$$

$$\therefore \boxed{I(x) = I_0 e^{-Kx}}$$

Where, I_0 and $I(x)$ are Intensities of Radiation at the surface $x=0$ and x.

K = Extinction Coefficient or Absorption Coefficient.

= $0.05\ m^{-1}$ for Clean Fresh Water

= $0.27\ m^{-1}$ for dirty water

= $0.50\ m^{-1}$ for Salty water

Thus, Solar Intensity decreases exponentially with depth. It depends upon 'K'. Almost all absorption occurs very close to the Surface of deep water. Water density decreases with an increase in Temperature.

– Thus it occurs no thermal Convection Current between Warmer and Colder Regions. Hence, the Ligher water is at the top and Colder and Heavier water is at the bottom. Thermal Conduction Heat Transfer between them across the large depths is Very Low.

Thus, the mixing is retarded. There are essentially two infinite Heat Reservoirs, a heat Source at the Surface of around 25°c and a Heat Sink of about 4°c at a distance of nearly 1000 m below the Surface in Tropical Ocean.

* Both Reservoirs are maintained annually by Solar Radiation. The Concept of OTEC is based on the Utilisation of this temperature difference in a Heat Engine to generate electrical power.

- The first OTEC plant was built in 1930 in Cuba by 'George Claude' and the plant generated 22 kW of electricity. Claude plant is the Second plant in 1935 was made of the Coast of Brazil and was mounted onto a Large Transporter Tanker

* OTEC Cogeneration plants deliver electrical energy and Fresh water. The unit size of turbine generators is in the range of 10 MW to 50 MW. The plant ratings are of 50 MW and 100 MW.

- OTEC technologies require high Capital cost and are difficult. The reason is that the temperature difference even in the tropical Region is less and hence, the efficiency is also less. The theoretical efficiency of OTEC is Small (~2%).

PRINCIPLE OF OTEC

Ocean Thermal Energy exists in the form of temperature difference between Warm Surface water and Cold deep water. The absorption of Solar Radiation by the Sea and Ocean Causes a moderate temperature difference between upper and Lower levels of water.

* Particularly, the oceans in the tropical Region collect and store a Large amount of Solar Energy. this Stored heat Energy can be converted Into work with the help of thermodynamic cycle. It is called 'Ocean thermal Energy Conversion.

- OTEC is a Very clean form of Energy. It has Virtually no dangerous pollution Risk.

OTEC is a method of producing electrical energy from difference in water temperature. The upper surface of the ocean water gets heated up naturally due to solar radiation similar to a solar collector and it is considered as infinite heat storage reservoir.

* The warmest water is found around the equator with surface water reaching a maximum temperature of 24°c to 27°c whilst the deep water can reach the temperature close to 0°c. The

- The OTEC system uses this change in temperature of the sea water to run a heat engine which converts the heat energy into mechanical work.

* For OTEC to work, there is a need of a minimum temperature difference between warm water and cold water of 20°c over a 1000 m depth. Systems at 20°c are very inefficient but they become more efficient with greater temperature difference.

• The most commonly used heat cycle for OTEC is a "Rankine cycle" using a low-pressure turbine. Systems may be either i) Closed cycle or ii) Open cycle.

i) CLOSED-CYCLE ENGINES

It use working fluids which are typically of refrigerants such as Ammonia or R-134a.

ii) OPEN-CYCLE ENGINES

It use the water heat source as the working fluid.

* A heat engine is operated between two temperatures such as T_1 and T_2. Here, 'T_1' is considered as a source temperature which is the temperature of 'warm surface water' of ocean and the sink temperature which is the 'cold deep water' of ocean is 'T_2'

- According to thermodynamic concept, the maximum theoritical efficiency of the heat engine based on Carnot cycle is given by

$$\eta_c = \frac{T_1 - T_2}{T_1}$$

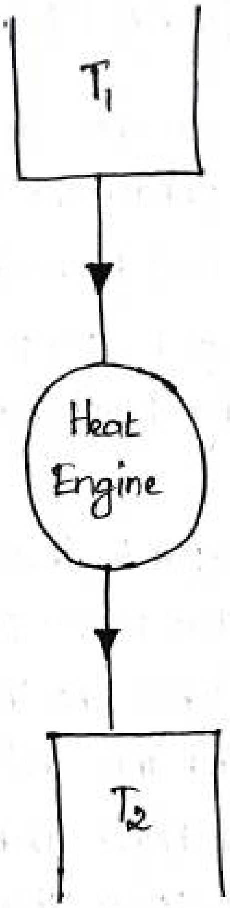


Fig. 1. Heat Engine

The average Surface temperature of tropical Ocean water is the range of 24°C and 27°C and the deep water temperature is about 4°C to 6°C per Km depth.

Thermal Efficiency of the cycle, $\eta_c = \frac{27-6}{27+273} \times 100 = 7\%$

* The actual efficiency of Practical OTEC plant Varies from 1.5 % to 2 %. The OTEC plant Should have the following to Increase its Efficiency.

i) Large Intake of Warm water

ii) Large Number of Units required to generate Large amount of Power.

The Above mentioned factors will lead to the requirement of Large Pipeline, Pumps, Heat Exchanger, Large plant Size, High cost of Installation High cost for Power Generation etc.,

SETTING OF OTEC PLANTS

Warm Water is Collected on the Surface of the tropical ocean and pumped by a warm water pump. The water is pumped through the Boiler where Some of water is used to heat the Working Fluid.

* The working Fluid may be propane or Some Similar Fluids. If a Cooler is used, the working Fluid having Low boiling point Such as 'Ammonia' is Selected.

- The propane Vapour expands through a turbine which is Coupled to a generator to generate electric power. Cold water from the bottom is pumped through Condensers where the Vapour Comes to the Liquid State. The fluid is pumped back into the Boiler.

* Some Small fraction of Power from the turbine is used to pump Water through the System and to power other internal operations but most of them are available as net power.

- There are two different Kinds of OTEC power plants Such as

~~Land~~ i) Land Based plant

ii) Floating Power plant

LAND-BASED POWER PLANT

The land based pilot plant has a building. This building will Contain Heat Exchangers, Turbines, Generators and Controls. It willbe Connected to the Ocean Via Several pipes

- First, Power input is Supplied to pumps to Start the Process. Fluid pump pressurizes and pushes the working Fluid to 'Evaporator'. Heat addition form hot water is used to evaporate the working Fluid within the heat Exchanger called 'Evaporator'

* The Vapour is expanded in the turbine thereby rotating the Shaft which is directly Coupled to the Generator. Therefore the electrical energy is produced in the Generator. The expanded Vapour is Condensed in the condenser. The Condensation is Carried out by Supplying Cold Water.

FLOATING POWER PLANT

The working principle of Floating Power plant is Similar to the Land-based plant but it differs in Construction as plant is 'Floating'

THERMO DYNAMIC CYCLES IN OTEC

There are two types of OTEC thermo dynamic Cycles as follows:

1. Open cycle (Claude Cycle, Steam cycle).
2. Closed cycle (Anderson cycle, Vapour cycle)

Both open and Closed OTEC Systems use the temperature difference between warm Surface water and Deep cold water to create a Pressure difference that can be used to generate Electricity.

OPEN CYCLE OTEC SYSTEM

In an open OTEC System, the Cold water is used to reduce the Pressure in the part of the System So that the warm Surface water actually get boiled into a Vapour at 80°F. The warm Ocean water is Converted Into Steam in an 'Evaporator'.

The Steam drives Steam-Turbine generator to deliver electrical Energy. A Specially designed Steam turbine drives the Electrical Generator. the Water Vapour travels from high-Pressure warm side of the System through a turbine to drive a generator and Into the Low-Pressure Cold side of the System.

