ANNAMACHARYA UNIVERSITY

EXCELLENCE IN EDUCATION: SERVICE TO SOCIETY

(ESTD. UNDER AP PRIVATE UNIVERSITIES (ESTABLISHMENT AND REGULATION) ACT, 2016)

RAJAMPET, Kadapa District, A. P – 516126, INDIA

Department of Electrical and Electronics Engineering

Course: **Renewable Energy Systems**

Course Code: **24AEEE5DT**

Branch: **Electrical & Electronics Engineering**

Prepared by: **Ms.SYED RUBEENA BI**

Designation: **Assistant Professor**

Department: **Electrical and Electronics Engineering**

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Title of the Course: **Renewable Energy Systems**

Category : PE

Course Code : 24AEEE5DT

Year : III

Semester : I

Branch : **EEE**

Lecture Hours	Tutorial Hours	Practice Hours	Credits
3	0	0	3

Course Objectives:

To create awareness among the students about the different types of Renewable Energy sources and emphasize its importance.

Unit 1 **Renewable Energy Sources** **10**

Different forms of energy, Renewable and non-renewable energy sources, Advantages and Limitations of renewable energy sources, comparison of conventional and nonconventional energy sources, Solar Radiation: solar constant, solar Irradiance, spectral distribution of solar radiationBeam, Diffuse and Reflected Radiation, Instruments for measuring solar radiation - pyranometer, pyrheliometer and sun shine recorder.

Unit 2 **Solar Energy Collection and Its Applications** **10**

Solar collector, Flat plate and concentrating collectors, classification of concentrating collectors. Energy Storage: necessity of energy storage methods-, Sensible, latent heat and thermo chemical storage. Solar Applications- solar water heating, solar distillation, solar ponds, drying, solar pumping and solar cookers.

Unit 3 **Wind Energy** **10**

Wind Energy: Air, wind, Classification of Wind turbines-Lift type and Drag type, Types of rotors-Multiblade, propeller, savonious and Darrieus, Parts of Wind Energy, types, Derivation for Power in the wind-power coefficient and Betz Limit, Performance Characteristics of Wind machines, Advantages and Disadvantages of WECS.

Unit 4 **Ocean Energies** **10**

Ocean thermal energy sources, working principle, Types of OTEC systems- Closed and open cycles. Advantages. Tidal energy: tidal characteristics, tidal Range, principle of tidal power, types of tidal power plants-single and double basin operation, advantages and disadvantages. Wave energy: wave energy conversion machines-Buoy type and Dolphin type energy generation.

Unit 5 Bio-Mass and Geothermal Energy and Grid Integration Techniques 10

Bio-Mass: Biomass Classification, Biochemical Conversion-Anaerobic and Ethanol fermentation, Bio gas plants: Floating Drum Type and Fixed Dome Type. Geothermal Energy: Geothermal field, Resources, Geothermal Power Generation and introduction to Grid Integration Techniques.

Prescribed Text Books:

1. Renewable Energy Sources and Emerging Technologies by D. P. Kothari, K. C. Singal, 2nd edition, PHI Learning Private Limited Delhi, 2014.

References Books:

1. Khan BH, Non-conventional energy resources, TMH, New Delhi, 2006.
2. G. D. Rai, Non-conventional energy sources, Khanna publishers, Delhi, 2007.
3. Ramesh and Kumar, Renewable Energy technologies, Narosa Publications, 2012.
4. G. N. Tiwari & M. K. Ghosal, Fundamentals of Renewable energy resources.
5. Twidell & Wier, Renewable Energy Resources, CRC press (Taylor & Francis).

Course Outcomes:

At the end of the course, the student will be able to Blooms Level of Learning

1. Describe fundamentals of solar energy and the basic concepts of solar radiation and its measurements. L2
2. Describe different types of solar collectors and its applications. L2
3. Explain design of wind energy conversion systems. L2
4. Realize power from oceans (thermal, wave, tidal) and conversion devices. L2
5. Describe biomass conversion technologies, geothermal resources. L2

CO-PO Mapping:

Course Outcomes	Engineering Knowledge	Problem Analysis	Design/Development of solutions	Conduct investigations of complex problems	Engineering tool usage	The engineer and the world	Ethics	Individual and collaborative team work	Communication	Project management and finance	Life-long learning	PSO1	PSO2
24AEEE5DT.1	3	2	-	-	-	-	-	-	-	-	-	3	-
24AEEE5DT.2	3	2	-	2	2	-	-	-	-	-	-	3	3
24AEEE5DT.3	3	2	-	-	-	-	-	-	-	-	-	3	-
24AEEE5DT.4	3	2	-	2	2	-	-	-	-	-	-	3	3
24AEEE5DT.5	3	2	-	-	-	-	-	-	-	-	-	3	-

Unit-I : RENEWABLE ENERGY SOURCES

Renewable and Non-renewable Energy sources:-

Renewable Energy Sources:-

The sources which cannot be exhausted even after continuous utilization are termed as "Renewable Energy Sources".

Examples are. The sun (Solar Energy), water (Hydal Energy), Wind (wind energy), Geo thermal Energy, Biomass Energy, Tidal Energy, Ocean Energy, Wave Energy etc.

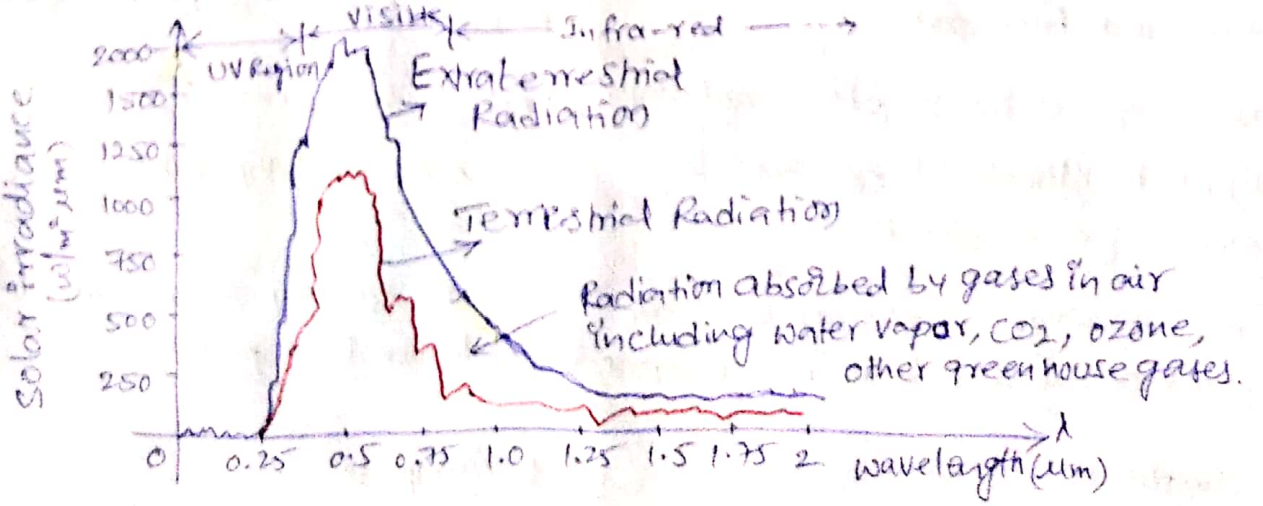
Non Renewable Energy Sources:-

The sources which cannot be immediately replaced once they are consumed (or) used are called "Non-Renewable Energy sources".

Examples are Fossile fuels like coal, oil, natural gas etc, Nuclear Energy etc.

Spectral distribution of Solar Energy:-

The spectral distribution is a shape that is drawn between Solar irradiance ($W/m^2 \mu m$) and wave length (μm). The maximum radiation intensity of the solar spectrum occurs at 0.5 μm. The spectral distribution of solar energy is as shown in figure.



The area under these curves indicate the total radiation (W/m^2) respectively for extra-terrestrial and terrestrial regions. Extraterrestrial radiation means "The solar radiation at the top of the atmosphere". The solar

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radiation at sea/ground level is called as "Terrestrial radiation".

About 99% of extraterrestrial radiation has wavelengths in region from 0.2 to 0.4 μm with maximum spectral intensity at 0.48 μm. About 6.4% of extraterrestrial radiation is contained in the UV region ($\lambda < 0.38$ μm), another 48% is contained in the visible region ($0.38\mu m < \lambda < 0.78$ μm), and the remaining 45.6% is contained in infra-red region i.e $\lambda > 0.78$ μm.

Comparison blw Convention and Non Conventional Energy sources:-

Conventional Energy Sources (Non Renewable Sources)	Non-Conventional Energy Sources. (Renewable Sources)
* These energy sources are also known as non renewable energy sources.	* These are also called as renewable energy sources.
* These resources available in limited quantity only.	* These sources are aviable in required quantity.
* The Conventional Energy sources are common and widely used sources	* These are relatively new and hence are not commonly used.
* More fuel cost, Causes pollution when used	* No fuel cost, causes no pollution when used.
* The Conventional Energy sources are not eco friendly in nature.	* The non-conventional energy sources are eco-friendly in nature.
* Comparatively expensive to maintain, store and transport.	* Initial cost for energy generation is high but cheaper in the long run.
* Causes greenhouse effect and major culprit in climate change and has serious heath effects.	* No such issues as energy source is ecologically safe.
* These energy sources are used for commercial and industrial purpose.	* These energy sources are mainly used for house hold purpose.
* Examples: Fossile fuels like coal, petroleum and burning wood etc.	* Examples: Solar Energy, Nuclear energy, Geo-thermal Energy, Biomass Energy, Energy from oceans.

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Importance / potentials / Advantages of Renewable Energy Sources:-

The renewable energy source is very important because of following benifits / advantages.

i) **Renewable energy is ECO-friendly:** It is clean energy since it doesn't cause any environmental pollution and it has low (or) zero carbon and green house emissions.

ii) **Energy will not run out:** This type of energy source will not run out, ever. Other sources of energy are finite and will some day be depleted.

iii) **Create jobs and Economy:-** It makes real economic sense because it is a cheaper alternative to most traditional energy sources. Since the inception of renewable energy, new and stable jobs have been added.

iv) **Less maintenance:-** These technologies requires less overall maintenance than conventional technologies. This renewable energy generating technology like Solar panels and wind turbines either have few or no moving parts.

v) **Safe for public heath:-** The sources for renewable energy generation emit little to no greenhous gases or pollutants into the air. This means a smaller carbon footprint and an overall healthier atomsphere.

vi) **It save money and profitable energy source:-**

It helps in saving money in the long term. We can save not only the maintenance cost but alro the operating cost. No need to pay money to refuel the power generation from sun, wind etc.

vii) **It is used to recycle the waste products:-** The biomass energy tends to have this specific benifit that more than any other form of renewable Biomass Consumes used organic products such as vegitable oil, corn and soybean by products to generate energy. At a same time it reduces the amount of waste that goes into land-fills, also reducing the amount of overall Carbon that goes into the atmosphere.

viii) **Available in multiple forms:-** The renewable energy sources are available in solar, water, wind, biomass, Geothermal, ocean etc.

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Limitations / Disadvantages of renewable Energy sources :-

The renewable energy sources are mainly suffers from the following disadvantages / limitations.

i) The electricity generation capacity is not large :- Large capacity of energy generation using renewable energy source is main challenge.

ii) It is unreliable source :-

These type energy soures depends on the wether for energy generation. In case of atmospheric conditions are not good enough, renewable energy sources would lack the ability to generate any electricity. For example,

* Hydro generators reauires enough rain to fill dams for their supply of flowing water.
* wind turbine reauires wind blowing, at least with minimum wind speed, to move their blades.
* Solar panel needs clear skies and sunshine to get the heat reauired to generate electricity.

iii) More Capital Costs :- For installation of renewable energy generation, the initial cost is more. For example, the installation of wind turbine, solar panels, hydro plants is relatively expansive. These plants reauires more investment to build, have high maintenance expentive and reauires careful planning and implementation.

iv) It takes lot of space to install (v) Expantive storage cost

vi) Low efficiency levels. (vii) It still generate pollution.

Solar constant :- It is the rate at which the solar energy / radiation is ~~reaciived~~ received per unit area in unit time at the top of the earth.

$$\text{Solar constant} = \frac{\text{Solar energy received}}{\text{Area} \times \text{time period}}$$. Units are W/m^2

The average solar constant is $1.37\ kW/m^2$ (or) $1367\ W/m^2$.

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Types of Renewable Energy Sources:-

The resources which cannot be exhausted even after continuous utilization are called renewable energy sources. The renewable energy sources are classified as (i) Solar Energy (ii) Wind Energy (iii) Hydal Energy (iv) Geo thermal Energy (v) Biomass Energy (vi) Ocean Energy.

Solar Energy:- It is a radient light and heat from the sun and is used for evolving technologies like solar heating, photo voltaic, solar thermal energy, solar cocking etc.

* Solar power is a energy from the sun that is converted into electricity. It is clean and most abundent renewable energy.

Wind Energy:- It is a renewable energy source that captures the wind power by using wind turbine, wind mills and then generate electricity.

* The wind energy is clean, free and readily available in nature.
* It will reduces the emissions of green house effect gases and preserve the environment.

Hydal Energy:- It is an eco-friendly renewable energy that generates the power by using the potential energy of water.

* It will produce negligible emissions i.e it does not emitts CO_2 other green house gases that drives the global climate changes.
* It is very safe form of power generation.
* It reauires more space to build and high initial cost.
* Flood risks, limited plant location.

Geothermal Energy:- It uses the thermal Energy from the Earth's magma to create steam that drives the turbine and generator to genererate the electrical power.

* It does not cause pollution, No fuel is used to generate the power.
* It does not reauires more space to build.

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* It is very efficient and long lasting.

Biomass Energy:- Biomass is a plant or animal material used as fuel to produce electricity or heat. Example for biomass energy are wood, waste from forest, yards, farms etc.

* It is a renewable, versatile source.
* It does not emits carbon products.
* It is not completely clean, High cost when compare to other renewable sources.
* It requires more space for power generation.

Ocean Energy:- It is a form of renewable energy derived from the sea. There are three types of ocean technogies. Tidal, wave and ocean thermal. All the forms of energy from the ocean are still at an early stage of Commercialization. The power generated by wave energy is more costlier than other ocean technology.

* Tidal energy is a form of hydro power that converts energy obtained from the tides into useful form of power such as electricity. The tides are created by gravitational effect of moon and sun on the earth causing cyclic moment of the seas.
* The tidal power generation depends on the tidal range and tidal streams. The potential of power generated by the individual tidal turbine is more than that of similar rated wind energy turbine because the water density is 832 time more than the air density.
* wave energy is derived from the waves. The wave energy is produced when a generator is placed on the surface of the ocean. The wave energy depends on the height of the wave, wave speed, wave length, wave density.
* The methods ~~of~~ that are used for power generation using waves are (i) oscillating water column (ii) surface following attenuator.

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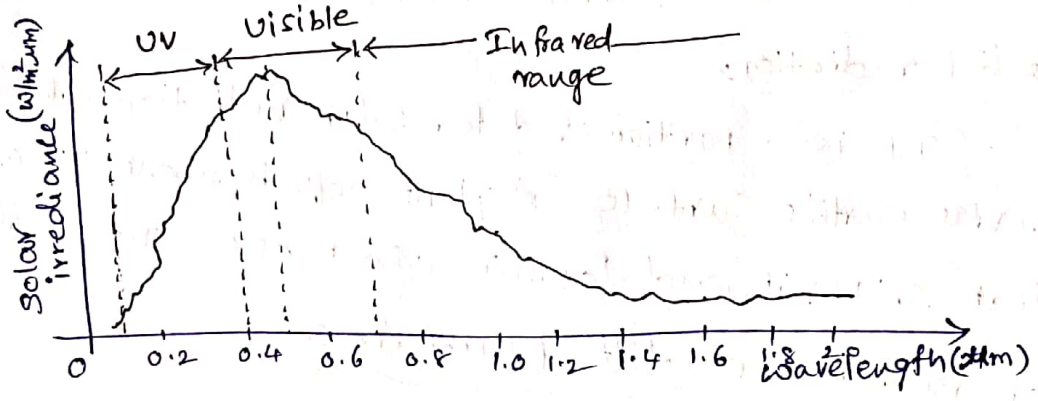
Solar Radiation:- It is a radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic Energy. The Solar radiation is Captured and converted into useful forms of energy such as heat and electricity using various technologies. The solar radiation is also known as solar source (or) sunlight.

* The solar radiation is measured in wavelength (or) frequency.
* The amount of solar radiation that reaches any one spot on the earth's surface depends on various factors like earth's latitude, season, time of the day, local weather.
* The solar radiation spectrum is as shown below. It has three relevant ranges along the solar radiation spectrum like Ultraviolet, visible and infrared.



From the spectrum, 7% of total solar radiation is available in Ultraviolet range, 47.3% of solar radiation is available in visible range (0.45 to 0.68 μm) and 45.7% of total solar radiation is in Infrared range (0.78 μm to 4.0 μm). The ~~Ultraviolet~~ visible radiation is more ~~energetic~~ energetic than the infrared radiation.

Beam & Diffuse solar radiation:-

The solar radiation that has not been absorbed (or) scattered and reaches the earth's surface is called Beam (or) direct radiation. This radiation will produces a shadow when interrupted by ~~non transp~~ non transparent objects.

The solar radiation received from the sun after its direction has been changed by reflections and scattering by the atmosphere is

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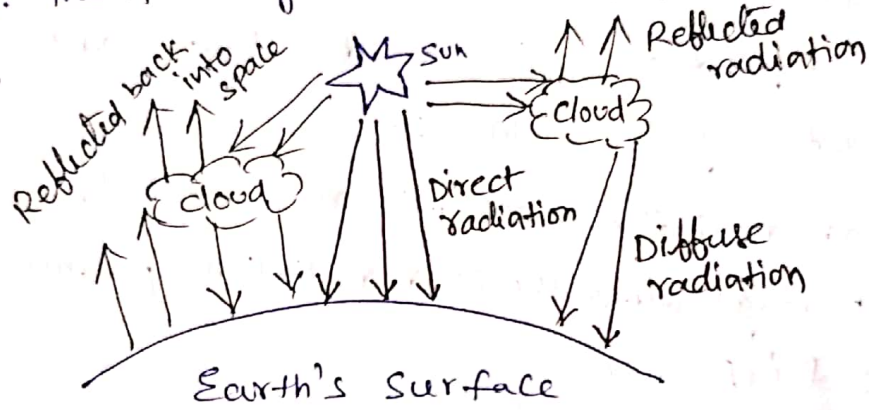
called diffuse radiation. Because the solar radiation is scattered in all directions in atmosphere, the diffuse radiation comes to the earth from all parts of the sky.

The total solar radiation received at any point on the earth's surface is the sum of direct and diffuse radiation. The total solar radiation received at a point on the earth surface is called insolation. The following figure shows the direct, diffuse and total radiation.