– Then, the Vapour Condenses into desalinated water. Steam is Condensed In a Contact Condenser and Condensate is discharged into Sea by an "Open Cycle OTEC"

ADVANTAGE:

The big advantage of open System OTEC is that the desalinated Water effluent has multiple uses especially drinking water and it Can increase the Economic Efficiency by over 30%

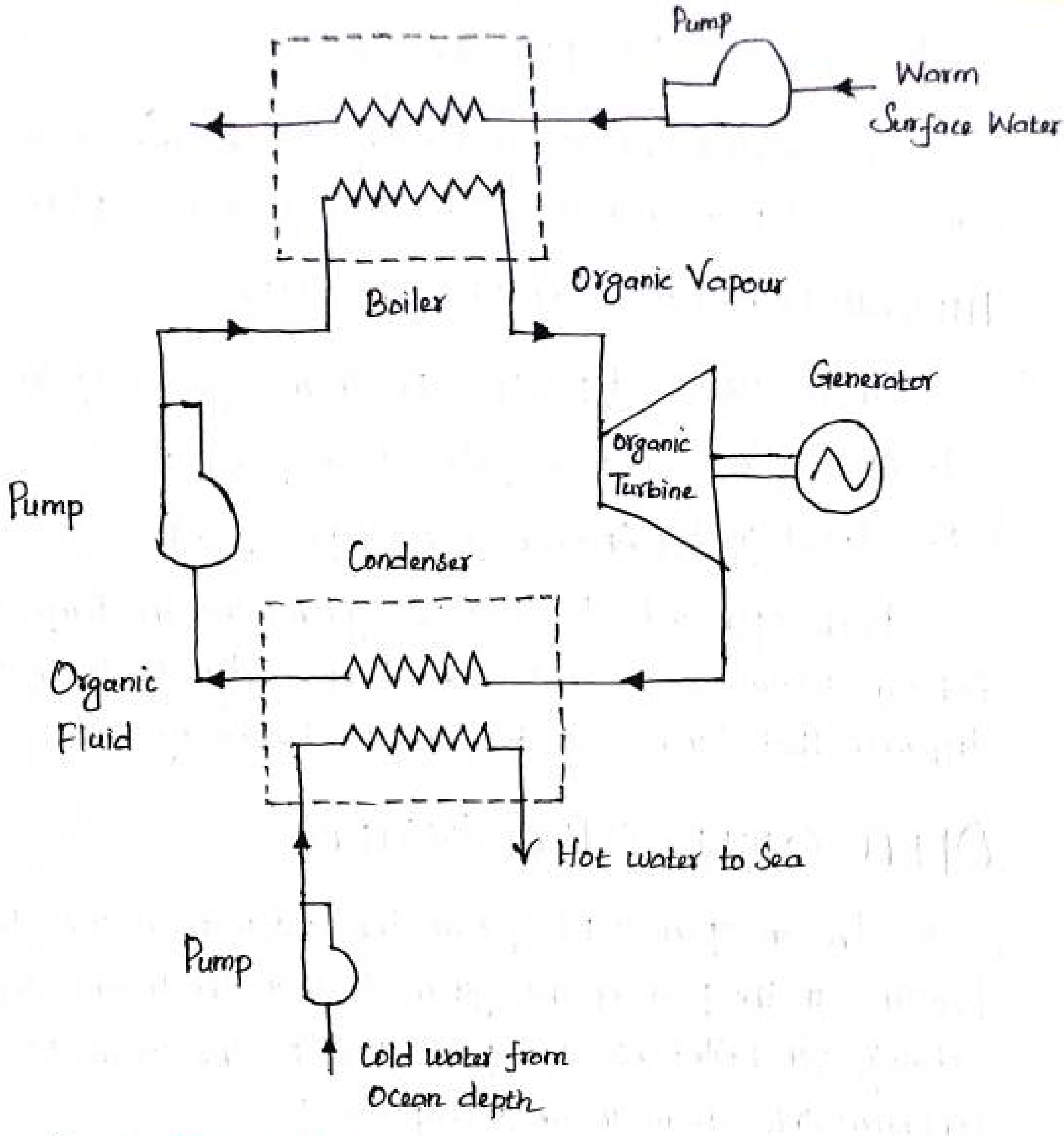


Fig. 1. OTEC plant.

Warm water is collected through a screened enclosure close to the shore. A long pipe laid on the slope collects the cold water. Power and fresh water are generated in the building by the equipment.

* Used water is first circulated into the marine culture pond (Fish Farm) and then it is discharged by the third pipe into the ocean, downstream from the warm water Inlet.

- It is done to avoid the re-entering of outflow to the plant since the reuse of warm water reduces available temperature difference.

* A land based plant costs three times as much per unit power output. One advantage of land based power plant is that it makes the process easy use of some of by-products without any Expensive Transport

WORKING OF OPEN CYCLE OTEC

In an open cycle OTEC, warm water from Ocean Surface (at about 26°C) is admitted into the Evaporator. The Evaporator is maintained at Vacuum Pressure by means of a Vacuum Pump.

* At low Vacuum Pressures, the boiling Point of water reduces and more Steam is generated. Steam generated in the Evaporator enters into a special Steam turbine ~~Gen~~ and the remaining water from ~~Eva~~ Evaporator is discharged into the Sea.

– Steam turbine Converts Thermal Energy into Mechanical Energy. Steam leaving the Evaporator is Comparatively at Low Pressure and High Specific Volumes as Compared to Conventional power plants.

* The Steam admitted in Steam turbine drives the steam turbine rotor and It is exhausted to the Condenser. Exhaust steam from turbine is Condensed and dischaged in the Ocean at 7°C. Cold water from deep Sea is admitted into the condenser. The temperature of cold water is about 15°C.

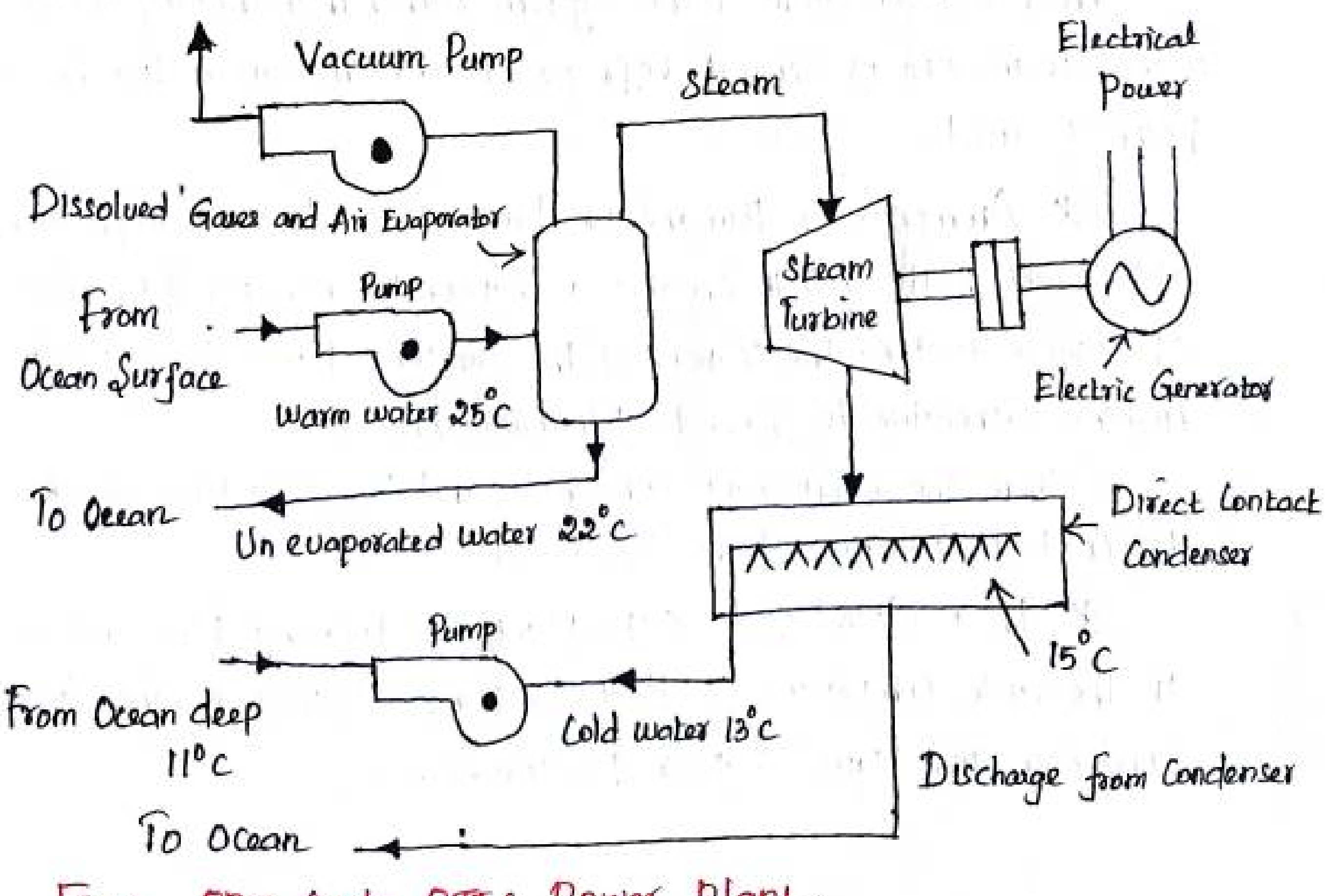


Fig. 1. Open cycle OTEC Power Plant.

The efficiency can be increased slightly with modified open cycle OTEC System. They are follows.

i) Controlled flash-Steam Evaporator is used instead of a Conventional type of Evaporator

ii) Contact Condenser is replaced by a Surface Condenser.

iii) The open cycle OTEC can be used as a Cogeneration cycle to produce both Electrical power and Fresh water

LIMITATIONS OF OPEN CYCLE OTEC SYSTEM

1. Turbine is physically Large
2. The cost of plant is High
3. It can allow a Very large flow of Ocean water interms of Mass and Volume
4. The plant is Subjected to ocean storms, High waves etc,

CLOSED CYCLE OTEC SYSTEM

In a closed cycle OTEC System rather than boiling water to make steam, one of several refrigerants which have a low boiling point is used.

* Ammonia or Butane or Freon is used as a 'Refrigerant'. The refrigerant boils and it creates a Vapour when exposed to the warmth of Surface water. The Vapour of the working Fluid drives a Vapour turbine Generator to generate Electrical Energy.

– Then, the refrigerant Condenses and losses the pressure when exposed to cold Temperature from deep water.

* In a closed cycle OTEC plant, the working Fluid is circulated in the cycle comprising of Heat Exchanger, Vapour Turbine, Surface Condenser and Liquid Vapour pressuriser.

WORKING

The working fluid (Ammonia, NH_3) is circulated through the closed cycle comprising of the following components.

1. Evaporator
2. Vapour Turbine (Turbo generator)
3. Vapour Condenser
4. Liquid Pressurizer.

The working fluid extracts heat from the warm ocean water and it is vapourised. The vapour having thermal energy is expanded in the vapour turbine. This vapour turbine drives the electrical generator rotor and thus, the power is produced

* The expanded vapour, from the turbine is condensed in the 'Condenser'. Liquified working fluid is passed through pressuriser into the 'Evaporator'. The working fluid is circulated again and again through the closed cycle to generate power continuously.

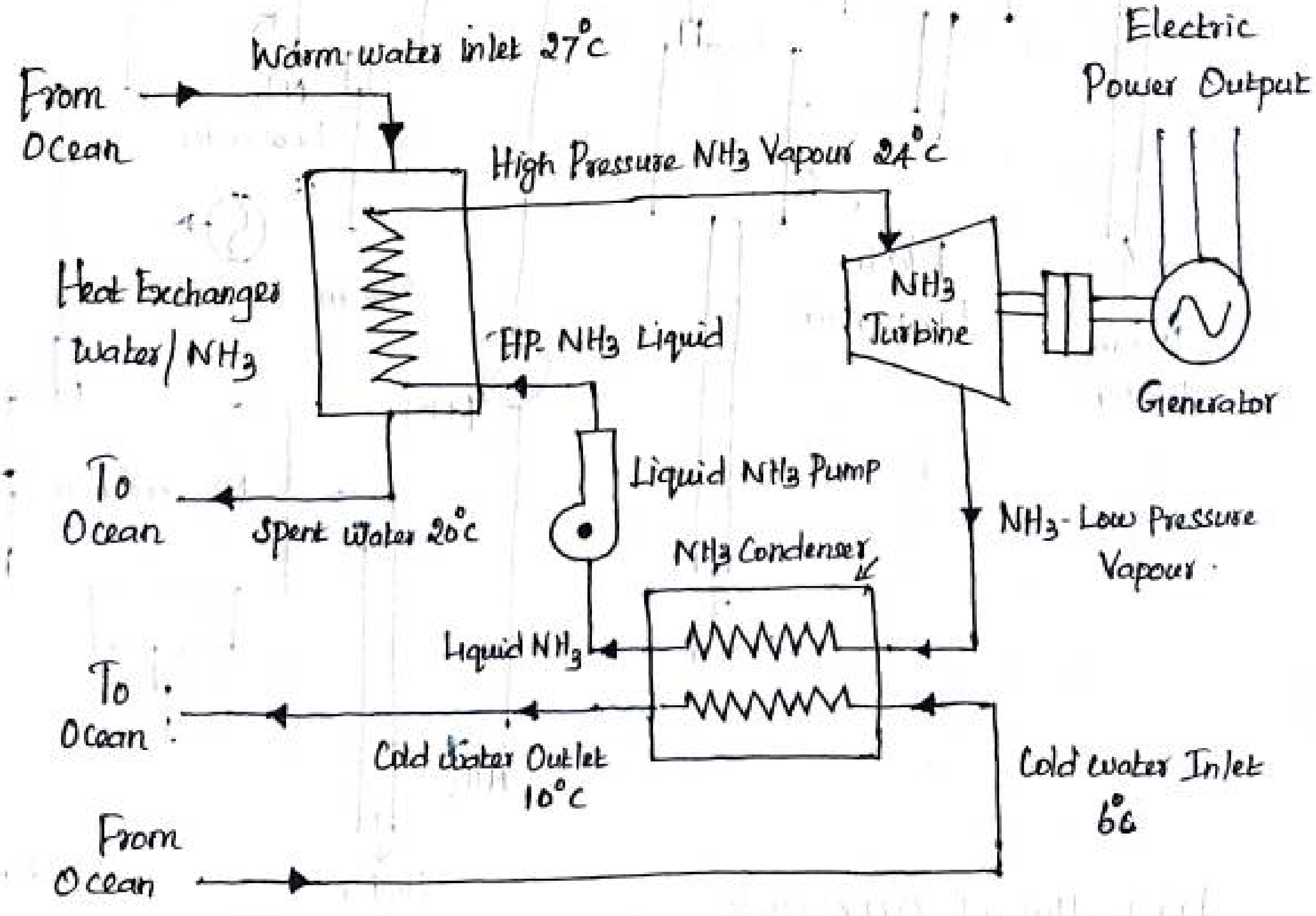


Fig.1. Closed cycle OTEC Plant.

HYBRID OTEC

In a Hybrid System, the Closed System OTEC or Open System OTEC is combined with other System that can offer some of the advantages of each System.

* The Essence of both open and closed system OTEC is that they bring cold water from depth and use it with warm surface water to generate Energy.

– Another option is to combine these two processes together into an Open-cycle or closed-cycle Hybrid which might produce both electricity and desalinated water more Efficiently.