Reflected radiation :-

It is a portion of total solar radiation which has been reflected from the earth's surface. Asphalt reflects about 4% of the radiation that strikes it. and lawn is about 25%. Snow reflects 80 to 90%.

Measurement of solar radiation:-

The measurement of solar radiation is important to predict the performance of solar applications like photo voltaics, solar heater, solar cooking etc. The are two types of instruments that are used for solar radiation measurement. Those are

(i) phyrano meter: It is used to measure total hemisperical solar radiation. It is most commonly used instrument for solar radiation measurent.

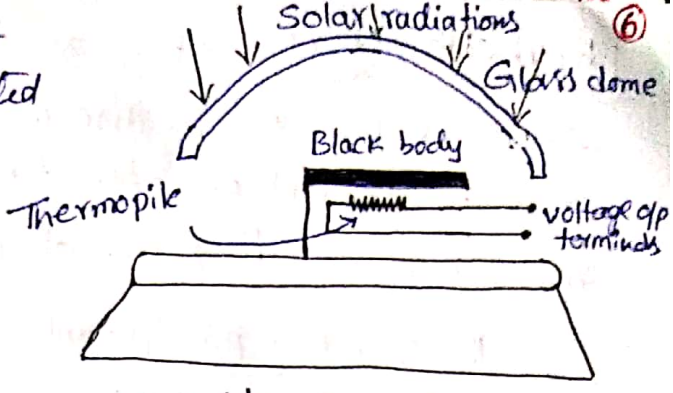
(ii) pyrheliometer: It is used to measure the beam radiation as a function of incident angle.

In addition to above solar radiation measuring instruments, the following methods are also used. Those are

(i) sunshine Recorder (ii) Solar radiation data

Phyrano meter:- It is an instrument which measures the total or global radiation over a hemisperical field of view. The Schematic diagram of phyranometer is as shown in fig. It mainly Consist of Thermopile, Glass dome and blocking sensor/disc.

* The thermopile is a sensor. It consists of thermocouples connected in series and coated in black colour, which absorbs solar radiation. It has a capability of producing a potential that is relative to temparature gradient.



phyrano meter.

* The glass dome is used to restrict the spectral response from 300nm to 3000nm i.e from nearly visible rauge to infrared region. It act as protecting cover for thermopile from wind, rain and convection. The radiation transmittion through the glass dome is 92%.
* The blocking sensor/disc is used for measuring the diffuse radiation by blocking the beam radiation. Generally it is located at the base of the dome whose axis is aligned with the direction of the sun's rays.

Working: It works on seebeck (or) thermoelectric effect. i.e it works on the measurement of temparature difference blw a clear surface and dark surface. A black coating on the thermopile absobs solar radiation, while the clear surface reflects radiation. As a result an emf propo- rtional to solar radiation is generated. This emf is in rauge of 0 to 10mv. The emf generated in the thermopile due to the diffence in tempa- rature blw two surfaces reveals information about the amount of Solar radiation.

The phyranometer mojorly used for (i) Designing solar power plants, (ii) measuring solar radiation data, (iii) predicting insulation reauirements for building structures etc.

Advantages:

(i) More accurate measurement of performance index and performance ratio
(ii) It measures solar radiation under all conditions.
(iii) very small temparature coefficient and calibrated to Iso standards.

Types of phyranometers are Eppley phyranometer, Yellot Solarimeter, bimetatic actinograph, Velochme pyranometer, Thermo electric phy- ranometer etc.

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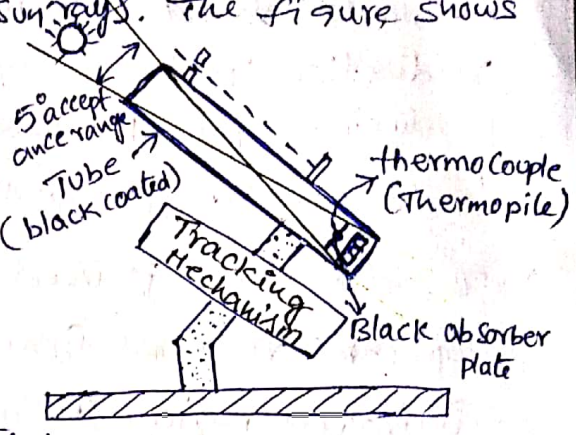
Phyrheliometer:- It is an instrument which measures the beam radiation. It has sensor disc which is located at the base of the tube whose axis is aligned with the direction of the sun rays. The figure shows the schematic diagram of phyrheliometer.



The operating principle and working of this type of instrument is same as phyranometer but it follow the sun to measure only direct or beam radiation and avoid the diffuse radiation. It mainly consists of black coated tube, thermopile junction i.e thermocouple, black absorber plate, Two axis tracking mechanism.

Working: The sun rays will enter in the black coated long tube and will incident on black absorber plate. The thermopile is in contact with black absorber plate when the black plate absorbs the radiation the emf will be generated between the hot and cold surface. This emf is used to measure the value of beam radiation.

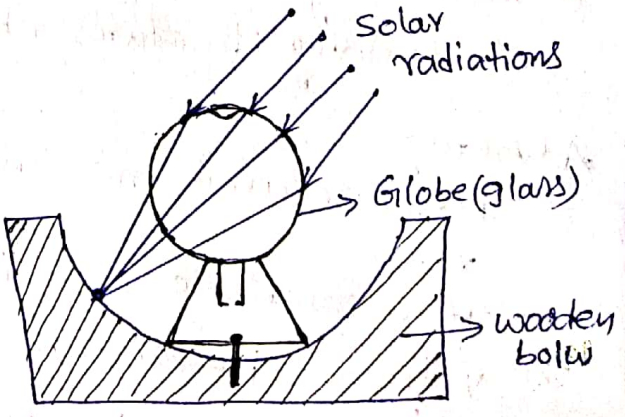
This instrument is used for climatological and weather monitoring reasearch purpose, observation of climate, pv devices.

Advantages: (i) It requires less power
(ii) wide range of voltage can be operated with it
(iii) It is stable and rigid device.
(iv) It will follows the sun position when the sun will moving the tracking system will follow the sun.

There are three types of phyrheliometers. Those are (i) Angstrom phyrheliometer (ii) Abbot silver disc phyrheliometer
(iii) Eppley phyrheoliometer.

Sun shine Recorder:-

It is a device that records the amount of sunshine at a given location or region at any time. The results provide the information about the weather, climate and the temperature of geographical area.



Sunshine recorder

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This information is used in meteorology, science, agriculture and other fields. The schematic diagram of Sunshine recorder is as shown in figure.

Working:- The sun rays are focused at a point on card strip which is placed in wooden bowl through the glass globe. When there is a bright sunshine that sunshine is enough to burn a spot on the card strip and forms a image. Through the days, the sun moves across the sky, the image moves along the strip. The length of the burnt space is proportional to the duration of sunshine.

The Sunshine Recorder is also known as heliograph.

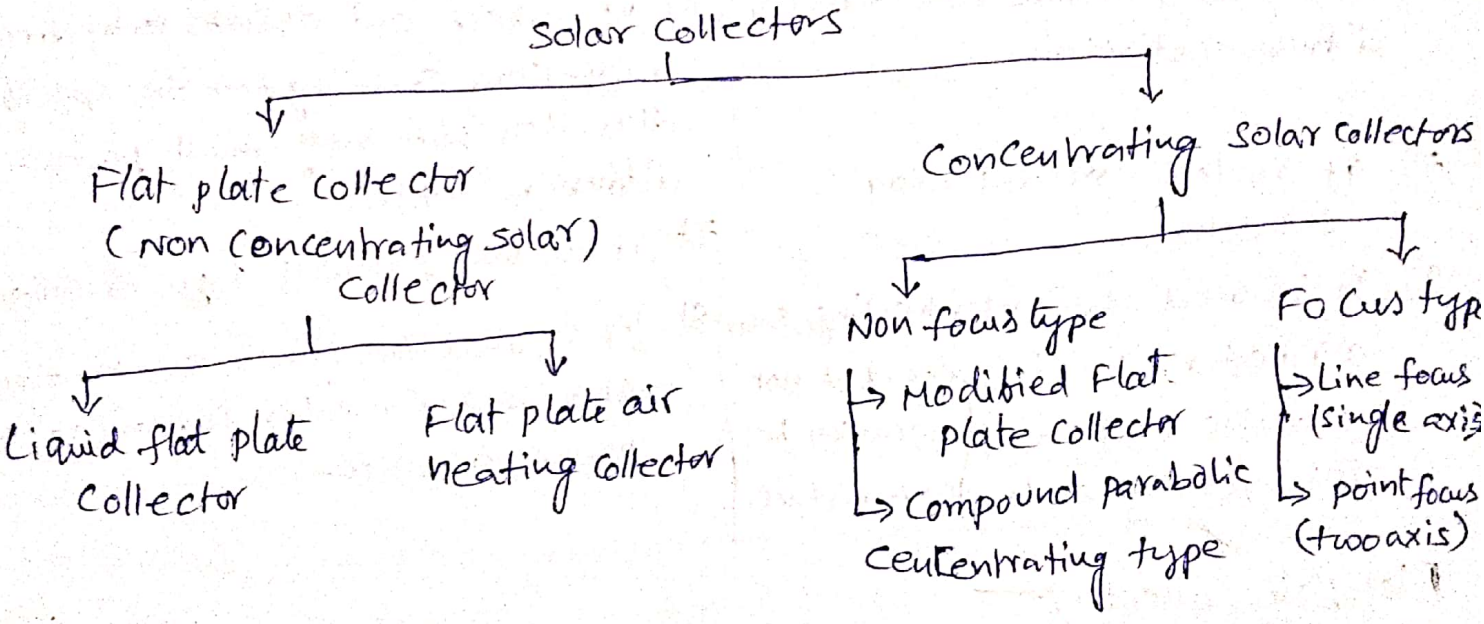
Different Forms of Energy:

Form of Energy	Description	Examples
Kinetic Energy	Kinetic energy is the energy possessed by an object due to its motion. The faster an object moves and the greater its mass, the more kinetic energy it has.	Moving car, rolling ball, flowing river, rotating fan
Potential Energy	Potential energy is the energy stored in an object because of its position, shape, or condition. It is converted into kinetic energy when the object starts moving.	Water stored in a dam, stretched spring, lifted object
Thermal (Heat) Energy	Thermal energy is the internal energy produced by the random motion of atoms and molecules within a substance. Heat naturally flows from a hotter object to a colder one.	Boiling water, steam, fire, heated metal
Chemical Energy	Chemical energy is the energy stored in the chemical bonds of substances. It is released during chemical reactions such as combustion or battery discharge.	Petrol, coal, natural gas, food, batteries
Electrical Energy	Electrical energy is the energy associated with the movement of electric charges (electrons). It is one of the most widely used forms of energy because it can be easily transmitted and converted into other forms.	Electric motors, household appliances, lightning
Light (Radiant) Energy	Light or radiant energy is the energy carried by electromagnetic waves. It travels through space without requiring a medium and is the primary source of energy for life on Earth.	Sunlight, LED bulbs, lasers, electric lamps
Sound Energy	Sound energy is produced when an object vibrates, creating waves that travel through a medium such as air, water, or solids. It cannot travel through a vacuum.	Human voice, loudspeaker, musical instruments, bell
Nuclear Energy	Nuclear energy is the energy stored in the nucleus of an atom. It is released during nuclear fission or fusion and produces a very large amount of energy from a small amount of fuel.	Nuclear power plants, the Sun, nuclear reactors

Unit-II : Solar collectors & its applications

Solar collector:- Solar collector is a device, it is used for collecting solar radiation and transfer the energy. For the utilization of solar energy, there should be solar collectors. The solar energy collector is the essential component of any stem for the conversion of solar radiation into usable form like heat or electricity. There are two type of solar collectors.

(i) Flat plate (or) Non Concentrating Solar collector.
(ii) Concentrating Solar collector.



Note:-
(i) The area that intecepts the solar radiation is called Collector area.
(ii) The area abosorbing the radiation is called absorber area.

* In Non-Concentrating type, the collector area is same as the absorber area. But in concentrating type, the Collector area is greater than the absorber area. The concentrating type collectors receives more temperature than the Non Concentrating type, hence its effeciency is more than the flat plate type.

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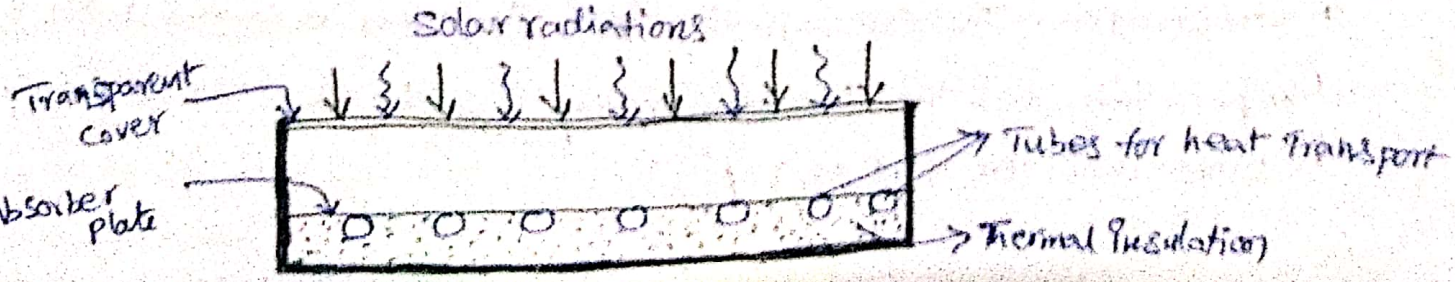
Comparison b/w Flat plate collector and Concentrating solar collector:-

Flat plate Collector	Concentrating solar collector
1) In Flat plate collector, both absorber and collector area are same.	1) Here the collector area is more than the absorber area.
2) It can reach to low temperature range.	2) It can reach to high temperature range.
3) Its design is easy, but requires additional equipment like anti-freeze.	3) It has complex design, but does not requires additional equipments.
4) Lower in cost.	4) Higher in cost.
5) Requires less maintenance.	5) Requires high maintenance.
6) It collects & absorbs both direct & diffuse radiations.	6) It collect and absorbs only direct radiations comming from the specified direction with very small portion of diffuse radition.
7) It is less efficient solar collector	7) It is very powerful type of collector.
8) It is used for water heating, solar air heater, cooking, etc. But not suitable for power generation bcz it is operating at low temperature.	8) It is used for power generation. Also used for solar furnances, solar power plants etc.

Flat plate Collector:-

The flat plate collectors are made in rectangular panels, from about 1.7 to 2.9 m^2 in area and are simple to construct and install. It can collect ~~both~~ and absorb both direct and diffuse solar radiation. They are partially effective even on cloudy days when there is no direct radiations. The schematic diagram of a typical flat plate collector is as shown in figure.



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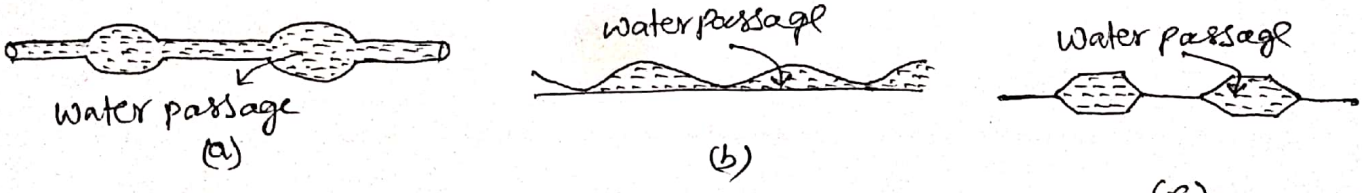
The main Components of the flat plate collector are.

* Transparent cover: It may be one or more sheets of glass (or) radiation transparent plastic films.
* Tubes (or) channels: These are connected with absorber plate. They can transfer the heat when water or air flow through it.
* Absorber plate: It is a metalic surface. Generally made with copper (or) Steel (or) Alluminium material.
* Thermal Insulation: It is provided at back and sides of the container to reduce the heat losses. The insulating material like fibre glass (or) .. styro-foam are used.
* The container: It enclose the other components and protect them the weather.

The Flat plate Collector construction Details:-

It consist of a flat surface with high absorbing surface. The absorbing surface is made with copper (or) steel (or) aluminium. The tubes (for heat transport) are in thermal contact with the absorbing plates at its bottom. The absorbing plate is made from 1 to 2 mm in thickness and the tubes are range in diameter from 1 to 1.5 cm.. The methods of conventional standard panel radiators are as shown in below fisure.



A Thermal insulation of 5 to 10cm thickness is usually placed behind the absorber plate to prevent heat losses from the absorber rear surface. fiber glass (or) mineral wool (or) glass wool is used as thermal insulating material. The transparent cover is made with glass (or) plastic sheets. Generally glass is preferable. The transparent cover act as a convection shield to reduce the losses from the absorber plate beneath. Generally a thickness of 3 and 4mm are used. In practice 1 or 2 covers with a specific ranging from 1.5 to 3cm. The advantage of 2nd glass are

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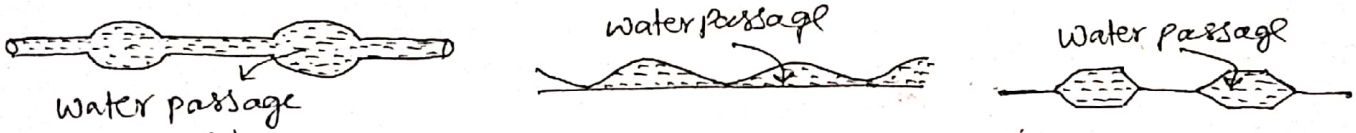
* Heat losses due to air convection are further reduced.
* Radiation losses in infra red region are reduced by 25%.

Transparent plastic sheets also used in place of glass, but they may suffer from following draw backs.

* Most plastics are not as transparent as glass
* permits more heat losses from the absorbers.
* They also suffers from decrease in transparancy and same time break up due to heating and action of solar UV radiations.

Liquid Flat plate Collector (or) Solar water heater :-

It consist of a flat surface with high absorbing surface. The absorbing surface is made with copper (or) steel (or) aluminium. The tube (-for heat transport) are in thermal contact with the absorbing plates at its bottom. The absorbing plate is made from 1 to 2 mm in thickness and the tubes are range in diameter from 1 to 1.5 cm. The methods of conventional standard panel radiators are as shown in below fisure.



(a) (b) (c)

A Thermal insulation of 5 to 10cm thickness is usually placed behin the absorber plate to prevent heat losses from the absorber rear surface. fibe glass (or) mineral wool (or) glass wool is used as thermal insulating materi The transparent cover is made with glass (or) plastic sheets. Generally glas is preferable. The transparent cover act as a convection shield to red the losses from the absorber plate beneath. Generally a thickness of 3 and 4mm are used. In practice 1 or 2 covers with a specific ranging from 1.5 to 3 cm. The advantage of use of second glass cover are

* Heat losses due to convection are further reduced.
* Radiation losses in infrared region are reduced by 25%.

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Working: The heat generated in absorber plate is collected by continuous flow of heat transport medium i.e water (or) air. The metal tubes are connected to common headers at each end of the collector. For maximum solar radiation, the collectors are tilted (or) sloped as shown in figure.

Cold water enter into the bottom header, flows upwards through the tubes where the water is warmed by the absorber, and leaves by way of the top header. water is a very good heat transport system, but it suffers from certain drawbacks.

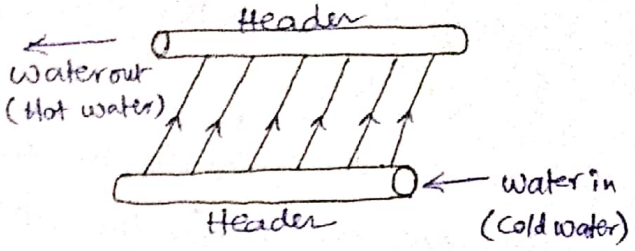


fig: Solar water heater

i) In cold weather, moisure may condense on the inside of transport cover plate and thus decrease the transmission of solar radiation.

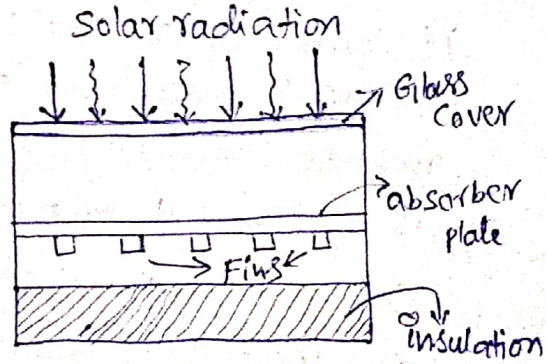
ii) During the cold nights, there is a possibility of freezing in the collector tubes. Ethylene glycol is added to prevent freezing.

iii) Corrosion of the metal tubes by the water. Corrotion can be reduced by using copper material for design of tubes.

iv) Leakage in water circulation system.

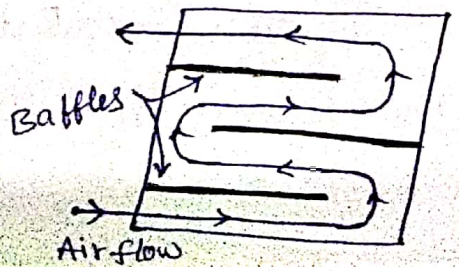
Air heating flat plate Collector(or) solar air heater:-

The typical solar air collector/heater is as shown below. Here an air stream is heated by the backside of collector plate. Fins are attached to the plate to increase the contact surface. Backside of the collector is heavily insulated with mineral wool or some other material. The orientation of the collector for heating is north facing at the angle of tilt (β) is equal to latitude plus 15°.



When the air is used as heat transport medium in solar collectors have some advantages than water.

* Less power is required to pump the required volume of air through the tubes.
* Wider flow channels are used.



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Working:- The air may be passed through the space btw the absorber plate and thermal insulation with baffles. The arrangement of baffles provides a long flow path as shown in figure. The use of air eliminates both freezing and corrotion problems, and small air leaks are of less concern than water leaks. Also the heated air can be used directly for space heating.

The solar air heaters can be used as sub systems in many systems meant for the utilization of solar energy. The main applications of solar air heaters are drying of agriculture products, space heating for comforts, regeneration of dehumidifying agents, curing of industrial products like plastic etc.

Advantages of Flat plate Collector:-

* The flat plate collectors have the advantages of using both beam and diffuse solar radiations.
* They do not reauires orientation towards the sun
* They reauires little maintenance.
* They are mechanically simpler than the concentrating ~~reflectors~~ collectors.

Concentrating Collectors:-

Focusing (or) type:- A focusing collector is a modified flat plate collector. It consists of an optical system in the form of reflectors. A reflecting surface is placed btw solar radiations and absorber. In these collectors radiations fall on large collector area. As result large amount radiation is available to heat the fluide. The focusing collectors consists of an optical system in the form of reflectors or refractors. The optical system directs the solar radiation on to an absorber area which is surrounded by a transparent cover.

The concentrating (or) Focusing collectors are classified as (i) Line focusing type (ii) point focusing type

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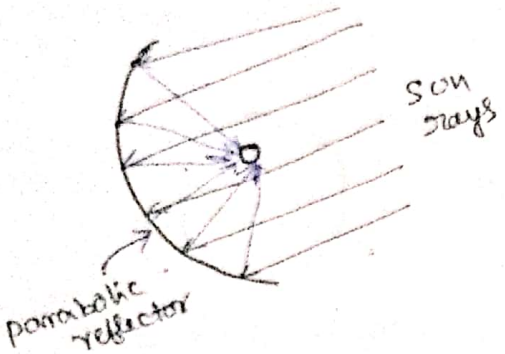
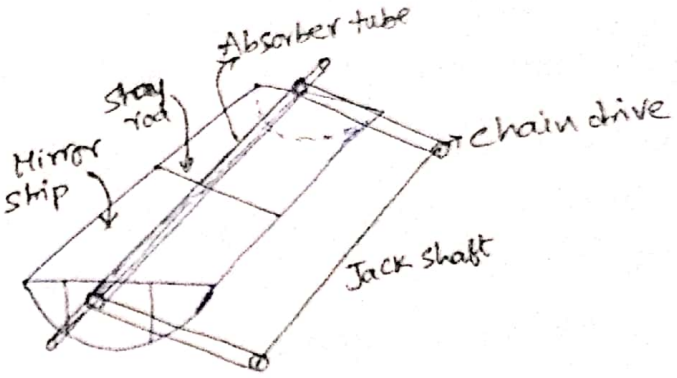
Line focusing Collectors:- The line focusing collectors are further classified as (i) Parabolic Trough Reflector (ii) Mirror Strip reflector (iii) Fresnel lens Collector.

Parabolic Trough Reflector:-

The cross-section view of parabolic Trough reflectors is as shown in fig. The solar radiation coming from the particular direction is collected by the area of reflecting surface and is concentrated at a focus point of the parabola. Mostly cylindrical parabolic concentrators are used because in this type of concentrators, the absorbing surface is placed along focus axis. The collector pipe is used as an absorber surface.



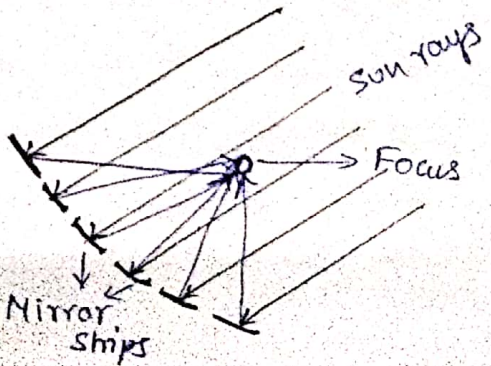
(a) cross-section of parabolic through collector



(b) Typical cylindrical parabolic system

The solar radiations are brought to the focus surface by parabolic through reflector. Since the orientation of the sun is always changing, either the reflector through or the collector pipe (absorber) must be turn continuously along with the sun orientation. The through type collectors are generally oriented in the east-west (or) North-South directions.

Mirror Strip Collector:- In this type of ~~reflector~~ collector, no. of plane (or) curved mirror strips are mounted on the flat base as shown in figure. The angle of the individual mirrors is arranged such that they reflects solar rays from the specific direction on the same focal line. The angle of mirrors must be adjusted to allow for changes in sun's orientation, while the focal line remains in a fixed position. Alternatively



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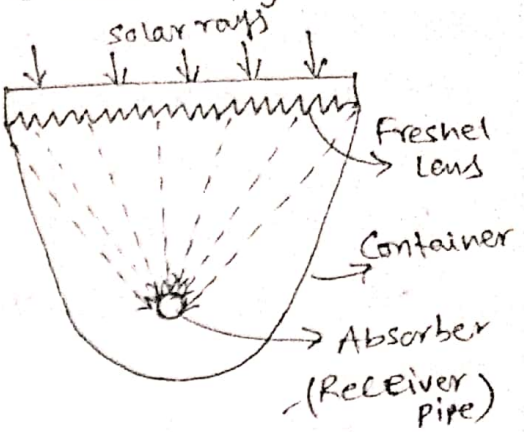
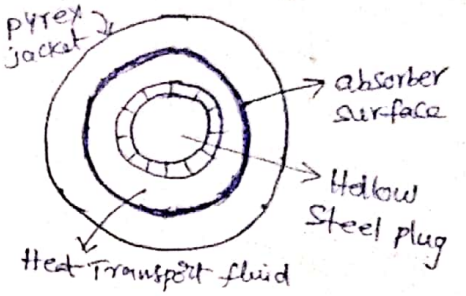
as mentioned in parabolic through collector, the mirror strips are fixed and absorber is moved continuously.

Fresnel Lens Collector:- It is a refraction type of focusing collector. It uses the focusing effect of Fresnel Lens as shown in fig.



The fresnel lens are continuously alined with the sun in two directions i.e along and perpendicular to its length.

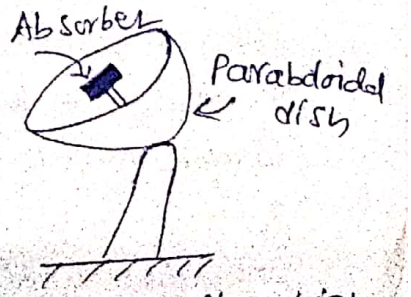
The receiver of Fresnel lens collector is as shown in figure. The absorber ~~pipe~~ is a central steel pipe with treated surface. The absorber surface is coated with black crome material. A hollow steel plug within the absorber pipe will restrict the flow of heat transfer fluid to a narrow annular region.



The absorber pipe is usually enclosed in a glass jacket in order to reduce the thermal losses by convection & radiation. The space b/w the pipe and the jacket is sometimes evacuated to reduce the convection losses. In a fresnel lens collector, the solar radiations are focused into the absorber from the top.

Point focusing Collector (or) paraboloidal type - point focusing Collector:-

A paraboloidal dish collector brings the solar radiation to a focus at a point as show in figure. The absorber is a cavity made ~~of~~ a zirconium-copper alloy with the black chrome coating. The heat-transport fluid flows into and out of the absorber cavity through the pipes bounded. The dish can be turned automatically about two axes so that the sun is always kept in a line with the focus and base of the paraboloidal dish. Thus, the sun can fully tracked at all times.



The concentration ratios are very high ~~as~~ in case of parabolic system and ~~hence~~ therefore can be used where high

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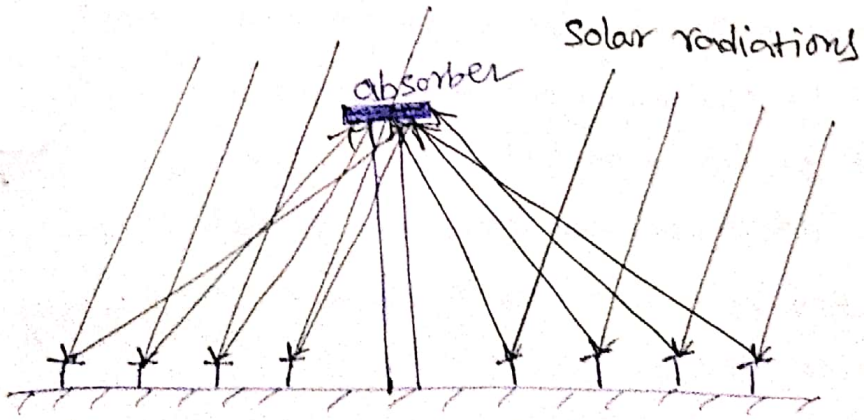
temparature is required. The Concentration ratios of about 30 to 60 or above would be needed to achieve temparatures in range 300 to 500°C or above. The collectors designed for such high Concentration ratios have small angles of field of view and hence need to track the sun continuously.

The point focusing Collectors are classified as

(i) The linear focus Collectors in the form of a parabolic trough.
(ii) Spherical and Conical mirror with aberrated foci.
(iii) Central receiver Collector, Such as the paraboloidal mirror and the tower power plant using heliostat mirrors.

A system, similar to large parabolic reflector system, consists of no. of mirrors distributed over an area on the ground as shown in figure. Each mirror (Called heliostat) can be movable independently about two axes so that the reflected solar radiation is always directed towards an absorber mounted on the tower. This type of Collector is Called 'Central Receiver Collector". This is most Commonly used tower power plant for electrical power generation.



Distributed helistat point-focus Collector (Central Receiver Collector)

The main problem/disadvantage of this type of Collector is that the heliostat mirror requires non-linear drive rate in two co-ordinates to achieve the required reflected image point on the fixed absorber.

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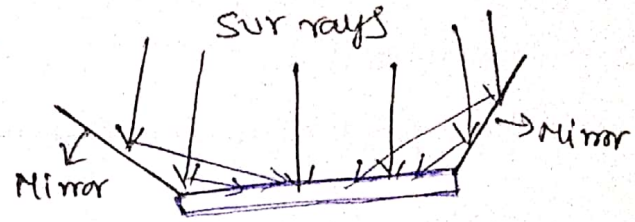
Non focusing type Concentrating collectors:-

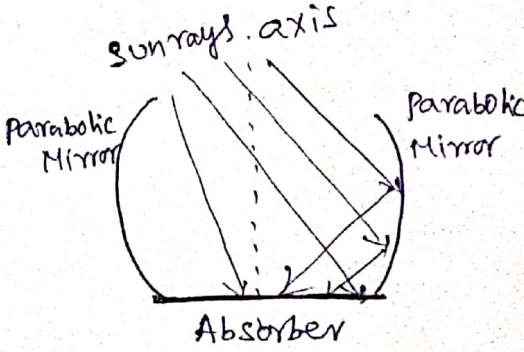
(i) **Modified flat plate collector:-** It is the simplest type of Concentrating collector. It consists of flat plate collector with mirrors attached as shown in figure. If the mirrors are set at the proper angle, they reflect solar radiation on to the absorber plate. Thus the latter receives the reflected radiation in addition to that normally falling on it. Only part of the scattered radiation falling on the mirrors will be reflected on to the absorber. The angle of the mirrors should be adjusted continuously as the sun's orientation change Because of this reason, the flat plate collectors with mirrors are not used widely.



Flat plate Collector

Compound parabolic Concentrator (CPC) :-

The CPC is a trough type arrangment of two facing parabolic mirrors as shown in figure. In CPC, the solar radiation from many directio is reflected towards the bottom of the collector. Because of this property, a large ~~portion~~ proportion of the solar radiation entering through the collector on the small area. The main advantage of the CPC is that it provide moderately good Concentration without adjustment for sun tracking. It is possible to Concentrate Solar radiation by a factor of 10 without sun tracking. The advantages of this type of collector are



(i) There is no need for tracking

(ii) Its Concentration ratio is equal to maximum value possible for a given acceptance angle.

(iii) The efficiency for accepting diffuse radiation is much larger tha Conventional Concentrator.

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ENERGY STORAGE :-

Necessity of Energy Storage [or] Advantages of Energy storage :-

The effective utilization of various energy sources requires the energy storage. The main necessity of energy storage are

(i) Improve the reliability of power supply: When cloudy days, the clouds will cover the sky for several days. This results in low electrical power generation with pv panel compare to high insolation cloud-free days. During such days, the energy stored previously stored is used to provide continuous electrical o/p. Thus the addition of storage can increase the reliability of power system.

(ii) The electrical energy may be generated either on land (or) at sea which is located at long distance from the consuption centre. This requires the both storing the energy and transporting it economically to a load centre.

(iii) The electrical vehicles utilizes the electrical energy and also require energy storage. ~~To supply~~ The electrical power continuously fed for electric vehicle with the help of energy storage.

(iv) The energy storage will permit a better match between the input energy and the load demand.

(v) The storage is required for "load leveling" in an electrical utility to reduce the overall cost of generating electrical power.

Classification of Energy storage methods :-

Energy can be stored in various forms and storage methods are classified based on the form in which it is stored. Some of the energy storage methods are:

i) Mechanical Energy Storage → pumped storage, Compressed air storage, Fly wheel Storage

2) Chemical storage → Battery storage, Hydrogen storage, Thermal chemical storage

3) Thermal Energy Storage → sensible heat storage, latent heat storage

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4) Electromagnetic Energy Storage
5) Electro-Static Energy Storage } Electrical Energy Storage
6) Biological storage.

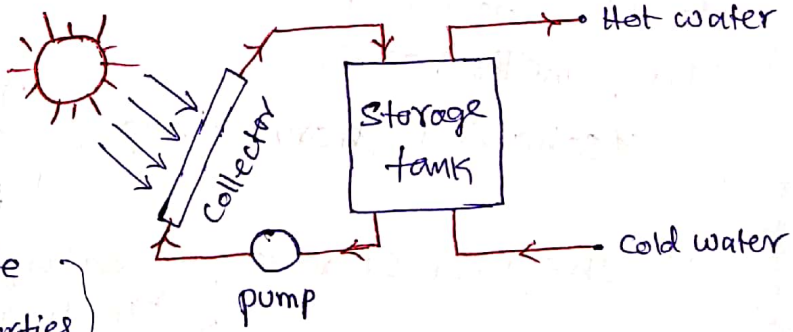
Sensible heat storage:- In this type of storage, the thermal energy is stored by the change in temparature of the material during the process of charging and discharging. The temparature of the storage material rises when energy is absorbed and drops when energy is withdrawn. on the basis of heat storage media, the sensible heat storage are classified as

(i) Liquid Media Storage
(ii) Solid Media storage
(iii) Dual media storage

Liquid Media storage:- Generally, water is most suitable liquid media for storage below 100°c because water has the following advantages

* It is abundant and inexpensive.
* Easy to handle, non-toxic, non-combustible.
* It has high density, high specific heat, good thermal conductivity, and low viscosity.
* charging and discharging of heat can occurs simultaneously.

The figure shows the thermal energy storage in water for short-term. Here the hot water is stored in insulated tanks. The storage is economically useful for few days because of heat losses.



Thermal Energy Storage for short-term.

Other liquids such as oils, liquid metals, molten salts are also used. The following table shows the thermo-physical properties of various liquids for sensible heat storage.