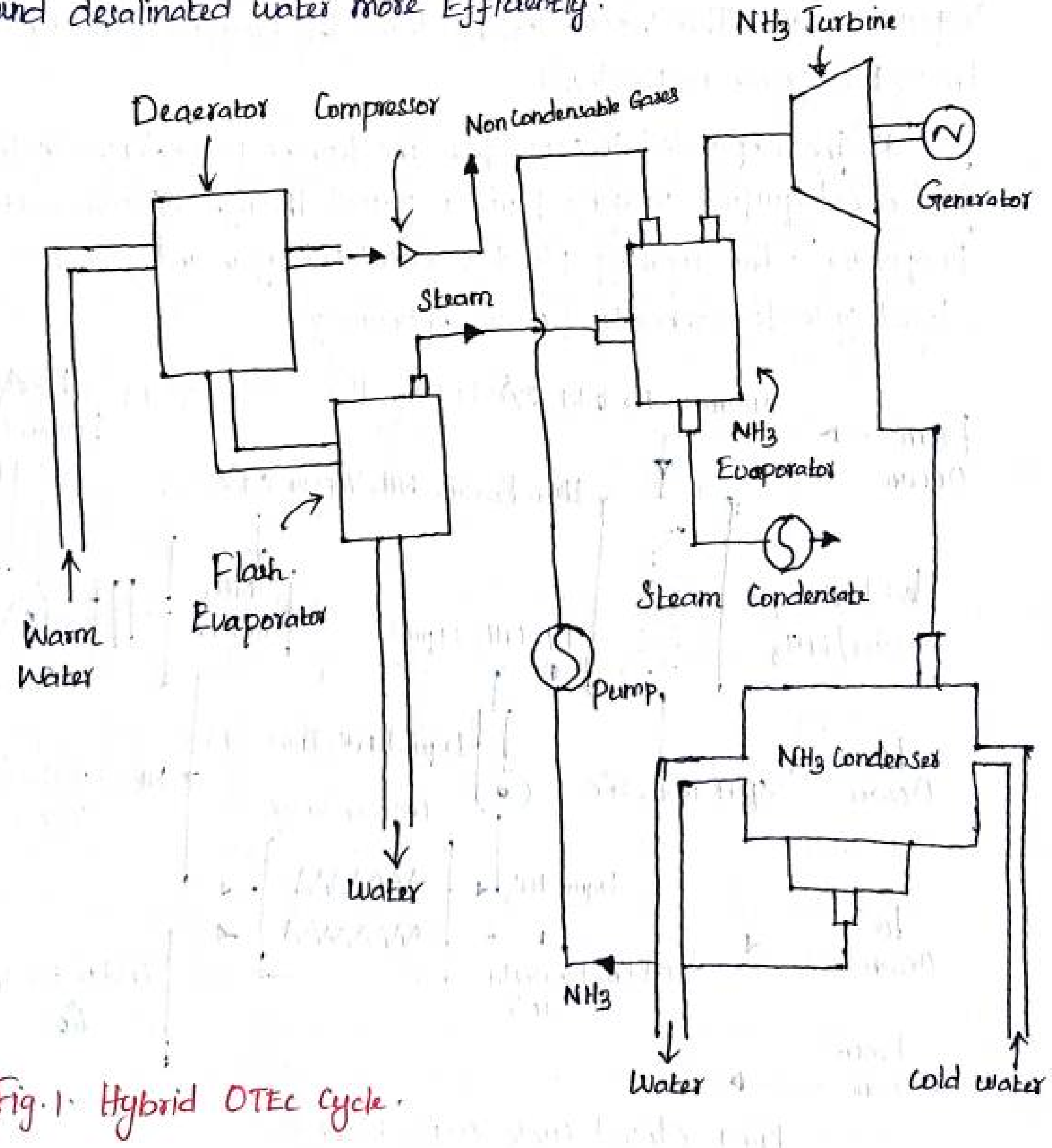


Fig. 1. Hybrid OTEC Cycle.

There are two methods used to run the 'Hybrid cycle'. In the first type of a hybrid OTEC System, the warm Sea water might enter a Deaerator where it would be Flash-Evaporated into Steam which is Similar to the 'Open-Cycle Evaporation Process'

* The Steam or Warm water might then pass through an Evaporator to Vaporize the working Fluid of a 'Closed-cycle Loop'. The Vaporized Fluid would then drive a turbine to produce Electricity, while the Steam would be Condensed within the Condenser to produce the desalinated water.

— In the Second type of a hybrid OTEC System, the Steam Coming out of a Flash Evaporator is Sent to the Ammonia Evaporator which has Low boiling point. Here the Super heated Ammonia is Produced and it will be Sent to Ammonia Turbine for Further Expansion to produce Electrical Generation.

* The Expanded Ammonia Vapour is Condensed in the Ammonia Condenser and pumped back to Ammonia Evaporator. Fig.1 Shows this type of OTEC System.

ADVANTAGES OF OTEC

i) Power from OTEC is Continuous, Renewable, Pollution free and Environmentally.

ii) Unlike other forms of Solar Energy, the Output of OTEC Shows Very little daily or Seasonal Variation.

— OTEC power plants Can Produce electricity 24 hours a day or 365 days a year

iii) Drawing of warm and cold sea water and returning of the Sea water, close to the thermocline, could be accomplished with minimum Environment Impact.

iv) Electric power generated by OTEC Could be used to Produce 'Hydrogen'

v) Tropical and Sub-tropical Island sites could be made free from pollution Caused by Conventional Fuels for Electricity Generation.

vi) OTEC System might help in Enrichment of Fishing grounds due to the Nutrients from the Unproductive deep waters to the warmer Surface waters.

vii) A Floating OTEC plant can generate power even at mid sea and can be used to provide power for Off shore Mining and processing of Maganese Nodules.

viii) Either open or Closed system OTEC Could be used in either On shore or Off shore Systems.

DISADVANTAGES OF OTEC

i) Capital Investment is Very High.

ii) Seasonal Variations and Natural Calamities affect OTEC performance

iii) Due to Small Temperature difference in between the Surface water and deep water, the Conversion Efficiency is Very Low about 3-4%.

iv) Low Efficiency of these plants coupled with high Capital cost and Maintenance cost makes them uneconomical for Small plants.

v) Construction of OTEC plants and laying of pipes in Coastal water may Cause a localised damage to reefs and near-shore marine ecosystems.

vi) It needs Very large Sized turbines due to the use of Low pressure of Steam having high Specific Volume in case of open cycle.

APPLICATIONS OF OTEC

i) Open cycle OTEC plant is used to Produce desalinated water which is mainly used for irrigation and Human Consumption.

ii) A closed cycle OTEC plant is used as a Chemical Treatment Plant.

iii) In majority of the air Conditioning Plant, open cycle OTEC is used

iv) The power generated by OTEC plants Can be used in Hydrogen Production through water electrolysis Process

Types of Tidal Stream Generators

They are major three types of Tidal Stream generators as follows:

a) Axial Turbines

b) Vertical and Horizontal Axis Cross flow Turbines.

c) Helical Turbine

Axial turbines are close in Concept to traditional windmills Operating under the Sea. Vertical and Horizontal axis Cross Flow turbines Can be deployed either Vertically or Horizontally.

* Generally, Horizontal Flow turbines are selected. Vertical axis Cross-flow Turbines are used with ebb generation.

1. Horizontal-Axis Tidal Turbine (HATT)

Horizontal-Axis Tidal Turbines (HATT) are the most mature and Promising Technology in Several Companies.

– HATT basically works on the Same principle as a Horizontal-Axis wind Turbine. Mainly, Pelton turbine is used as HATTs. HATT rotor blades Convert the Tidal current Kinetic Energy into the shaft Mechanical Energy and a Generator Converts this Mechanical Energy into Electricity.

* Irrespective of Configuration used, the Rotor blade is the Important Component to extract Energy from Tides.

– It mainly elaborates the performance, Loads and dynamics of the whole Turbine System. Therefore, an Efficient blade design is Critical to the Success of the HATT.