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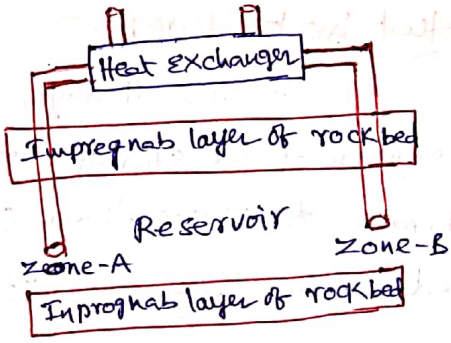
Medium	Temparature range (°c)	Density (Kg/m³)	Heat Capacity
water	0 to 100	1000	4190
Molten Salt	142 to 540	1680	1560
Engine oil	upto 160	888	1880
Lithium	180 to 1300	570	4190
Sodium	100 to 760	960	1300

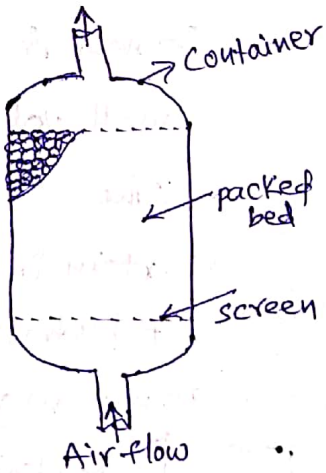
The following fisure shows the thermal Energy storage in water for large size and long term storage.



Here, the cold water from zone-A of reservoir is heated by passing it through a heat exchanger and returned to zone-B where it is stored. In the discharge mode, the hot water from zone-B flow back through the heat exchanger where it gives out the stored heat and return to zone-A. The heat from such process can be retrieved with negligible losses i.e about 1% only.

Solid Media Storage :- It is also known as packed bed storage. It utilizes heat capacity of the bed of the loosely packed solid material like rocks, sand, concrete, metal, bricks etc. The figure shows the rock packed bed storage.

The packed storage unit consists of Container, a screen to support the bed, inlet and outlet ducts. An air is circulated through the bed to add or remove the Energy. Here the energy can be used at low or high temperature. The air-flow is maintained through the bed in one direction during the addition of heat, opposite during removal of heat. This type storage system has the following advantages (i) Rocks are abundant, low cost, easy to handle and non toxic.



(ii) High storage temperature is possible.
(iii) No freezing and no corrosion problem

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but this method suffer from following limitations.

* Large storage volumes
* Simultaneous charging and discharging of heat is not possible.

Dual media storage:- In dual media storage, both solid and liquid ~~heat~~ sensible heat storage materials are used. These solid and liquid materials may be combined in the following possible ways. For example

* Jointly use of bed rock and water tank - Aslo known as hybrid system.
* Arraugment of water tank surrounded by bed rock.

Latent heat Storage:-

In this storage, the energy is stored by the virtue of latent heat of the phase of the storage medium. The phase change materials have more thermal storage densities than sensible heat storage materials and are able to absorb and release large quantity of energy at constant temperature.

These storages are compact in size but more expensive than sensible heat storage. Various phase changes that occurs are

(i) solid - solid (ii) Solid - gas (iii) Solid - liquid (iv) Liquid - gas.

Solid - gas and liquid - gas transformations are not used because, it requires large change in volume which makes the system as complex and impracticable.

In solid - solid transition, heat is stored as the material is transformed from one crystalline form to other. These transitions involves small volume changes.

The solid - liquid trans-formations include storage in salt hydrates. certain in-organic salts (which are soluble in water and form crystalline salt hydrates) are used. The heat transfer properties of some phase change material are given as

Material	Melting point(°)	Heat of fusion	Density (Kg/m³)
Sodium thio Sulphate	48 to 49	209	1666
Calcium choride hexahydrane	29 to 39	177	1634
Sodium Carbonate decahydrane	32 to 36	247	1442
Di Sodium phaspate decahydane	36	265	1522

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Let an inorganic salt (which is soluble in water) $X(Y)_n$, crystalline salt hydrate is represented by $X(Y)_n \cdot mH_2O$. on heat up, the hydrate crystal release water of crystallization and remaining solid will dissolves in released water.

i.e. $\underbrace{X(Y)_n \cdot mH_2O}_{\text{Crystalline salt}} + \underbrace{\Delta H}_{\text{change in heat}} \leftrightarrow \underbrace{X(Y)_n}_{\text{In-organic salt}} + \underbrace{mH_2O}_{\text{water.}}$

One problem with the salt hydrates is that the release water of crystallization is not sufficient to dissolve all the solid remainder.

Thermo chemical Storage :- It is called as reversible chemical reactions. This type of storage is suitable for medium and high temperature applications. The main advantages of this storage system are

* High energy density storage for long periods without thermal/heat losses.
* It has potential for heat pumping and energy transport for long distance.

This type of storage is explained with the following hypothetical reaction.

$$A + B \leftrightarrow AB$$

Here the forward reaction takes place with absorption of heat from solar energy and heat is stored in the form of products and the products are mixed to allow the reversible reaction. Both forward and reverse reactions takes plate at constant but passes different temperatures i.e the forward reaction generates more/high temperature than the reverse reaction.

The following table shows the chemical reactions that are illustrated based on the above criteria and are found suitable for use in solar application.

Reaction	Temp. of Forwar reaction	Temp. of reverse reaction	Energy Stored/m3
$CH_4 + H_2O \leftrightarrow CO + 3H_2$	780°	610°	209.4 KJ
$SO_3 \leftrightarrow SO_2 + 0.5O_2$	1025°	590°	460.6 KJ
$NH_4SSO_4 \leftrightarrow NH_3 + H_2O + SO_2$	498°	435°	2143.7 KJ

For example, let 2nd reaction, the sulphur trioxide is decomposed into sulphur dioxide & oxizen in forward direction and recombination of sulphur dioxide & oxizen is used to form sulphur trioxide in the reverse direction. This storage system is suggested for use in 100MW central tower solar power plant operation.

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Solar applications:- The major applications of solar energy are

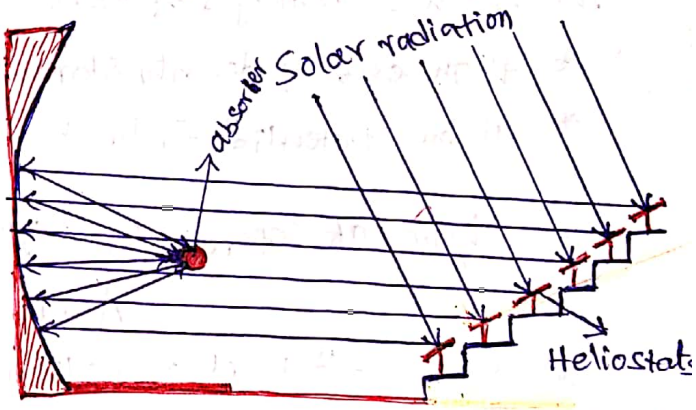
i) solar water heating/cooling (ii) Solar Distillation (iii) Solar pumping
iv) Solar ponds and drying (v) Solar furnance (vi) Solar Cooking
(vii) Solar Electric power generation (or photovoltaic Energy Conversion)
(viii) Solar thermal power production (ix) Solar green houses etc.

Solar furnance :-

Solar furnance is a basically an optical system in which the solar radiations are concentrated at a small absorbing area.

It has two main components: (i) Concentrator, (ii) Group of large number of small heliostats. The basic schematic diagram of solar furnance is as shown in figure.

The large no. of heliostats directs the solar radiation onto the parabolic reflector surface. The heliostats are adjusted such that they direct the radiation parallel to the optical axis of the paraboloid.



Solar furnance

There is another possible configuration of solar furnance, where the optical axis is vertical. A large heliostat directs the radiation upward and ~~reflect~~ Concentrator reflects it downwards at its focus. The advantages of solar furnance are

* Heating without contamination, * Easy control of temperature
* Simple working, * Absent of Electromagnetic field,
* High heat flux is obtained, * Continuous observation is possible.

Even the solar furnance has more advantages, these are not become popular industries because of following limitations.

* Their use is limited to sunny days and that too for 4 to 5 hrs only.
* High cost
* High temperatures are ~~possible~~ obtained only over a small area.

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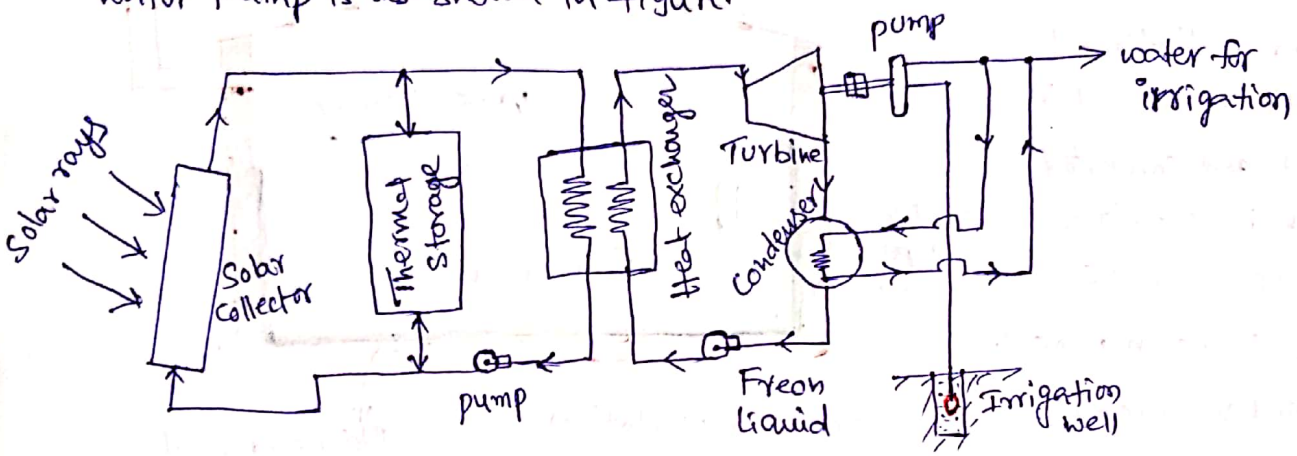
Solar pumping (or) solar thermal water pump:-

The features of solar energy makes its utilization attractive for irrigation water pumping. These are

* More irrigation water is required in summer when solar energy is aviable
* Surplus energy can provide pumped storage in the form of a pond.

The schematic diagram of a typical solar pumping (or) solar thermal water pump is as shown in figure.



Solar pumping (or) Solar thermal water pump.

The solar collector system consists of flat plate collectors (or) Non-focusing type collector (or) Sun tracking collectors. water is used as heat transport fluid, and yeilds its heat to a low boiling point in the heat exchanger. The surplus heat is stored in thermal storage which is used later i.e when the sun is not available. The high pressure vapours of working fluid expand in the turbine, condense in the condenser and return in the heat exchanger. A part of the irragation water is diverted through the condenser for cooling purpose.

The overall efficiency of the solar pumping is obtained by $\eta_o = \eta_e * \eta_c$ where η_e is the Heat exchager efficiency and η_c is the collectors efficiency. The energy efficiency of the solar pumping system is 13 to 14% only because low temperature of the working fluid entering the turbine. The irregation pump operating at a rated power of 19kw (or) 25Hp and delivers water at 500 to 600 gal/min from a well of 30m deep.

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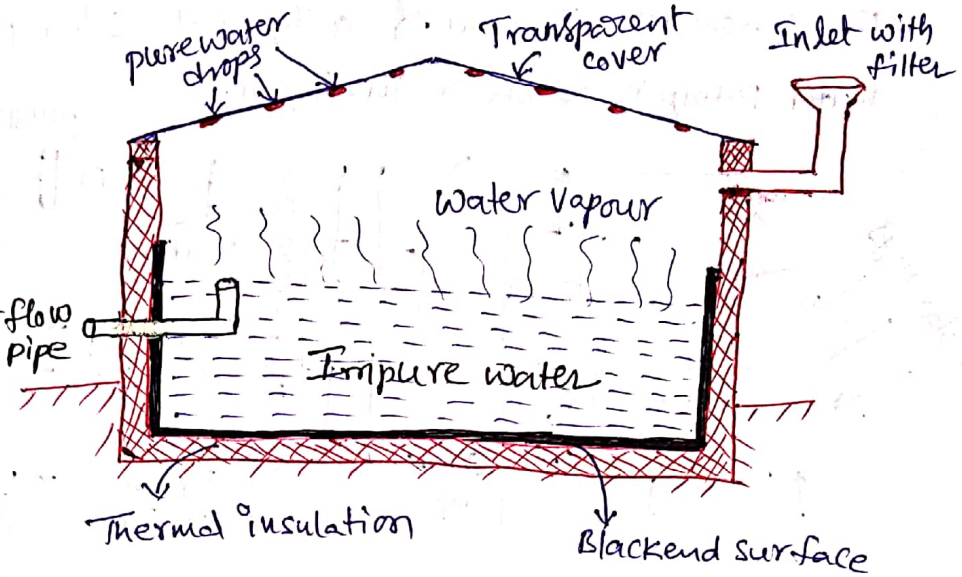
Solar Distillation (or) Distillation of water:-

Fresh water is a necessary for the sustenance of life and also the key to man's prosperity. The pure water can be be obtained by distillation in the simplest solar still. The schematic diagram of the solar still or solar distillation is as shown in figure. It consists of a blackend basin having saline water, and it is enclosed by a transparent cover at above the basin. The cover may be usually glass or plastic and is sloped towards the collecting trough.



The solar radiations passes through the cover and is absorbed and converted into heat in the black surface. The impure water in the basin is heated and vapour produced is condensed to purified water on the interior of the roof. The transparent roof transmits all radiations falling on it and absorbs very little, hence it remains cool enough to condense the vapour. The condenseted water flows down the slopping roof and is collected in troughs at the bottom. Although there are different types of configurations, their basic operation is same.

The operating efficiency of solar still is around 35 to 50%. The solar still may provide about 15 to 50 lt/day per 10 m^2 area.

Solar dryer:-

The drying process removes the moisture and helps in the preservation of any product. The dis advantages that are associated with the general heating or drying process are (i) The process is slow, (ii) Dust get mixed with the product, (iii) The product is attacked by inserts or birds etc. The use of solar dryer will prevents these dis advantages.

A simple cabine type solar dryer is as shown in fig. It is enclosed by the transparent cover. The material to be dried is placed on the trays. The solar radiations enters the encloser

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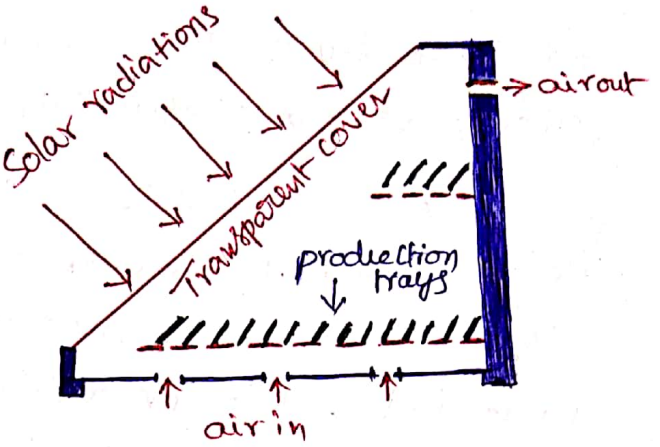
and is absorbed by the product as well as surrounding internal surface of the enclosure. The air inside the enclosure will heat up to a temperature from 50 to 80°C and above. The moisture will removed from the product by natural circulation of air at the top and bottom. For large scale drying forced circulation of air is used.

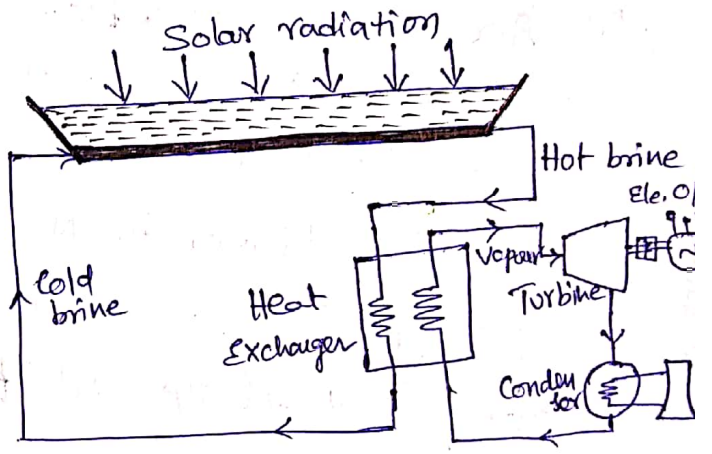


Advantages of solar drying are (i) Drying process is fast, (ii) It is controllable and (iii) better quality product can be produced.

The solar drying process are suitable for drying the food gains, products like tea and tobacco etc.

Solar pond [solar pond electric power plant] :-

A solar pond electric power plant is as shown in figure. The sola pond acts as large flat-plate collector and as well as thermal storage which provides the sufficient heat for the entire year. The blackend surface act provides as absorber. The solar pond has 1 to 2m deep and salt concentration of about 20 to 30% at bottom.



The Solar radiation penetrates through the water upto the blecked bottom and the water at bottom get heated. The hot water at bottom is pumped through the heat exchager and return to bottom of the pond. With the heat exchager, the the water circulated at turbine side may become vapour and it will drive the turbine-generator. The exhaust from the turbine is Colled and return to the (evaparator) Heat exchager.

Applications of solar pond:

(i) power generation, (ii) cropdrying (iii) process heat; (iv) Desalination.

Demerits of solar pond:

(i) Requires more land/space
(ii) Availability of water, salt
(iii) Availability of sun radiations.

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Unit-III: Wind Energy

Syllabus: Introduction, Wind and its Properties, site selection consideration, Basic principles of Wind Energy Conversion Systems (WECS), Parts of WECS, types of wind machines, Classification of WECS, modes of wind power generation, Derivation for Power in the wind, energy storage, performance characteristics of wind machines, applications, Advantages and Disadvantages of WECS.

Wind: Wind is the movement of air caused due to air pressure in the atmosphere. Wind flows from high air pressure area to low air pressure area. If the air pressure difference is more, the wind flow is more/faster.

The Nature of Wind

The circulation of air in the atmosphere is caused by the non-uniform heating of the earth's surface by the sun. The air above a warm area expands, it is forced upward by cool, denser air which flows in from surrounding areas causing wind.

The nature of the terrain, the degree of cloud and the angle of the sun in the sky are all factors which influences this process.

In general, during the day the air above the land mass tends to heat up more rapidly than the air over water. In coastal regions this manifests itself in a strong onshore wind. At night the process is reversed because the air cools down more rapidly over the land and the breeze therefore blows off shore.

Despite the wind's intermittent nature, wind patterns at any particular site remain remarkably constant year by year. Average wind speeds are greater in hilly and costal area than they are well inland. The winds also tend to blow more consistently and with greater strength over the surface of the water where there is a less surface drag.

Wind Mill (or) Wind energy conversion system (WECS): The wind mill or WECS is an energy conversion system that converts the wind energy (*kinetic energy*) into mechanical energy, with wind turbine-generators, this mechanical energy is converted into electricity. The wind energy conversion systems are also known as *aero generators* or *wind turbines*.

Uses/applications of wind energy:

1. The wind energy is used to propel the sailboats in river and seas to transport men and materials from one place to another.
2. Wind energy is used to run the pumps to draw water from the grounds through wind mills.
3. Wind energy has also been used to run flourmills to grind the grains like wheat and corn.
4. Wind energy is being used for battery storing and to generate electricity.

Advantages of Wind Energy (or) Wind energy conversion system (WECS):

(i) It is available in free and is inexhaustible.
(ii) It is a form of renewable energy source.
(iii) It is clean and Non-Polluting, so it has no adverse influence on the environment.
(iv) The Wind energy system avoid the fuel provision and transportation
(v) On small scale (upto few KW), the system is less costly. On a large scale costs can be competitive with conventional electricity and lower cost could be achieved by large power generation.
(vi) Creates new jobs.

Disadvantages of Wind Energy (or) Wind energy conversion system (WECS):

(i) Wind energy available in dilute and fluctuating in nature.
(ii) These systems are noise in operation, a large unit can be heard many kilometers away.
(iii) Large areas are required because the propellers 1 to 3m in diameter are used to deliver the power in range of 30 to 300w.
(iv) Wind mills/plants can effect the local wildlife.
(v) Good land-based wind sites are often located in remote locations, far from cities where the electricity is needed.
(vi) Present system are neither maintenance free nor practically reliable.
(vii) It has practically high overall weight because it involve the construction of high tower, gear box, a hub and pitch changer, a generator coupling shaft etc. For large systems a weight of 110Kg per KW has been estimated.

Classification of WECS (Wind Energy Conversion System): The WECS are classified as

Based on axis: The wind energy convention system (WECS) are classified as two types based on the axis. Those are

(i) Horizontal axis machine/turbine: Here the axis of rotation is horizontal and the aero-turbine plane is vertical facing the wind.
(ii) Vertical axis machines/turbine: The axis of rotation is vertical and the blades may be vertical facing the wind.

Based on size: Based on the size, the WECS are classified as

(i) Small size WECS: These WECS generates power upto 2 KW. These are used for forms, remote applications, the places where the power required is relatively low etc.
(ii) Medium size WECS: Here the power generation is 2 to 100 KW. There are used to supply less than 100Kw rated capacity, to serve residences or local uses.
(iii) Large size WECS: These WECS will generate above 100 KW. There are used to supply for distribution in central power grids. There are two sub classes:
(a) Single generator at a single site, (b) Multiple generators at several places over the area.

Based on the types of output: Based on the output power, the WECS are classified as

(i) DC output: It uses DC generator (or) an alternator with rectifier
(ii) AC output: AC generator or alternator is used
(a) Variable frequency, variable or constant AC voltage
(b) Constant frequency, variable or constant AC voltage

Based on turbine speed: The WECS are classified as three types based on the rotational speed of the turbine.

(i) Constant speed and variable pitch blades: It uses a Synchronous generator with constant frequency output.
(ii) Nearly constant speed with fixed pitch blades: It uses a Induction generator.
(iii) Variable speed with fixed pitch blades: In this WECS, for constant frequency output, the following generators are used.
(a) Double output indication generator, (b) AC commentator generator,
(c) Field modulated system, (d) Variable speed constant frequency generating system.

Based on the utilization of output: Based on the utilization of output, the WECS are classified as

(i) Battery storage, (b) Direct conversion to electricity, (iii) Thermal potential

(iv) Inter connection with conventional electric utility grids.

SITE SELECTION CONSIDERATION FOR WECS:

The power available in the wind increases rapidly with the speed, hence wind energy conversion machines should be located preferable in areas where the winds are strong and persistent.

The most suitable sites for wind turbines would be found in areas where the annual average wind speeds are known to be moderately high or high.

If the WECS sites are wrongly or poorly chosen, the net power generation per year is not optimal optimal and resulting high capital cost for the WECS apparatus, high costs for wind generated electric energy, and low Returns on Investment.

Technical, Economic, Evironmental, Social and Other factors have to examined before a decision is made to erect a generating plant on a specific site.

Some of the main site selection consideration are:

i) High annual average wind speed:

The WECS are located where the high average wind velocities available are in the range of 6 m/s to 30 m/s throughout the year since power developed is proportional to cube of wind velocity. For example, Doubling the velocity, increases power by a factor of 8. It is obviously desirable to select a site for WECS with high wind velocity.

ii) Availability of anemometry data:

It is an improvement factor. The aenometry data should be available over some time period at the precise spot where any proposed WECS is to be built and that this should be accomplished before a sitting decision is made.

iii) Wind structure at the proposed site:

The ideal case for the WECS would be a site such that the V(t) Curve was flat, i.e., a smooth steady wind that blows all the time; but a typical site is always less than ideal. Wind specially near the ground is turbulent and gusty, and changes rapidly in direction and in velocity.

iv) Altitude(Height) of the proposed site:

The height of the WECS location affects the air density this will affects the wind power and also the WECS electric power output. We well known, the wind velocity increase with the height.

v) Local Ecology

If the surface is base rock it may mean lower hub height hence lower structure cost. If trees or grass or vegetation are present, all of which tend to destructure the wind, the higher hub heights will be needed resulting in larges system costs that the bare ground case.

vi) Distance to road or railways:

This is another factor the system engineer must consider for heavy machinery, structure, materials, blades and other apparatus will have to be moved into any choosen WECS site.

vii) Nearness of site to local centre/users:

The WECS must be located for away from cities and forests since the buildings and forests offer resistance to the air movement. There should be not all structures in 3 km radius from the installation.

viii) Nature of ground:

Ground condition should be such that the foundation for a WECS are secured. Ground surface should be stable. Erosion problem should not be there, as it could possibly later wash out the foundation of a WECS, destroying the whole system.

ix) Favourable land cost:

Land cost should be favourable because it will affects the total WECS system cost.

x) Other conditions such as icing problem, salt spray or blowing dust should not present at the site, as they may affect aeroturbine blades, the machinery and electrical apparatus.

The Power in Wind:

Wind possesses energy by virtue of its motion. There are three factors determine the output power generated from the wind mill, they are

(i) The wind speed,

(ii) The cross section of wind swept by rotor, and

(iii) The overall conversion efficiency of rotor, transmission system and generator or pump.

The power is equal to energy per unit time. The energy available is the kinetic energy of the wind. The wind mill works on the principle of converting Kinetic energy of the wind to mechanical energy.

Let m = Mass of wind/air (kg), V = Velocity of air/wind (m/s), ρ = air/wind density

A = Area swept by the rotating blades of aero turbine

The kinetic energy of the air/wind = $\frac{1}{2} mV^2$ ----- (1)

Where Mass of air (m) = Air density * Volume of the air

Volume of the air = The amount of air passing in unit time, through an area 'A', with velocity 'V'

= A.V

Mass of air (m) = ρ.AV Kg.

The kinetic energy = $\frac{1}{2} (\rho.AV)V^2 = \frac{1}{2} \rho.AV^3$ watts ------- (2)

Since the area swept by the wind blades is nearly in circular fashion with diameter D,

The area swept by the wind blades (A) = $\frac{\pi}{4} D^2$

The available wind power $P_a = \frac{1}{2} \rho(\frac{\pi}{4} D^2)V^3$

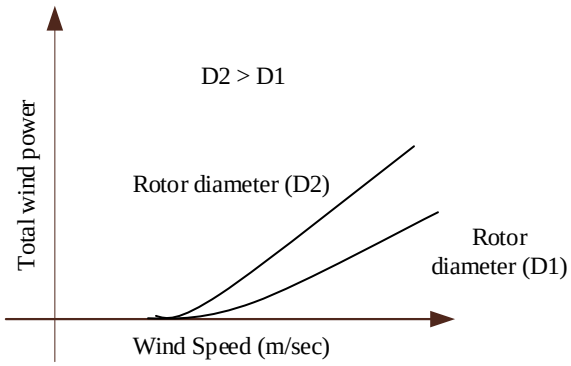
$= \frac{\pi}{8} \rho D^2 V^3$ watts --------- (3)

From equation (3), the maximum available power form the wind varies as a square of the diameter of the area swept by the aero turbine. The total wind power variations on the wind speed and rotor diameter is as shown in figure.

Practically, the wind velocity is not constant, it is represented by 'Noisy' wind speed time curve. Let the variations in wind speed wrt time as V(t),

The instantaneous power $P_a(t) = \frac{1}{2} \rho.A(V(t))^3$ watts

The above equation tells us that for a non-steady state wind, it is necessary to cube the measured wind speeds and take the average to find the average available wind power.



The average wind power density (average wind power per area) = $P_a(t)/A = \frac{1}{2} \rho(V(t))^3$ watts/m^2

The above equation indicates that the average available wind power per unit area is directly related to the cube of the average of wind speed. In practice a wind turbine's output will vary. There will be periods when there is insufficient wind for the machine to generate any power at all, and times when the wind speeds are so high that the machince has to be shutdown to prevent damage.

Force on the Blades or Torque developed

When the wind strikes the blades of the aero turbine, two types of forces will act on the blades. They are

(i) Circumferential force: It is acting in the direction of wheel rotation and provides the torque.

(ii) Axial force: It is acting in the wind direction and provides an axial thrust.

Circumferential Force or Torque (T): Let T = Torque developed, ω = Angular velocity (m/sec),

D = Turbine diameter, N = Turbine operating speed(rps) or No. of revolutions per sec

$$\text{Torque developed (T)} = \frac{\text{Power developed(P)}}{\text{Angular velocity}(\omega)} = \frac{P}{\pi DN}$$

Where the power developed (P) = η * Total available power because

$$\text{We have efficiency } (\eta) = \frac{\text{Utilized Power (P)}}{\text{Total available Power}}$$

Power developed (P) = η * Total available power = $\eta .\ ½\ \rho . AV^3$ watts

$$\text{Torque developed (T)} = \frac{\eta .* \frac{1}{2} * \rho A V^3}{\pi DN} = \frac{\eta .* \frac{1}{2} * \rho \left(\frac{\pi D^2}{4}\right) V^3}{\pi DN}$$

$$\text{Torque developed (T)} = \eta \frac{1}{8} \frac{\rho_D V^3}{N} \text{ Nm}$$

If the efficiency is maximum, then the torque developed also maximum i.e

$$\text{Maximum Torque developed } (T_{max}) = \eta_{max} \frac{1}{8} \frac{\rho_D V^3}{N} \text{ Nm, but } \eta_{max} = \frac{16}{27}$$

$$= \frac{16}{27} \cdot \frac{1}{8} \frac{\rho_D V^3}{N}$$

$$\text{Maximum Torque developed } (T_{max}) = \frac{2}{27} \frac{\rho_D V^3}{N} \text{ Nm}$$

PERFORMANCE OF WIND MACHINES

As WECS is a capital intensive technology, it is desirable for the overall wind electric plant to have the highest efficiency possible, thus optimally utilizing capital resources and minimizing the busbar electric energy cost. The overall conversion efficiency, $\eta_o$of an aerogenerator of the general type is Overall conversion efficiency, $\eta_o = \frac{\text{Useful power output}}{\text{Wind power input}} = \eta_T\ \eta_{gear}\ \eta_{coupling}\ \eta_{gen}$

Where η_T = Aero turbine efficiency, η_{gear} = Gear efficiency, $\eta_{coupling}$ = Mechnical coupling efficiency and η_{gen} = Generator efficiency

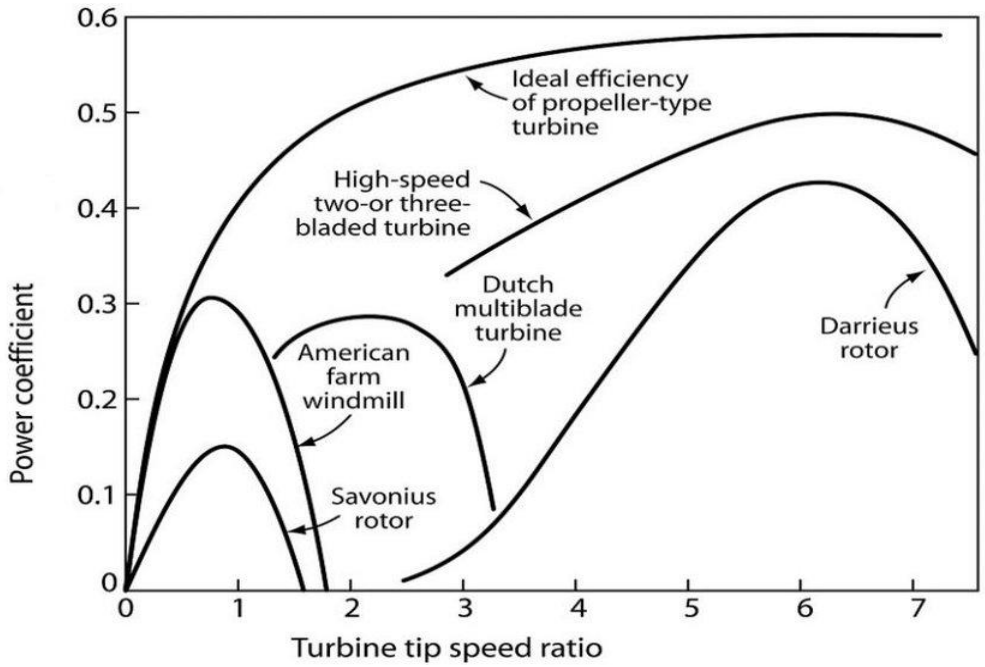
Above equation shows an application of cascaded energy conversion, from which overall efficiency will be strongly determined by the lowest efficiency converter in the cascade. Except for the aeroturbine;

the efficiency of the remaining three elements can be made quite high but less than 100 percent. Consider an aeroturbine (Here Aero turbine is not equal to aerogenerator) of cross-sectional area 'A' driven by the wind. Its efficiency would be:

$$\eta_T = \frac{\text{Useful shaft power output}}{\text{Wind power input}} = \text{Coefficient of performance } (C_p)$$

Thus the coefficient of performance of an aeroturbine is the fraction of power in the wind through the swept area which is converted into useful mechanical shaft power. We have the theoretical efficiency for horizontal axis wind machine as 0.593.

The convertible power of energy is proportional to the cube of the wind speed. Thus if the wind speed decreases by 20% the power output is reduced by almost 50%. The wind speed may vary considerable from day to day and from season to season. The efficiency of a wind generator depends on the design of a wind rotor and rotational speed, expressed as the ratio of blade tip speed to wind speed i.e., V_T/V (is called as TSR – Tip Speed Ratio), if n is the rotation frequency, ie., rotation per second, if a rotor diameter D meters, the tip speed is πnD m/sec.he variations in the efficiency or power coefficient on the tip speed ratio (TSR) for some common rotor types is indicated in Fig. It is seen that the two-bladed propeller type of rotor can attain a much higher power coefficient (i.e., it is more efficient) than the American multi-blade wind mill and the classical Dutch four-bladed windmill. In practice two-bladed propeller (horizontal axis) rotor are around to attain a maximum power coefficient of 0.40 to 0.45 at a tip speed ratio in the range a roughly 6 to 10.

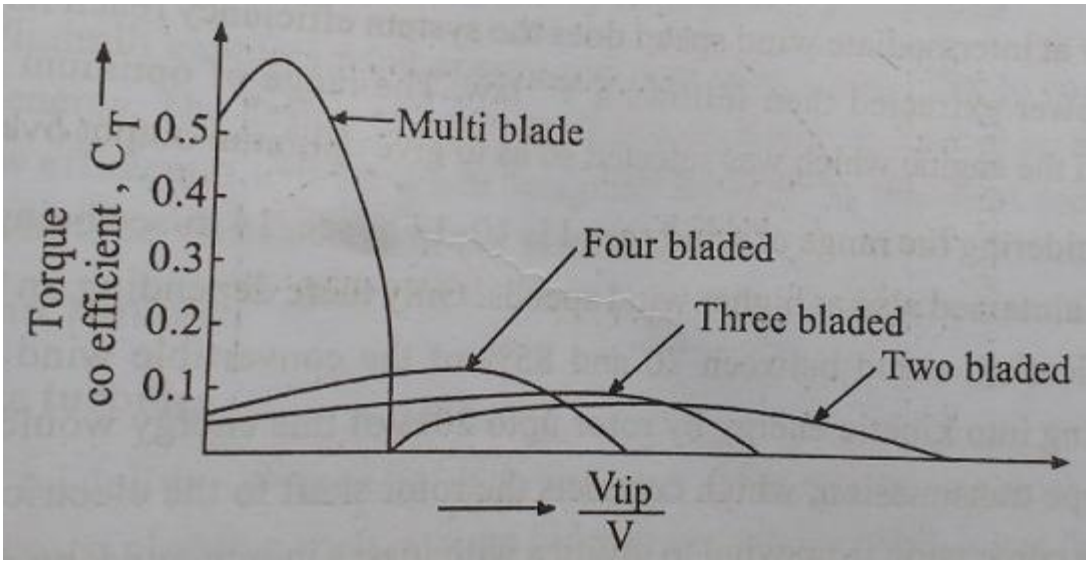


Golding has derived the expression for aeroturbine efficiency as, $(\eta_T) = \dfrac{1-K\frac{V_T}{V}}{1+K\frac{V_T}{V}}$

Where K = drag to lift ratio

It is Clear that, if there were no drag, i.e., K=0, then efficiency would be unity (η_T =1). In actuality K can be made very small, depending on the airfoil choosen and the angle of attack. Also above equation tells us the efficiency would be low if V_T/V were very large or again If it were small. One suspicions that there exists an optimum ratio of V_T/V (i.e., TSR).

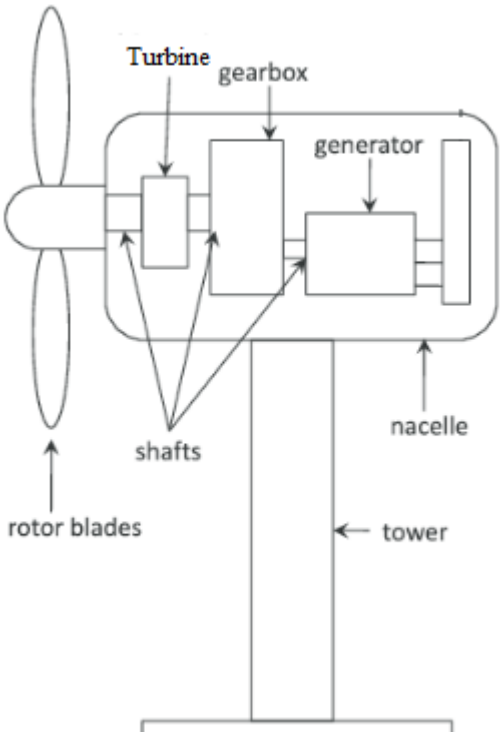
The various types of windmills performance characteristics with respect to TSR and torque coefficient are shown in Fig.



Only at intermediate wind speed does the system efficiency reach its optimum and the power extracted then follows a V^3 law. The range of optimum operation depends on the engine which was selected so as to give optimum output over the year.