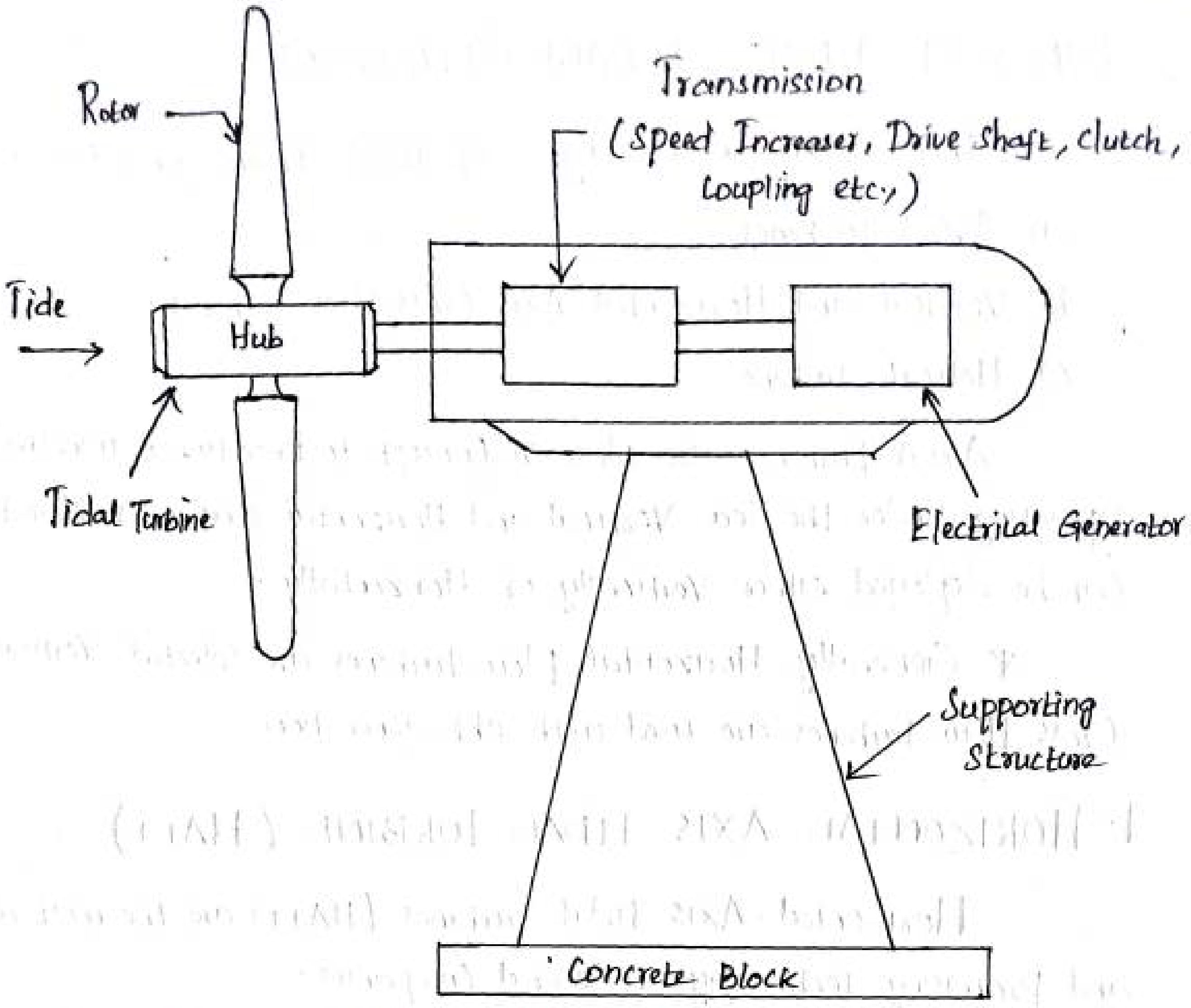


Fig.1. Horizontal Axis Tidal Turbine

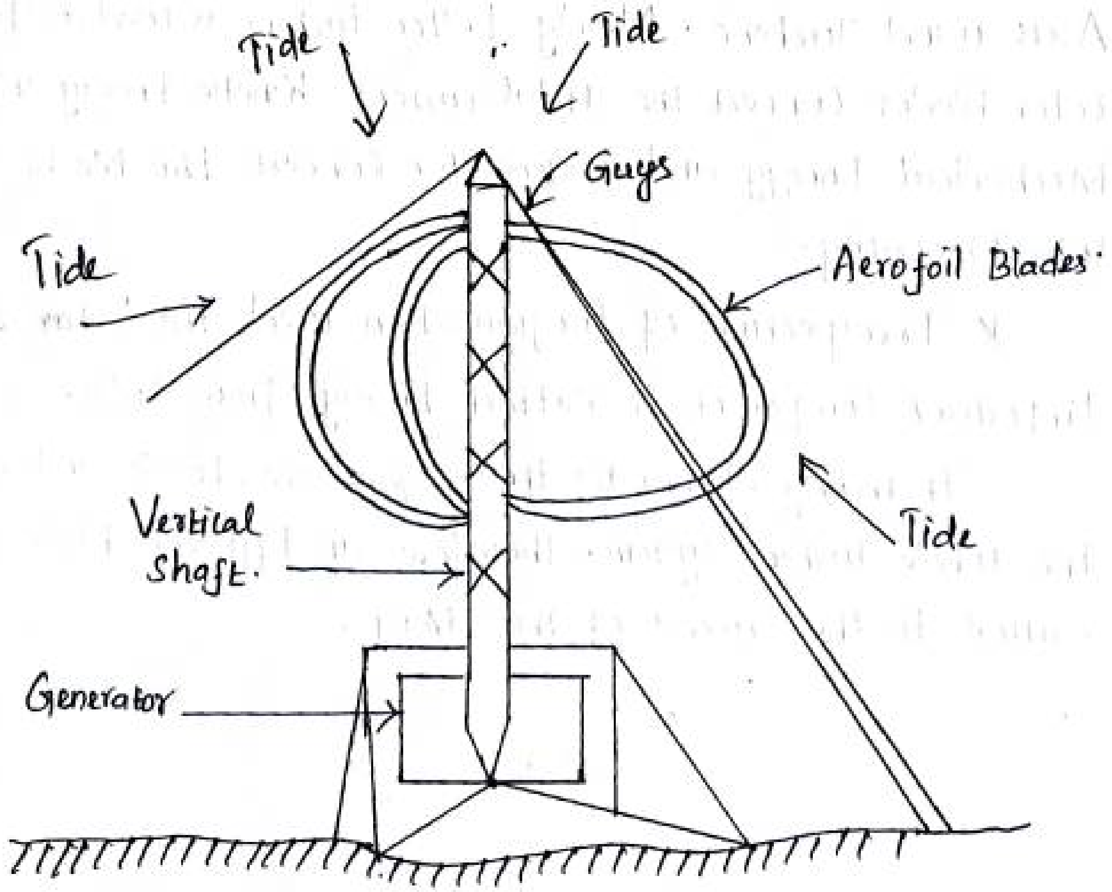


Fig.2. Vertical Axis Tidal Turbine.

2. HELICAL TURBINE

Tidal Energy can be captured efficiently and inexpensively using the helical turbine. Fig.1 describes the construction of helical Turbine which is Self-explanatory

Features of Helical turbine

i) It is designed for hydroelectric Applications in free-flowing water.

ii) It operates in Ocean, Tidal and River Currents.

iii) It does not require Expensive dams that can harm the Environment.

iv) It is Self-Starting with flow as low as 0.6 m/s.

v) It runs Smoothly.

vi) It rotates in the Same direction regardless of the direction of Flow thereby making it ideal for Tidal Applications.

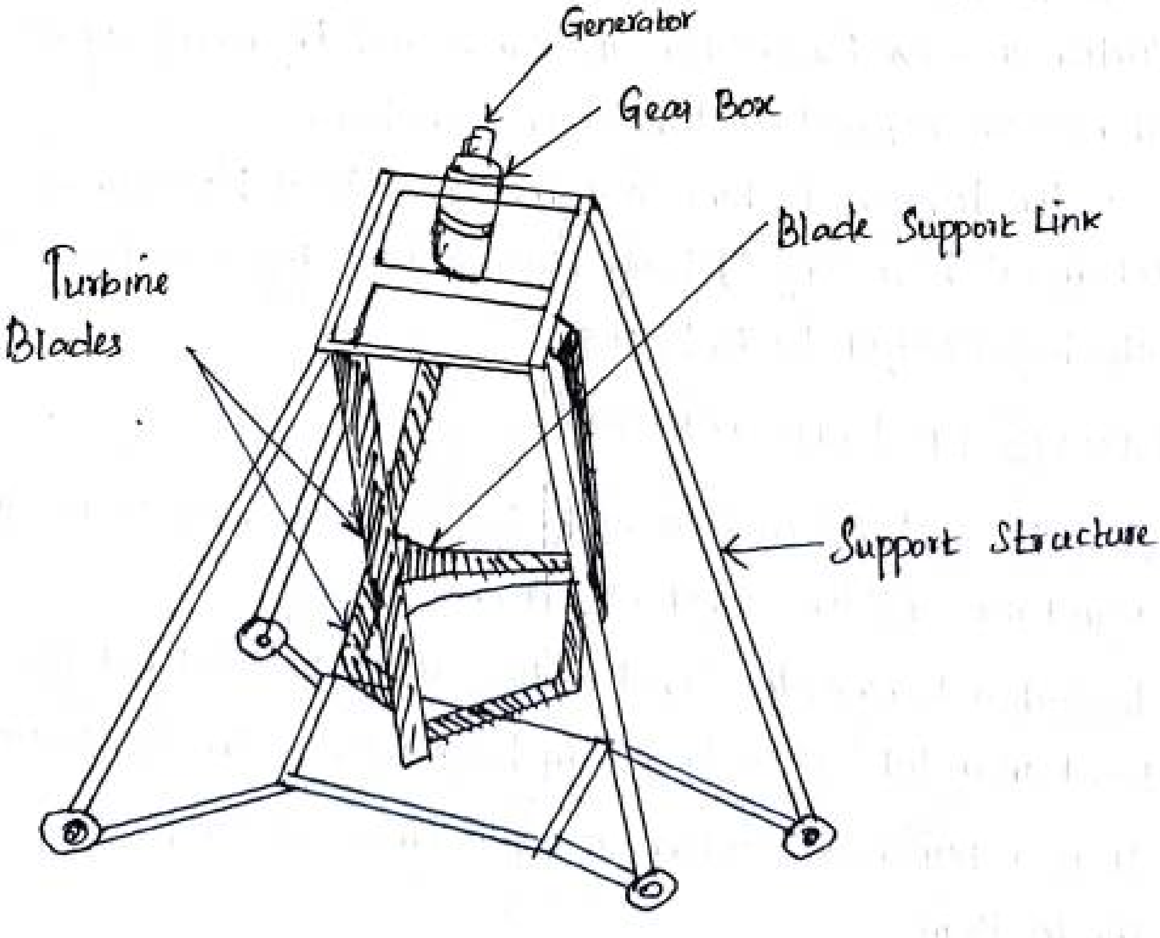


Fig.1. Helical Turbine.