Construction and working (or) Working of WECS:

Wind energy conversion systems (WECS) are designed to convert the energy of wind movement into mechanical power. It consists of **components** mainly foundation, nacelle, generator, tower, and rotor blades as shown in figure. Here the rotor shaft & electric generator which are arranged at the top of the tower. Small wind turbines use a simple wind vane, whereas larger wind turbines use wind sensors that are connected through an auxiliary motor. Most wind turbines contain a gearbox, which is used to change the blade rotation from slow to fast, so used to operate an electric generator.



With wind turbine generators, the mechanical energy is converted into electricity or this mechanical energy is used to do work such as pumping water, or drive machinery etc.

Foundation: For any wind turbine, the foundation gives support to the tower because the wind turbine includes different parts which weigh in tonnes.

Tower: A tower is used to give support to the rotor hub and nacelle on the top of the window turbine. The materials used to make this are concrete, tubular steel, or steel lattice. While

designing this turbine, the height of the tower is very important because wind speed enhances with height. So taller towers allow these turbines to capture a huge amount of energy & produce more electricity.
Generally, the output power of a wind turbine enhances by increasing its height & also decreasing the turbulence within the wind. There are different wind turbine towers available like tubular, lattice, guyed wind, tilt upwind & free standing.

Wind Turbine Blades: These blades are mainly used to convert the kinetic energy (KE) of wind into the mechanical energy. These types of blades are designed with wood-epoxy or fiberglass-reinforced polyester. These turbines include a minimum of one and maximum multiple blades depending on the design.
Most of the horizontal axis wind turbines include three blades that are connected to the rotor hub. In earlier days, multiple blades based turbines are used as a single blade, two-blade and three blades for grinding & pumping water, etc.

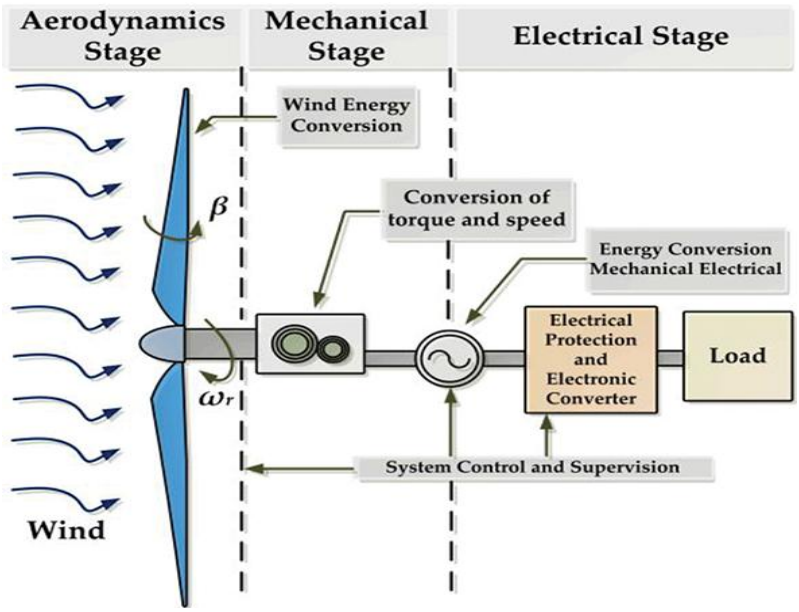
Nacelle: The nacelle includes different components which are used to operate the wind turbine efficiently like the gearbox, brakes, controller, low & high-speed shafts & generator. It is arranged at the top of a tower & a wind vane is arranged on the nacelle.

Gear Box: In wind turbines, a gearbox is used to change high toque power with low-speed which is received from a rotor blade to low torque power with high speed. This power is used for the generator. The gearbox is connected in between the generator and main shaft for enhancing rotational speeds from 30 – 60 rpm to 1000 – 1800 rpm.
Gearboxes are made with different materials like superior quality alloys, aluminum cast iron, stainless steel, etc. In wind turbines, there are three types of gearboxes are used like Planetary, Helical, and Worm.

Generator: The rotating mechanical energy of the gearbox is given to the generator through the shaft. It works on ‘Faraday’s law of electromagnetic induction principle. So it changes the energy from mechanical to electrical.

Working of WECS:

Wind energy conversion systems (WECS) are **designed to convert the energy of wind movement into mechanical power**. With wind turbine generators, this mechanical energy is converted into electricity and in windmills this energy is used to do work such as pumping water, mill grains, or drive machinery. The following figure shows the simple wind energy conversion system.



When wind hit the wind turbine blades, they. Tthe blades of most of the turbines will start turning at a wind speed of 3-5 m/sec, which is a gentle breeze. This spinning motion will turns a shaft in the nacelle – which is the box-like structure at the top of a wind turbine. A generator built into the nacelle then converts the kinetic energy of the turning shaft into electrical energy. This then passes through a transformer, which steps up the voltage so it can be transported on the National Grid or used by a local site.

Types of wind turbines/machines:

A wind turbine is an electrical device that converts the energy from the wind into electricity. These turbines are available in different types, sizes, and shapes. There two types of wind turbines are there

(i) Horizontal-axis wind turbine, (ii) Vertical axis wind turbine.

Working: Once the wind blows, a wind turbine converts the kinetic energy of the wind into mechanical through the revolution of the rotor. After that, this converted energy can be transmitted through the shaft & the gear train toward the generator and then, this generator converts the mechanical energy into the electricity.

The wind flows on both faces of the blade create pressure difference on the blade. The pressure difference between both the top & bottom surfaces results within the aerodynamic lift. As the blades of a wind turbine are constrained to move in a plane with the hub as the center, the lift force causes rotation about the hub. In addition to the lift force, a drag force perpendicular to the lift force prevents rotor rotation. The horizontal axis wind turbine design mainly includes a high lift to drag ratio, especially for the blades. So this ratio can change through the blade's length to optimize the output energy for the wind turbine at different speeds of wind. The generator & rotor shaft are arranged within the box at the top of the array.

Types: Horizontal-Axis Wind Turbines may be designed with **one, two, three, or more blades**. The fewer blades a wind turbine has, the faster the blades must turn to harvest the same amount of energy as a wind turbine with more blades. **For example**, a **three-blade** wind turbine does not have to turn as fast as a two-blade wind turbine to harvest the same amount of energy. Therefore, the tip speed ratios of a two-blade wind turbine and a three-blade wind turbine are different.

Single-Blade Turbines

In this arrangement, a long blade is mounted on the **rigid hub**. At other end of the blade, a counter weight is attached for mechanical balancing of blade. Single-blade wind turbines are used in a few limited applications, but they are the least used of all the Horizontal-Axis Wind Turbines.

To rotate smoothly, single-blade turbines must have one or two counterbalances as shown in Figure

.The **advantage of this type of wind turbine** is the lower cost because of the use of only one turbine blade (and the small weight savings), but single-blade turbines must run at much higher speeds to convert the same amount of energy from the wind as two-blade or three-blade turbines with the same size blades.

But it suffers from the drawbacks

(i) Because the single-blade turbine must run at higher speeds, more wear and fatigue are generated on the blade and bearings in the mounting mechanism.

(ii) Requires higher maintenance costs over the life of the turbine.

(iii) Single-blade turbines also require extensive setup procedures to ensure that the blade is mounted perfectly and is balanced to limit oscillation and vibration.



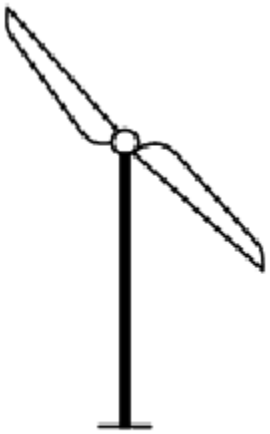
Single blade

Two-Blade Wind Turbines

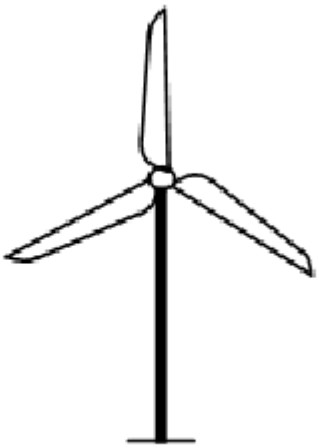
This type of wind turbine consist of two blades as shown in figure. Compared to three-blade turbines, two-blade wind turbines **have the advantage** of saving on the cost and the weight of the third rotor blade, but they **have the disadvantage** of requiring higher rotational speed to yield the same energy output. Also it surreres form more noise, and wear of critical bearings, shafts, and gearboxes.

Two-blade turbines have high-fatigue failures of the blade and other mechanical parts, so they have limited application. For more the efficiency of the two-blade turbine, the turbine blades should be thicker and wider than traditional turbine blades so that the two blades can convert more wind energy. The thicker blades also mean that the blades are stronger and better able to resist fatigue problems.

Even with these more efficient blades, however, the two-blade turbine is still slightly less efficient than the three-blade turbine. One of the main advantage of the two-blade turbine is that it is faster and safer to install than the three-blade version.



Two blade wind turbine

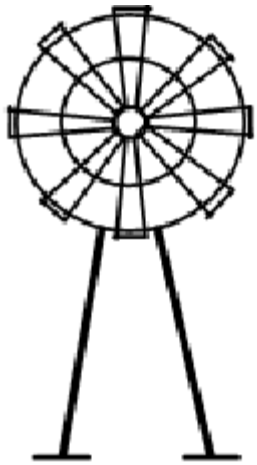


Three blade wind turbine

Three-Blade Wind Turbines: The majority of large horizontal-axis wind turbines use three blades with the yaw control. Figure shows a three-blade wind turbine. The three blades provide the most energy

conversion while limiting noise and vibration. The three blades provide more blade surface for converting wind energy into electrical energy than a two-blade or single-blade wind turbine. The blades for the larger horizontal-axis wind turbines are so large they must be transported individually by a truck and trailer. The tower to hold the larger three-blade turbine must also be larger and reinforced to support the weight and to withstand the increased wind power that is harvested to produce its maximum output.

Multi Blade Wind Turbines: A few wind turbines have multi blades to produce electrical energy efficiently from low-speed winds. Figure shows a multi blade wind turbine. A multi-blade wind generator normally has narrower and thinner blade. They are excellent in low-speed winds, they become inefficient in high-speed winds and they are noisier. The tower and base are mounted into the roof of the building, which is a concrete-reinforced building. This type of multi blade wind turbine needs a very strong base and tower to hold the wind turbine in the wind.



Multi blade wind turbine

Advantages and Disadvantages of a Horizontal axis wind turbine:

The **advantages of a horizontal axis wind turbine** include the following.

- It includes high output power as compared to the vertical wind turbine.
- A tall tower gets stronger winds once the wind shear alters.
- High efficiency.
- It is not expensive as compared to vertical type turbine.
- It has high reliability.
- It has a high rate of capacity.
- Its rotational speed is high.
- It is more consistent.
- These turbines are self-starting.
- In this turbine, the vanes are located one face of the turbine center of gravity, which improves stability.
- It can bend the blades so that the turbine blades have the best attack angle.
- The blade can also tilt the rotor during a storm to reduce damage.

The **disadvantages of horizontal axis wind turbine** include the following.

- These are available in large size.
- Weight is high.
- Installation is difficult.
- High noise.
- To design this wind turbine, large machinery is needed.
- Its maintenance is difficult as compared to other wind turbines.

The **applications of horizontal axis wind turbines** include the following.

- These are the most frequently used wind turbines for commercial and industrial purposes due to their large power output and high efficiency.
- These are mostly used in wind farms

- Horizontal axis wind turbines achieve better power output & higher energy efficiency, so used in large-scale wind power plants & also for electricity generation.
- In industrial plants, large-scale wind farms, or national projects, these wind turbines are most frequently seen. So they are the perfect solution for the production of mass electricity.

Vertical axis wind machine:

The Vertical Axis Wind Turbine is a type of wind turbine and it is most frequently used for residential purposes. The turbine which uses a vertical axis wind machine is called Vertical Axis Wind Turbine (VAWT). This turbine includes the rotor shaft and two or three blades. The rotor shaft moves vertically. In this turbine, the generator is placed at the bottom of the tower whereas the blades are covered around the shaft.

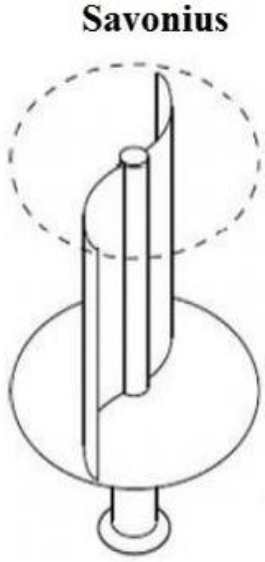
Working principle of vertical axis wind turbine: In this turbine, the rotor rotates/spins around a vertical shaft by using vertically oriented blades. Since the generator is coupled with the turbine, as a result the electricity will be generated using this wind power. These wind machines are simple in design than the horizontal axis wind machine. But it suffers from main drawback that it generate the power lower than the horizontal axis wind machine.

The vertical axis type wind machines are classified as

(i) Savonius or S type wind machine – used for low wind velocity.
(ii) Darrieus type wind machine – used for high wind velocity.

Savonius Wind Turbine:

The savonius wind turbine is used for the conversion of wind force into torque based on the rotational shift. The turbine consists of two or multiple aerofoils (blades).



Construction: The blades of this type of turbine has a shape of half-cylindrical parts attached to the opposite sides of a vertical shaft. This turbine operate on the drag force created by the blades. Since it operate on drag force, so it can't rotate faster than the wind speed i.e the the tip speed ratio of this type of rotor is ≤ 1. Tip Speed Ratio (TSR) is defined as it is the ratio between the wind speed and the speed of the tips of the wind turbine blades.

Working: As the wind blows into the structure and contact with the opposite faced surfaces (one convex and other concave), two different forces (drag and lift) are exerted on those two surfaces. In this turbine the vertical shaft will rotates based the difference of the drag force between the convex and the concave parts of the rotor blades. This mechanical power is transmitted to generator via gear and couplings and generator generates electricity.

The advantages of Savonius Wind Turbine include the following.

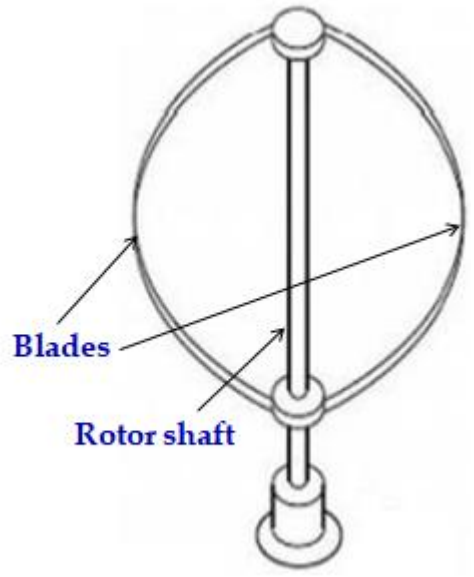
- It operation on any wind direction. Hence it does not requires any kind of yaw process which means that these are completely stable.
- The turbines are cost-effective and the operation is so streamlined.
- It is also suitable for minimal applications which have minimal electric loads.
- The blades in the turbine need no mechanism to alter the angles, it results in simple maintenance.
- Provides minimal noise.
- Integration with building is also easy.

The main disadvantages of Savonius Wind Turbine is that it is not suitable in locations where the high range of turbulent winds are there.

Darrieus Wind Turbine:

These turbines consists of long and curved wings where each end of these wings is connected to the top & base of the rotor shaft. These types of wind turbines use the aerodynamic force to revolve.

Working: By the flow of wind around the construction, it will create suction force on the front face of the wind turbine to drive the wings to revolve. Once the revolution begins, these turbines will go faster to rotate faster than the speed of the wind. These turbines do not experience as much drag like Savonius turbines.



Advantages:

- The rotor shaft is vertical. Therefore it is possible to place the components, like a generator, gear and couplings at ground level.
- The rotor can take wind from every direction to operate. Hence it does not requires yaw control.
- Easily integrates into buildings.

Disadvantages:

- Difficult start unlike the Savonius wind turbine, bcz it produces low starting torque.
- It possesses **low** efficiency.

Advantages and Disadvantages of a vertical axis wind turbine:

The advantages of a vertical axis wind turbine include the following.

- Safety for manpower.
- They can generate electricity in any direction of the wind. Hence it does not requires the yaw control.
- It doesn't require a strong supporting tower because the gearbox, generator and other components are arranged on the ground.
- These turbines are cheaper in design cost compared to horizontal axis turbines.
- Installation is easy as compared to all other types.
- These are portable in size, hence these turbines can move from one location to another.
- They work in all weather conditions like variable winds & mountain conditions.
- These are allowable where **taller structures** are not allowed.
- Its operation is simple, hence it requires a little maintenance.
- Since these turbines are arranged on the ground, hence the maintenance, the cost for construction can be reduced.
- These type of wind turbines are **used** where tall structures are not allowed.
- These are economical, quiet, efficient and **ideal** for residential energy sources, particularly in urban areas.

The disadvantages of a vertical axis wind turbine include the following.

- These are hard to arrange on towers because they are connected on bases like buildings or ground.
- They produce noise pollution.

- Components Wear-down.
- Low efficiency.
- Some animals or birds may interrupt its rotation because it is arranged in an ground/open area.
- They have high vibration due to the air flow close to the ground and makes the turbulent flow.
- Lower accessible wind speed.

Applications: The applications of a vertical axis wind turbine include the following.

- Used in small wind projects
- Used in residential applications
- These turbines are used to generate power even in not stable weather conditions like gusty wind & turbulence.

Unit-IV: Ocean Energies

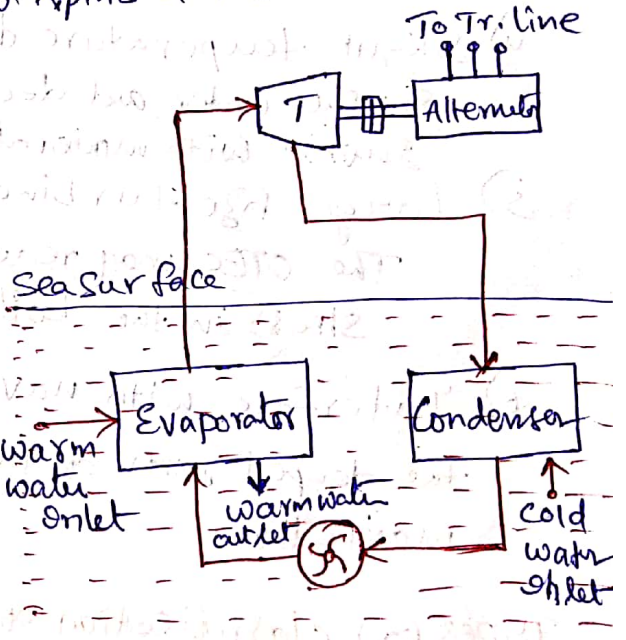
Ocean Thermal Energy Systems (OTES)

Defination:-

Ocean thermal energy conversion (OTEC) is a process/Technology for producting the power by harvesting the temperature difference b/w ocean surface water and deep ocean water. The energy from the sun heats the surface water of the ocean.