TYPES OF TURBINE

There are many types of turbines used in Tidal power stations as follows

a) Bulb turbine

b) Rim turbine

c) Tubular Turbine

a) BULB TURBINE (TUBULAR TURBINE)

In this type, the electric Generator coupled to the Kaplan Turbine is enclosed and works inside a straight passage having the shape of a Bulb.

– The water tight Bulb is submerged directly into a stream of water and bends at inlet to casting, draft tube etc, which are responsible for the Loss of head dispensed.

* The Unit then needs Less Installation space with a consequent reduction in ~~area~~ Excavation and other civil Engineering works. These turbines are referred as Tubular or Bulb turbines

– The tubular turbine is a modified Axial Flow turbine. The Economical harnessing of Fairly Low heads on major rivers is possible with high-Output Bulb turbines.

FEATURES OF BULB TURBINES :

i) A tubular Bulb turbine is an Axial Flow turbine with either adjustable or Non-adjustable Runner Vanes

ii) In such a turbine, the Scroll Casting is not provided but the runner is Placed in a tube extending from head water to the Tail water.

iii) It is a Low head Turbine and it is employed for head Varying from 3m to 15 m.

iv) The disposition of Shaft in a tubular Turbine may be Vertical or inclined or horizontal.

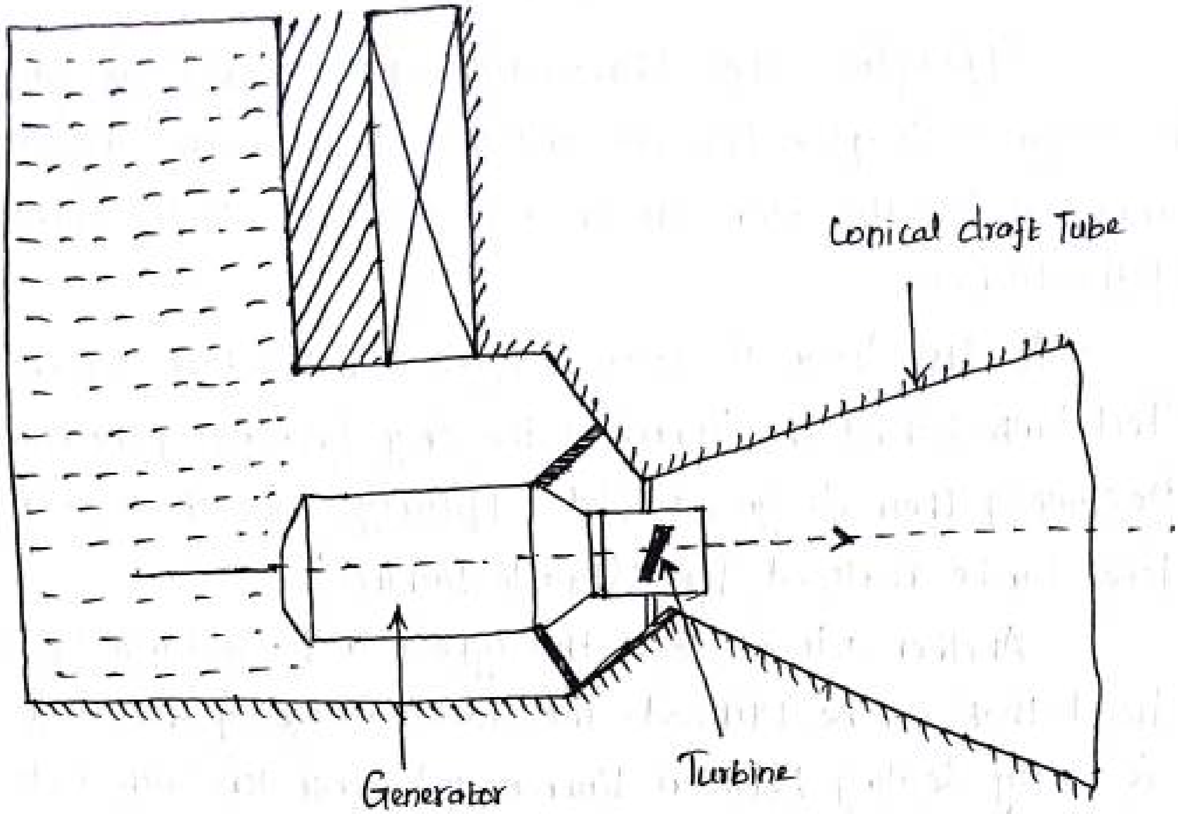


Fig. 1. Bulb Turbine

ADVANTAGES :

i) Due to the Absence of Spiral Casting, the plant width is Small.

ii) It can be used for the sites having Very Low head

iii) Because of almost Straight flow and Straight draft tube, the Maximum turbine Efficiency is Increased by 3 %.

iv) Bulb Units are able to pass higher discharge

v) At Part Loads, there is reduced Loss of Efficiency

vi) It is quite Suitable for operation on widely Varying heads.

vii) Because of Small dimension of Power house, there is Saving in excavation and civil Engineering works.

DISADVANTAGES :

i) Leakage of water into generator chamber and Condensation are Sources of trouble.

ii) The Erection techniques may be time-Consuming.

b) RIM OR STRAFLO TURBINE

Straflo is the abbreviation of Straight Flow which is similar in design as Kaplan turbines and it operates with external Rim Generators i.e., the rotor sits on a ring attached to the Runner blades of the turbine

* Its design is shown in fig.2. In this type of turbine, the Steel Bulb behind the Runner is the only bearing of the turbine. Because of their design, a flat Efficiency curve at an overall high level can be realized for "Straflo-turbines"

- Another advantage in this type is a Large range of Output and head that can be Utilized. The disadvantage of this design is that it is costly Sealing between Runner and Generator. Such a design requires Smaller size of the power House.

* Rim turbine reduces these Problems due to mounting a Generator in the Barrage which is at Right angle to turbine blades shown in fig.2 Unfortunately, it is difficult to Regulate the Performance of these turbines and it is not Suitable for the use in pumping.

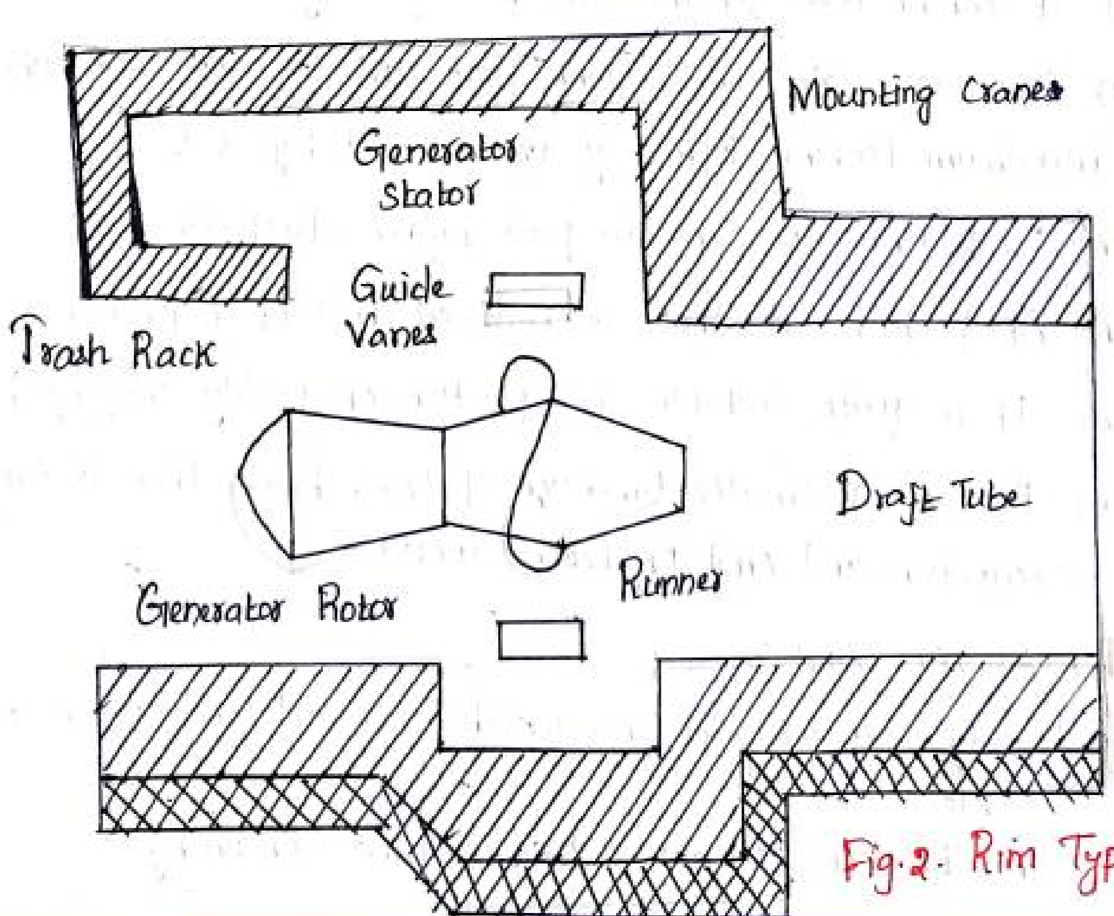


Fig.2. Rim Type

c) TUBE TURBINE

In tubular Turbine Configuration, Blades are Connected to a Long Shaft and oriented at an angle so that the Generator is Sitting on the top of barrage Shown in figure 3.

– Tube Turbine with Inclined axis is shown in fig. 3. The turbine is housed in a Slightly curved tube-shaped flow path. The turbine Shaft is Inclined and extended upto the Generator Room through guide Bearing.

* The Generator is mounted away from the water Passage tube either in up-Stream Location or in downstream location. The downstream Generator Location is preferred for very large, Low speed and Low head Units.

– This type of turbine is a Variant of Bulb turbine. In this, only the turbine is housed inside the Conduit and the generator is mounted Outside in a pit by bringing the turbine Shaft out of the turbine Casing. It is also Known as 'Pit type' Turbine

* It has the advantage of easy accessibility of the Generator. It is the modification of the Kaplan type which has been developed for water-heads below 15 m.

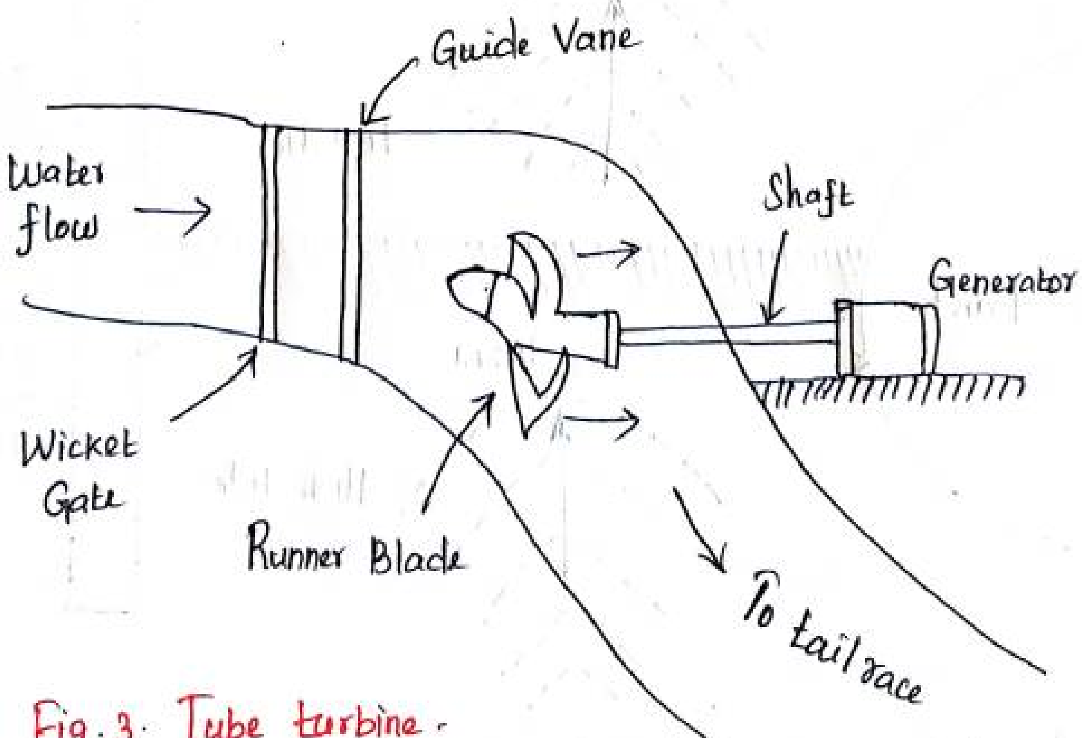


Fig. 3. Tube turbine.

DYNAMIC TIDAL POWER GENERATION (DTP)

Dynamic Tidal power (DTP) is a new and Untested Method of Tidal power Generation

- It would involve in Creating a Large dam-like Structure extending from the Coast Straight to the Ocean with a perpendicular barrier at the far end forming a Large 'T' Shape called 'Tidal Lagoons'.

* They are Similar to barrages but they are constructed as Self-Contained Structures not fully across an estuary. They are Claimed to incur much Low Cost and Impact overall. Furthermore, they canbe configured to generate Continuously which is not the case with barrages.

- A DTP dam is a long dam of 30 Km to 60 Km which is built Perpendicular to the Coast running Straight out into the Ocean without enclosing an Area. By this, tidal phase differences are introduced across the dam

* There is an Interaction between Potential and Kinetic Energies in Tidal Flows. A Single dam can accomodate over 8 GW (8000 MW) of installed capacity.