Working principle of OTEC :-

An OTEC power system works by pulling the ocean's warm surface water (around 25°c temp) to vaporize the working fluid as shown in figure. These working fluids have a low boiling temperature (such as ammonia (or propane) and convert into gas (or) vapour. The vapour expands and spins a turbine. Since the turbine is connected to Generator, the generator will produce electricity.



Advantages:-

(i) It is a form of Renewable Energy. We can generate the electrical power for lifetime without this source draining.

2) Clean Energy: The OTEC plants does not requires fuels like coal or any other fossil fuels to run, thus the generation of electricity is clean.

3) Reliable: Due to weather variation, the electricity generated by wind or solar power can be inaccurate. Therefore, the OTEC is reliable source of energy due to having minimal variations.

4) Environmental friendly :- Since it is not producing any

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emission into the atmosphere, the OTEC is environmental friendly source.

5) Low maintenance :- since the machinary for production of Energy requires low maintenace, the OTEC also required low maintenance.

6) No significant effect of weather on the ocean thermal Energy Conversion system.

Dis advantages :-

1) The locality of production: The power generation is possible only in coastal line areas.

2) High commercing cost : The price to obtain and fix the required devices for controlling OTEC is high. It needs a large no. of professionals to install the plant.

3) It causes disruption in aquelic and marine life

4) Slight temperature diffenence :- The discrepancy in temperature blw surface water and deep water is small. So this may generate electrical Energy with moderate efficiency i.e it efficiency is blw 30 to 35%.

5) Large size turbines are required
The OTEC may requires large size of turbines, because of the low stress in the boilling propene.

6) Interfere with navigation: The OTEC has pipes running down to the deepest parts of the ocean. Thus, these pipes may disturb the marine life.

Types (or) classification of OTEC plants :-

The Ocean Thermal Energy Conversion power plants are classified as three types based on the power cycle. Those are

(i) closed cycle OTEC plant
(ii) open cycle OTEC plant
(iii) hybrid OTEC plant

closed cycle OTEC plant :- In this plant, the working fluid (like

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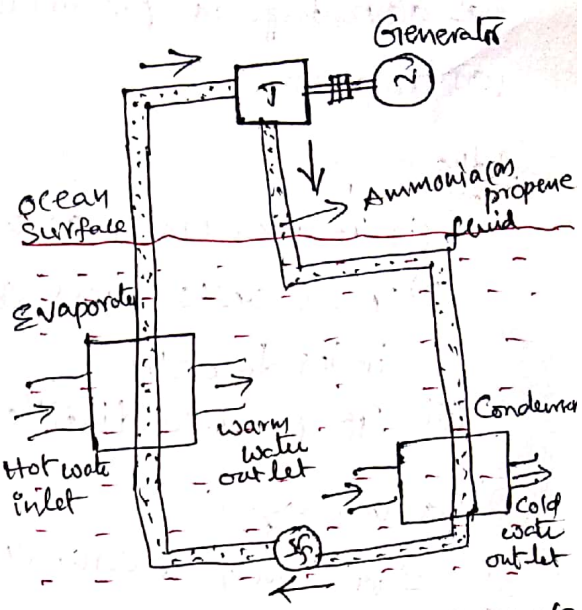
ammonia (or propene) with low boilling point is used to rotate the turbine to generate the electricity. The connection diagram of closed cycle OTEC plant is as shown in figure.



Working: A warm surface water is pumped through a (heat exchanger) evaporator where the low boilling point working fluid is get vaporized. The expanding vapour rotates the turbo-generator. Then cold, deep sea water is pumped through the condentor to Condensate the vapour backs into its original state which is then recycle through the system.

Advantages:

(i) power developed is continuous and is independent of weather
(ii) there is small variation in power generation from season to season.

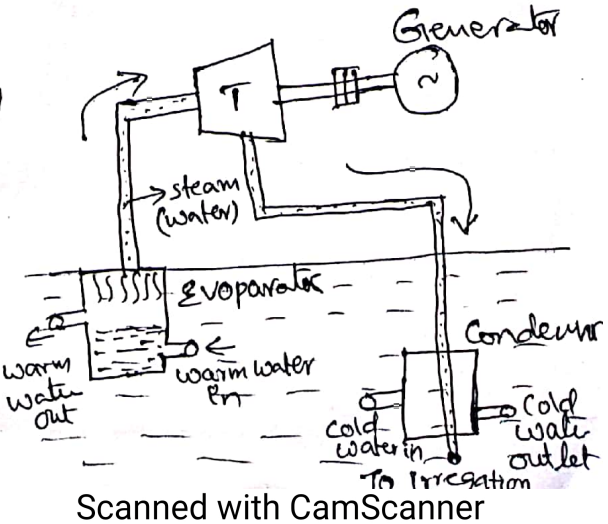
Dis advantages:

(i) More capital cost, more cost for electrical power generation /kwh.
(ii) It uses expantive power working fluid.
(iii) Need large size turbine due to low pressure of steam.

Open cycle OTEC plant :-

In open cycle OTEC plant, ~~steam~~ water is used as working fluid to produce electricity. The schematic dia of open cycle OTEC plant is as shown in figure.

Working :- When a warm sea water is placed in low-pressure container (evaporator), it boils and produces a steam. This steam drives the low pressure turbine and electricity is generated by the generator.



The steam, which has left its salt and contaminants behind the low pressure container, is the pure water. It is

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Condensed back into a liquid by using the condensor. This method has advantage of producing desalinized fresh water, suitable for drinking (or) irregation.

Advantages:

(i) It uses water as working fluid which is available free of cost.
(ii) This system uses conventional power plant with small modifications in its design.
(iii) It produces distilled water and nutrients for agriculture.

Disadvantages:-

(i) Efficiency of energy conversion is low.
(ii) Needs large size turbines due to the use of low pressure steam.
(iii) Cost of power generation per KWh is high.

Hybrid OTEC plant :- This power plant combines the features of both closed cycle and open cycle OTEC plants. In Hybrid OTEC plant, warm sea water enters a vaccum chamber (evaporator) where it is evoporated into steam, similar to open cycle process. The steam vapourizes the working fluid of a closed cycle on other side. The vapour fluid then drives the turbine coupled to an electrical generator producing the electricity. The steam from the open cycle is condense with in the condensor and provide the desalinated water.

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Wave Energy

Wave energy:- It is form of renewable energy that can be obtained from the motion of the wave. The vertical motion of the surface ocean waves consists of lot of kinetic energy that is captured by the wave-Energy technologies to do useful work like generation of electrical power, desalinization of water and pumping the water into reservoirs.

The wave power generation is not a widely used technology Compared with other renewable energy sources such as wind power, hydro power and solar power. As comparion, the power density of PV Cell is $1 Kw/m^2$ at peak solar radiation, power density of wind is $1 Kw/m^2$ at peak velocity of 12m/sec and the avg power density of wave is $25 kw/m^2$.

Working principle:- When wind blows across the sea surface, the wind energy is tranfered to the waves, it is called kinetic energy, and they create movement. This movement can be used to rotate the turbine and create the mechanical power. This mechanical power is converted into electricity using the generator.

Factors affecting the wave energy:-

There are three main factors that are affecting the wave energy. They are (i) wind velocity/speed (ii) wind Feteh (iii) wind duration.

Wind velocity/speed:- wind velocity is speed of the wind. The amount of wave energy can be determined by wave steepness and wave period.

$$\text{Wave steepness} = \frac{\text{wave height}}{\text{wave length}}$$

$$\text{Wave Energy} = \frac{\rho g^2}{64\pi} H^2 T_e \qquad g = 9.81$$

H = wave height, T_e = wave duration, ρ = sea water density

If the wind speed is more, greater the wave height, the greater the wave energy.

Wind Feteh:- It is distance coverd by the wind over ocean water with-out obstructions. If the wind feteh is more, the

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wave height also more, more energy will generated by the generator.

Wind duration:- It is amount of time that wind blows over ocean water. The longer the duration of wind, the larger the wave height and thus generate more wave energy.

Advantages of wave Energy:-

i) The wave can travel longe distances without significant energy loss.

ii) power generation is almost constant and more predictable day to day and season to season.

(iii) wave Energy Contains about 1000 times the KE of the wind.

(iv) More reliable renewable source compared with wind and solar.

(v) power production is more smother and more consistent than wind and solar.

(vi) water is 850 times dense as air, this results in high power generation.

(vii) wave Energy generation needs 1/200 the land area of wind, does not need any road access, infrastructure cost is low.

(viii) wave Energy varies as the Saure of wave height bcz wind power

$$(P) = \frac{\rho g^2}{64\pi} H^2 Te$$. where H = wave height, Te = wave duration, ρ = sea water deity ; g = acceleration of gravity.

(ix) No damage to land i.e wave power does not cause any damage to the earth.

Disadvantages of wave energy:-

(i) The electricity generation from wave technology is suitable only for coastal areas.

(ii) Even though, it is clean energy, it still creates hazards for some of the creatures near it.

(iii) The wave power generation depends on wave speed, wave length and wave density. They reauires a consistent flow of powerful waves to generate a significant amount of wave power.

(iv) The wave energy generators may be unpleasant for some who live close to coastal regions. (v) Most cost of power generation

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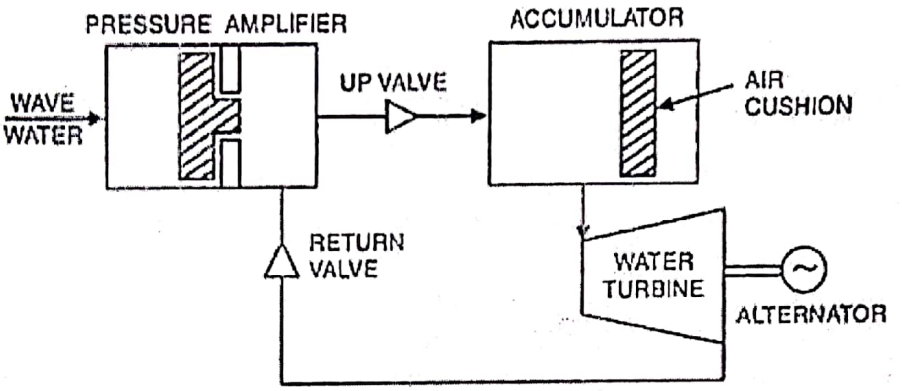
Wave energy conversion machines/Devices: The machines/devices used for conversion of wave energy are: 1). Hydraulic Accumulator Wave Machine, 2). High Level Reservoir Wave Machine

3). Dolphin Type Wave Power Machine, 4). Other wave machines

Hydraulic Accumulator Wave Machine:

The schematic diagram of hydraulic accumulator wave machine is as shown in figure. It mainly consists of the following main components:



Pressure Amplifier: The waves enter the cylinder of pressure amplifier at the bottom and move the main piston. The pressure of the closed loop fluid is amplified to about 5 bars.

Hydraulic Accumulator: When the high pressure fluid is passed through the up valve to a hydraulic accumulator, the air cushions in side the accumulator will maintains a constant pressure.

Water Turbine: The turbine will produce the mechanical energy when the high pressure fluid flows through a Pelton wheel or Francis hydraulic turbine. Since the electric generator is coupled with the turbine, the generator consumes the mechanical energy and converts it into electricity.

Working:

The piston inside the pressure amplifier will moves up and down with the entering of wave water through the opening. The pressure on the main piston is magnified on the small piston during the upstroke. The high pressure water is pumped through the "up valve" to a hudraulic accumulator at the top of the generator. Two air volumes counter balance and act as cushions in a chamber above the main piston and maintain the constant high water pressure. Apart of high pressure water flows through the water turbine that drive an electrical generator and is then discharged to a storage chamber below the turbine. The capacity of hydraulic accumulator is large enough to permit continuous turbine operation though the waves are cyclic.

High Level Reservoir Wave Machine:

The schematic diagram of High level reservoir wave machine is as shown in figure. It mainly consists of (i) Pressure amplifier, (ii) Highlevel reservoir, and (iii) Water turbine

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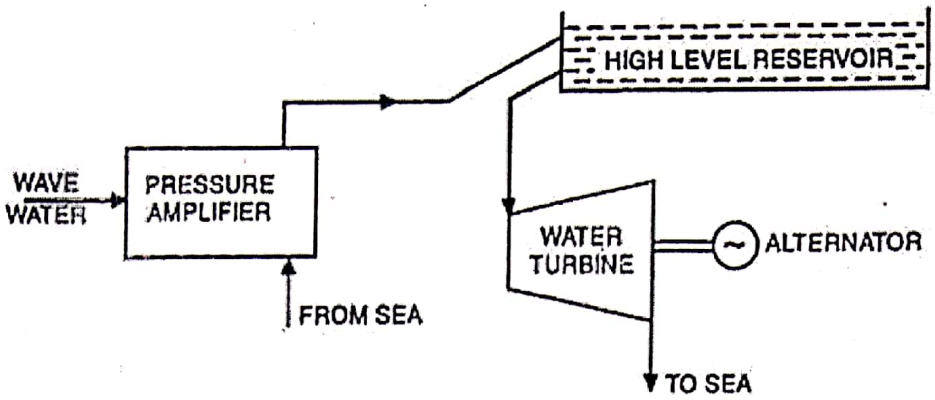


Pressure Amplifier: The pressure amplifier will sends a high pressure water to a high level reservoir on a shore line.

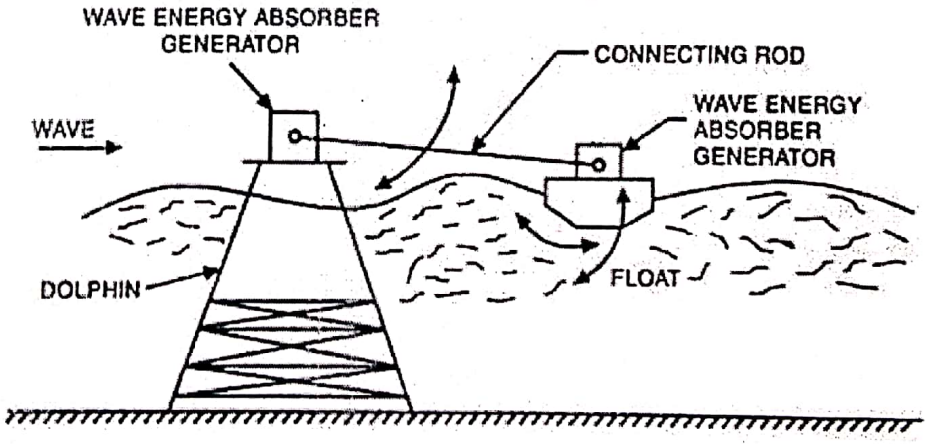
High level resorvoir: It will store the water at more potential energy, since it kept at more height. The potential energy of water in the reservoir is used to run a water turbine coupled to an electrical generator.

Water Turbine: The water turbine will converts the potential energy of water into mechanical energy. Generally, Francis or Pelton wheel turbines are used for this purpose.

Working: When the wave reaches near to pressure amplifier, the pressurized water is pumped to reservoir. When the high potential energy of water in the reservoir flows through a Pelton wheel or Francis hydraulic turbine, the potential energy is converted into mechanical energy. Since the electric generator is coupled with the turbine, the generator consumes the mechanical energy and converts it into electricity. The water expanded at turbine will come back to sea level.

The Dolphin Type Wave Power Machine:

The major components of the system are a dolphin, a float, a connecting rod and two electrical generators as shown in figure.



Working: This device uses float which has two motions. First one is a rolling motion about its own fulcrum with the conneting rod. The other is vertical motion about the connecting road. This will cause the relative movements between the connecting rod and stationary dolphin. In both cases, The movements are amplified and converted into continuous rotary motion with the help of gears that drive the two electrical generators.

Other wave machines:

There are two other wave machines to convert the wave energy into electrical genergy. Those are (i) Nodding duck wave machine, (ii) Savanius rotor wave machine.

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Nodding duck wave machine: The nodding duck scheme is a model in testing stage only.

Savanius rotor wave machine: The savanius rotor is fixed with its axis horizontal and perpendicular to the direction of wave propagation. Water passing the rotor flowed both forward and back at different time and depths. This type of wave machine will generates the power output of a few KWs/m^2.

Properties of Waves

The main properties of waves are as follows:

Amplitude – Amplitude is the height of the wave, usually measured in meters. It is directly related to the amount of energy carried by a wave.

Wave length – The distance between identical points in the adjacent cycles of crests of a wave is called a wavelength. It is also measured in meters.

Period – The period of a wave is the time for a particle on a medium to make one complete vibrational cycle. As the period is time, hence is measured in units of time such as seconds or minutes.

Frequency – Frequency of a wave is the number of waves passing a point in a certain time. The unit of frequency is hertz (Hz) which is equal to one wave per second.

Wave Speed – The speed of a wave refers to the distance travelled by a given point on the wave (crest) in a given interval of time.

Tidal Energy

Tide: Tide is defined as the alternate rise and fall of the ocean water. It is caused due to the combined effects of the gravitational force on Earth by the Sun, Moon, and Rotation of the Earth.

Tidal Energy: **Tidal energy** is a form of renewable energy which converts the energy obtained from tides into other useful energies (electricity).

Properties of Tide:

(i) The tides are periodical phenomenon, but no two tides are same.
(ii) There will be a rise in sea level for several hours - Flood tide.
(iii) The sea level stop rising and reaches a local maximum - maximum tide.
(iv) The sea level will fall/sink for several hours – Ebb tide.
(v) The sea level of stops fall/sink and reaches a local minimum – Minimum tide.
(vi) The mean tidal range varies from place to place.

Advantages of Tidal Energy (or) Tidal energy conversion system (WECS):

- It is a form of renewable energy source because this energy is inexhaustible source of energy .
- This power generation is free from pollution because it does not use any fuel and produce any unhealthy waste like gases, ash etc.
- These power plant does not requires large valuable land because they are on the sea shore.
- High energy density
- Highly predictable energy source.

Disadvantages of Tidal Energy (or) Tidal energy conversion system (WECS):

- High constructional cost.
- Construction of plant in the sea is difficult.
- Limitation of location.
- The machinery may get corrode.
- The tidal power generation is variable because of variations in the tides. This effects the efficiency of the plant.