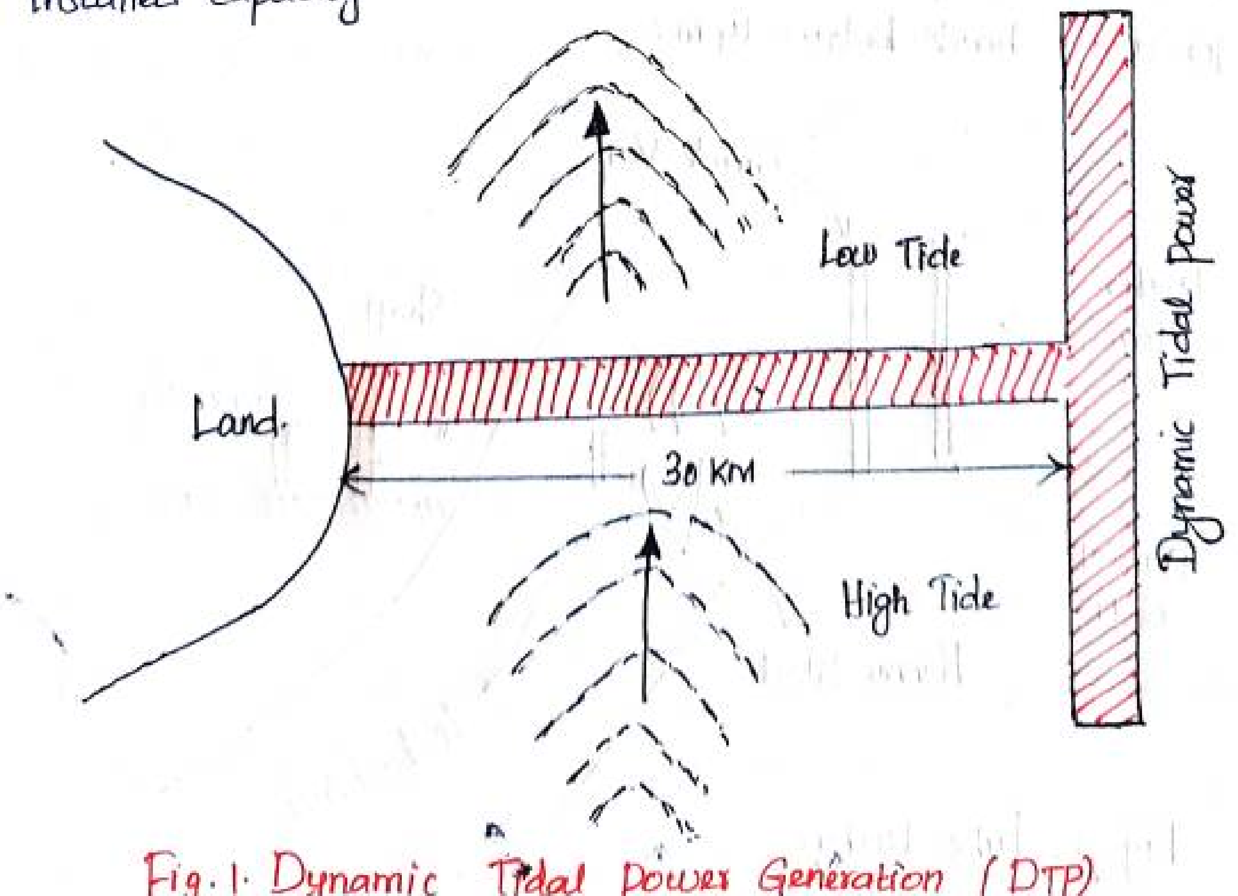


Fig. 1. Dynamic Tidal power Generation (DTP)

IMPACT OF TIDAL ENERGY ON THE ENVIRONMENT

i) Changing the Tidal flows by damming a bay or estuary could result the Negative Impact on aquatic and Shoreline Ecosystems as well as Navigation and Recreation

ii) Construction of a Barrage across a tidal River affects the Conditions on both Sides of the Structure.

iii) Water movement Patterns are affected due to Sediment movement which alters the Landward and Seaward sides of the barrage.

iv). The movement of marine Animals is also affected which Leads to a drastic Effect on both marine and avian Life. For Example, fish migration will be Significant.

SITE SELECTION FOR TIDAL POWER PLANTS

The Site Requirements are as follows :

i) Short Length of dam is to Create a basin of Reasonable Storage. It is possible at a Narrow inlet to an Estuary of Bay.

ii) It Should be near the Local location or near the Ocean

iii) It Should be Protected from high waves.

iv) It Should not hamper Shipping Traffic

v) The tidal Range of Ocean is Large

vi) The Geographical features of the plant must enclose the Large areas with Short dams

vii) the Sluice gate of dam Should allow water to or from Basins.

ADVANTAGES OF TIDAL POWER PLANTS

1. Tidal power is a Renewable and Sustainable Energy Resource
2. It is free from pollution as it does not use any Fuel.
3. Large Area of Valuable Land is not Required.

4. It doesnot produce any unhealthy waste Such as gases and Ash.

5. It has Unique capacity to meet the peak power demand effectively When it works in Combination with thermal or hydro electric System

6. It is much Superior to hydro power plants as it is totally Independent of Rain which always fluctuates year to year.

7. It is free from problems of uprooting the people and disturbing the ecology Balance.

8. Tidal Currents are both predictable and Reliable feature which gives them an advantage over both wind and Solar Systems.
   - Power Output Can be accurately Calculated in advance by allowing for easy Integration with existing electricity Grids.

9. Tidally driven Coastal Currents provide an Energy density four times greater than Air, meaning that a 15 m diameter turbine will generate as much Energy as a 60 m diameter windmill.

10. It reduces country's depedence upon ~~fossil~~ Fossil Fuels.

DISADVANTAGES OR LIMITATIONS OF TIDAL POWER PLANTS

1. Due to Variation in tidal Range, the output is not Uniform.

2. There is a fear of Tidal plant Components and Machinery being Corroded due to Corrosive Sea water.

3. It is difficult to Carry out Construction in Sea.

4. As Compared to other Sources of Energy, the tidal power plant is Costly.

5. The power transmission Cost is high because the tidal power plants are located away from Load centres

6. the Efficiency is affected due to Variation in Tidal Energy.

7. Sedimentation and Siltation of basins are Serious problems.

WAVE ENERGY

Wave Energy is energy of Interchanging Potential and Kinetic Energy in the wave. Among other types of Renewable Energy, Ocean contains Energy in the form of waves and Tidal Currents.

* Ocean Wave Energy is an important Renewable Energy. At the Same time, it is Regular, Periodic and Consistent. Ocean wave Energy (OWE) Can be either Converted into Mechanical Energy or Electrical Energy through wave energy Conversion plants

- Ocean wave Energy is needed to be developed in Coastal Areas. Usually, power extracted from ocean Energy is in the range of 10 KW/m to 70 KW/m with respect to Amplitude and Wavelength.

• Ocean waves are created by the Interaction of winds with the Surface of Sea water. Sea water contains both Kinetic Energy and potential Energy.

- Energy available in the Ocean depends on the wind Speed, duration of the wind and distance from which Interacts with Sea Surface water.

* Waves retain energy differently depending on water depth i.e.,

a) Lose Energy slowly in deep water (or)

b) Lose Energy quickly as water becomes Shallower because of Friction between moving water Particles and Sea bed

- Wave Energy Conversion devices are designed for optimal Operation at a particular depth Range. So devices are characterized in terms of their placement or Location Such as

a) At the Shoreline

b) Near the Shoreline

c) Off-Shore

The most generally and successfully used wave Energy Conversion System at each of these locations is 'Oscillating water Column'.

* The maximum wave Energy is obtained between latitudes of 40° and 60° in each hemisphere. Wind Coming from Atlantic and Pacific Oceans generates waves with more than 100 m.

— The Area of west Coast of Europe, United States, the Coast of New zealand and Japan are more Suitable for wave Energy Conversion.

WAVE ENERGY POTENTIAL

The world's first Commerical wave Energy plant having 0.5 MW is located in Isle of Islay and Scotland. Some small prototype devices have been tested.

— The Resource is more Concentrated in deep Sea where it is difficult to harness and deliver. The estimated potential is 2000 GW. It has been estimated that total available US wave Energy resource is 23 GW, which is more than twice as much as 'Japan' and nearly five times as much as 'Great Britain'.

* It has been estimated that improving technology and economies of Scale will allow wave Generators to produce Electricity at a Cost comparable to wind-driven turbines which Produce energy at about Rs. 3.5 per Kwh.

ESTIMATION OF WAVE ENERGY

The total Energy obtained from waves is the Sum of Potential Energy and Kinetic Energy.

1. POTENTIAL ENERGY :

The Potential Energy available in waves is due to the head of Sea water above the mean Sea Level.

Potential Energy, $\boxed{P.E = \frac{1}{4} \rho a^2 \lambda g W}$

where, ρ = Density of the Sea water (Kg/m^3)

a = Amplitude of wave (m)

λ = Wave length (m)

W = Width of the wave (m)

g = Acceleration due to Gravity (m/s^2).

2. KINETIC ENERGY (K.E) :

The Energy associated with the movement Sea Water is called 'Kinetic Energy'

– For harmonic motion of waves, Average Kinetic Energy is equal to the Potential Energy. Therefore,

Kinetic Energy, $\boxed{K.E = \frac{1}{4} \rho a^2 \lambda g W}$

Total Energy, $E = P.E + K.E$

$$= \frac{1}{4} \rho a^2 \lambda g W + \frac{1}{4} \rho a^2 \lambda g W$$

$$\boxed{E = \frac{1}{2} \rho a^2 \lambda g W}$$

Power, $\boxed{P = \frac{\text{Energy}}{\text{Time}}}$

Wave Energy is Proportional to wavelength times wave height Squared ($L \times H^2$) Per wave length per unit of Crest Length.

– A four-foot (1.2 m), ten-Second wave striking a coast expends more than 35,000 HP per mile of coast.