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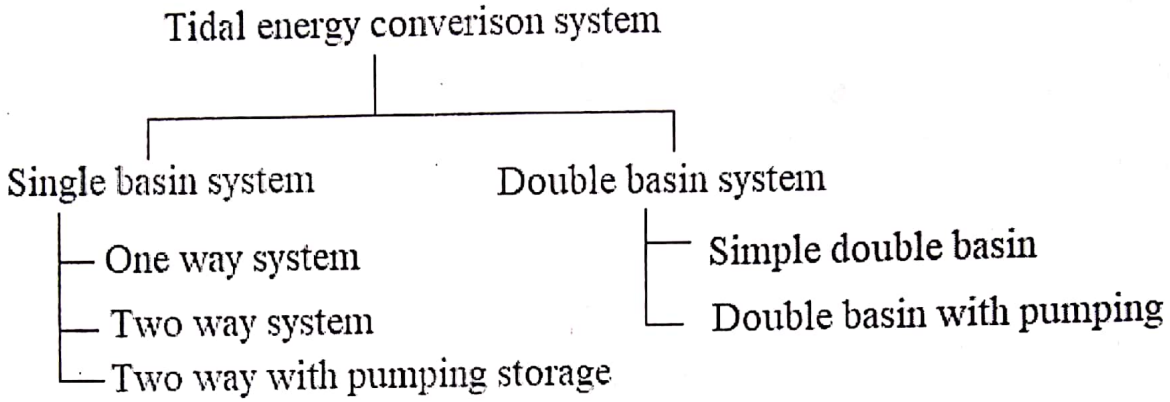
Tidal energy conversion machines/device:

The tidal power plants are generally classified on the basis of the number of basins used for the power generation. They are further subdivided as one-way or two-way system as per the cycle of operation for power generation.

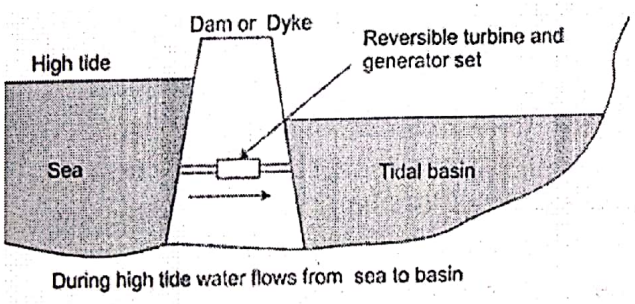


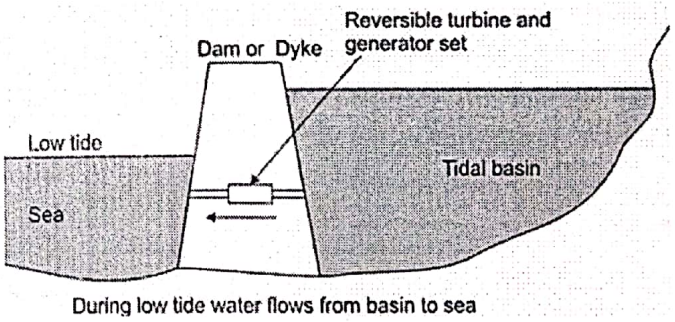
Single basin tidal power plant:

In this Power plant, the power generation is periodical or intermittent only. It consist of a basin and is separated from the sea by a wall called dam. The flow of water between sea and basin and vice versa is through sluice. Single basin tidal power plant it uses reversible turbine that means whenever the water flow from the sea to basin or from basin to sea, the power generation it is possible with the help of this reversible turbine.

Working /operation of single basin power plant:

When the incoming tide sea level and tidal basin level are equal the turbine sluice gate is closed then the sea level rises. Once the seal level rises, the turbine walls are opened and the sea water flows into the basin, the turbine will run generator and generates power.





This also rises the level of water in the basin the turbine will continuous to generate power until the tide passes through its high point and begins to drop. When the sea and basin water level are again equal, the turbine sluice gate is closed. The plant continues to generate power till the tide reaches its lowest level and again during the high tide water flows from the sea to tidal basin there by generating power.

The main drawback of the single basin tidal power plant is that it cannot generate power continuously.

Double Basin tidal power plant:

The double basin power plant will provide power continuously. It consists of two basins called upper and lower basin. One basin is maintained always at a lower level than other. So this lower basin it is always maintained at a lower level than the upper basin. A dam is constructed between sea and basins as

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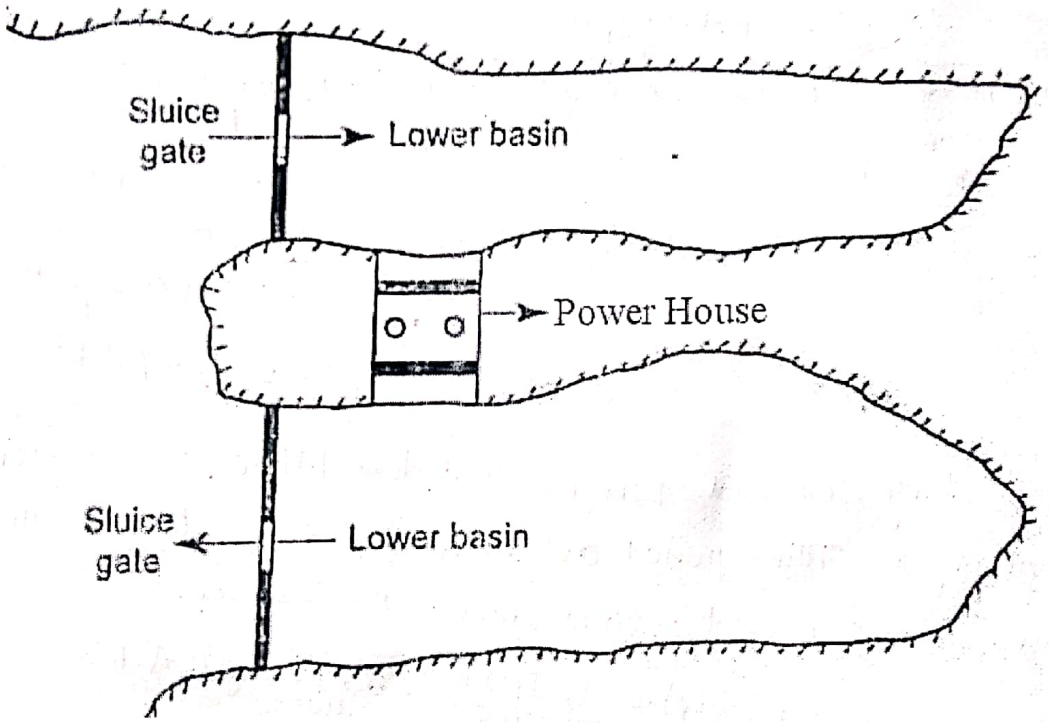
well as between basins. A power house is mounted in the dam constructed between the upper basin and lower basin.

Working or operation:

During the high tide the wall or the sluice gate it is opened so as there is a level difference between sea and upper basin. Water starts to flow from sea to the upper basin during this the wall or the sluice gate between lower basin and sea. It is closed the gate is sluice between upper basin and lower basin it is also closed. So as soon as the level the upper basin it is raised then at the same time the lower basin it is emptied. It is in the condition of empty so as soon as the sluice gate is opened sluice is slowest gate between the upper basin and lower basin.



When it is opened the water starts to flow from the upper basin to lower basin and as there is turbine mounted. The electricity is generated now the water level of the lower basin increased so as soon as the water level of the sea they were in the low tide is decreased. The sluice gate between lower basin and sea is opened and water starts to flow from the lower basin to sea. In this way the lower basin is emptied. Again during the high tide the sluice gate between sea and upper basin is opened and this upper basin it is filled so in this way the electricity is generated as it when require which means there are the two basins which are kept at a certain height. Certain difference of height between them so when it is filled then ever there will be the demand of electricity the gate between the upper basin and lower basin it is open and the electricity generated. So in this way the power generation is continuously produced.

Estimation of Energy and power in tidal plant :-

(i) Single basin Tidal system :-

The power and Energy that can be generated during the generation period can be derived with the help of following diagram. Let, during the emptying process, the work done by the water is

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caused to its potential energy at the time.

Assume R = Tidal range (m), A = Basin area (m^2)

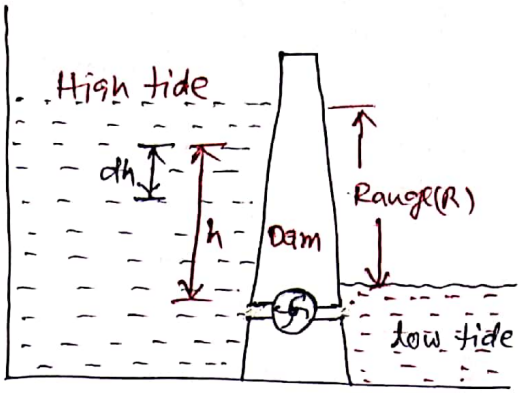
h = Intermediate head (m)

dh = Small head, ρ = water density kg/m^3

W = work done by water Joule (or) Kcal/kg

g = gravitational Constant

m = mass of water flowing through turbine (kg)



Single basin system

work done by the small amount of water mass is

$$dw = dm.g.h \quad \text{but} \quad dm = -\rho.A.dh$$

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

Total work done during full emptying period, $W = \int_R^0 dw$

$$= \int_R^0 -\rho.A.dh.gh$$

$$= -\rho.A.g \int_R^0 h.dh.$$

$$\boxed{W = \tfrac{1}{2} g \rho A R^2}$$

power mean doing work and power = work done / time. The power is generated during emptying (or) filling period and no power generated during the rest of the time. Time period = 6h. 12.5 min = 22 350 sec.

$$\therefore \text{The avg power (watts)} = \frac{\frac{1}{2} g \rho A R^2}{22350} = \frac{1}{44700} g.\rho.A.R^2$$

Estimation of power & Energy in double cycle/basin system :-

In this system, the power and Energy can be Calculated by considering the average discharge and available head at any instant.

let V = volume of the basin, A = cross section area of the basin (m^2) and ho is the difference b/w maximum and minimum water levels.

$$\therefore \text{volume of basin (V)} = A h_o$$

$$\text{Avg discharge (Q)} = \frac{\text{volume of basin}}{\text{time}} = \frac{A h_o}{t}$$

where t = Total duration of generation in one filling / emptying process.

$$\text{Now power generated (P)} = \frac{\rho Q h}{75} \times \eta_o \text{ HP} = \frac{\rho Q h}{75} \times \eta_o \times 0.736 \text{ KW}$$

$$= 0.01 \rho Q h \eta_o \text{ KW}$$

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Total Energy (E) $= \int_0^t P\,dt = \int_0^t 0.01 \rho Q h \eta_0$ Kw/tidal cycle

prob The observed difference b/w the high and low water tide is 8.5m, for a proposed tidal site. The basin area is about 0.5 km^2 which can generate power for 3H in each cycle. The avg available head is assumed to be 8m, and the overall efficiency of the generation to be 70%. Calculate the power in HP at any instant and Year power output. Avg specific wt of sea water is assumed as 1025 kg/m^3.

Solve Given that Difference in water level $h_0 = 8.5m$, Basin area $A = 0.5\ km^2 = 0.5 \times 10^6\ m^2$

Time period for power generation (t) = 3 Hrs = 10,800 sec

Avg available head (h) = 8m, Efficiency (η_0) = 70% = 0.7

Volume of basin (V) = $Ah_0 = 0.5 \times 10^6 \times 8.5 = 4.25 \times 10^6\ m^3$

Avg discharge (Q) = $\frac{V}{t} = \frac{4.25 \times 10^6}{10,800} = 393.5\ m^3/s$

Power (P) = $\frac{Q\rho h}{75}\eta_0 = \frac{393.5 \times 1025 \times 8}{75} \times 0.7$

$= 310.15 \times 10^2$ HP

Total Energy in kwh/tidal = $\int_0^t 0.01 \rho Q h \eta_0 = 0.01 * \rho * Q * h * \eta_0 * t$

$= 0.01 \times 1025 \times 393.5 \times 8 \times 0.7 \times 10800$

$= 664.93 \times 10^2$

No. of tidal cycle in a Year are "705"

$\therefore$ The Total o/p power/annum $= 664.93 \times 10^2 * 705$

$= 468.78 \times 10^5$ kwh/yr.

prob A tidal power plant of simple single basin type, has a basin area of $30 \times 10^6 m^2$. The tidal has a range of 12m. The turbine stops operating when head on it falls below 3m. Calculate the energy generated in one filling process (in Kwh), if the turbine efficiency is 0.73.

Given that Basin area (A) = $30 \times 10^6 m^2$, Tidal range (R) = 12m.

r = Head below turbine stops operating = 3m

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Total work done $(W) = \int_R^r dw = \int_R^r -\rho . A . g . h . dh = \frac{1}{2} g \rho A (R^2 - r^2)$

Avg power $(P) = \frac{W}{t} = \frac{\frac{1}{2} g \rho A (R^2 - r^2)}{22350}$

$= \frac{\frac{1}{2} (9.81)(1025)(30 \times 10^6)(12^2 - 3^2)}{22350}$

$= 911.25 \times 10^6 W$

Energy Generated $= \frac{911.25 \times 10^6 \times (60 \times 60)}{1000} Kwh \times 0.73$

$= 2395 \times 10^6 Kwh$

Assignment Questions

1) What is OTEC system. Explain various OTEC with neat sketches.

2(a) Define wave energy. List the factors affecting the wave energy.

(b) List the various wave energy conversion system. Explain any two with neat diagrams.

3(a): Define tide. Explain how the tide energy is captured using the following conversion systems.

(i) Single basin system (ii) Double basin system.

(b) write the adantages and disadvantages of wave Energy Conversion.

4(a) List the advantages & disadvantages of tidal energy Conversion.

(b) List the properties of

(i) wave Enegy (ii) Tide Energy

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Bio-Mass

Bioconversion: *Bioconversion i*s the conversion of organic materials, such as plant or animal waste, into usable products or energy sources by biological processes. It is also as *biotransformation*.

Biodigestion or Anaerobic Digestion: It is a biological process that occurs when organic matter is decomposed by bacteria in the absence of oxygen. As the bacteria decompose the organic matter, biogas is released and captured. Biogas consists of approximately 60% methane and 40% carbon dioxide. The remaining byproduct is called Digestate. It contains valuable plant nutrients like nitrogen and potassium. Digestate can be used as a fertilizer and soil conditioner. Anaerobic digestion systems also known as "anaerobic digesters", "biodigesters".

Anaerobic digestion process consists of following steps:

Pre-Treatment: In pre-treatment, wastes may be processed, separated, or mixed to ensure that they will decompose in the digester.

Digestion: During digestion, waste products are broken down by bacteria and biogas is produced and collected.

Biogas Processing: Biogas produced is either combusted or upgraded and then used to displace fossil fuels. During upgrading, scrubbers, membranes or other means are used to remove impurities and carbon dioxide (CO2) from biogas.

Reuse or disposal of solid digested waste: Digested waste has a high nutrient content and can be used as fertilizer so long as it is free of pathogens or toxins, or it can be composted to further enhance nutrient content.

Advantages of Anaerobic digestion: Anaerobic treatment processes have many advantages over aerobic treatment processes. Those are

(i) The biogas produced during an anaerobic treatment process can be used as a source of renewable energy (natural gas/methane).

(ii) It is less expensive.

(iii) Simpler, and more flexible in construction compared to aerobic treatment processes.

Aerobic Digestion:

Aerobic digestion is a microbialogical process which occurs in the presence of oxygen. Organic material is oxidized under aerobic conditions, and products like nitrate, phosphate, and carbon dioxide are produced as a result. In an aerobic system the majority of input material is converted as heat and then converted into carbon dioxide and water by oxidisation.

Aerobic digestion process consists of following steps:

Pre-Treatment: In pre-treatment, wastes may be processed, separated, or mixed to ensure that they will decompose in the digester.

Digestion: During digestion, waste products are broken down by bacteria and biogas is produced and collected.

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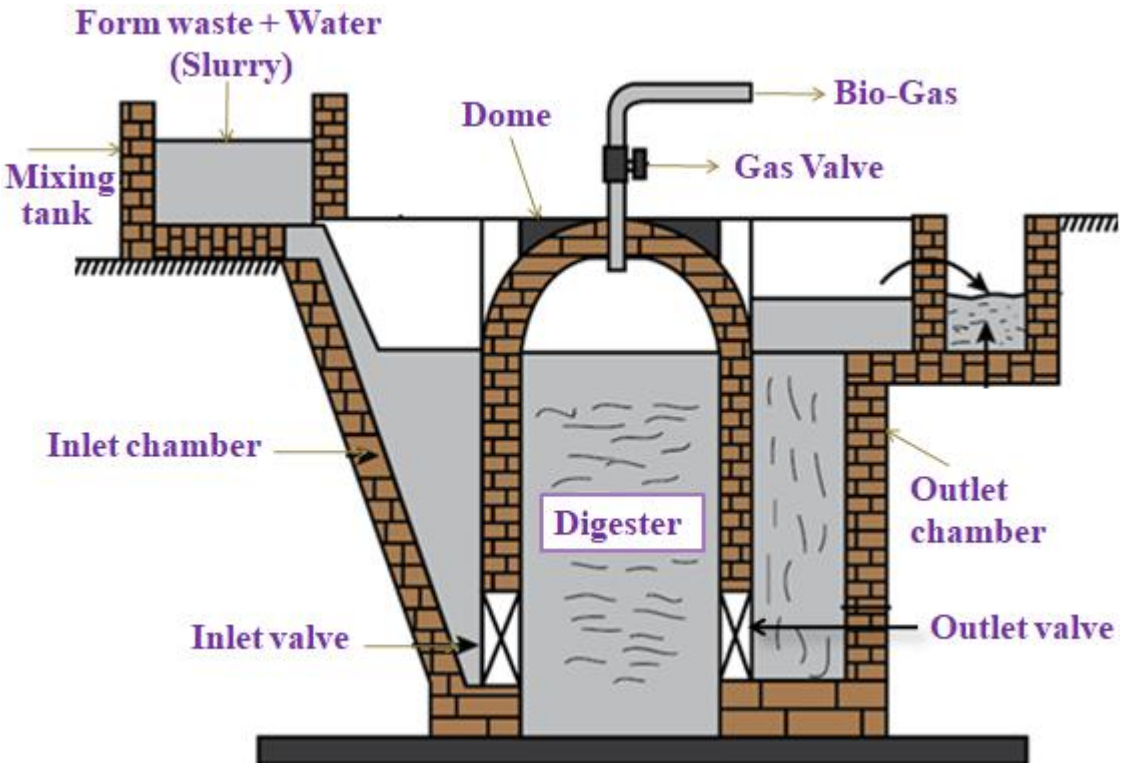
Reuse or disposal of solid digested waste: Digested waste has a high nutrient content and can be used as fertilizer so long as it is free of pathogens or toxins, or it can be composted to further enhance nutrient content.

Working principle of Bio-gas plant:

Bio-gas is produced by the decomposition of organic materials, such as plant or animal waste by biological process. Biogas consists of approximately 60% Methane (CH_4) and 40% Carbon Dioxide (CO_2). When it burns, it leaves negligible smoke and no residues.



Working: The basic structure of bio-gas plant is as shown in figure. At mixing tank, the farm waste and water are mixed to form a slurry. This slurry is fed into the digester. The digester is an air-tight chamber and oxygen is not present in it. Anaerobic bacteria in digester will decompose the slurry and produce the bio-gas. The bio-gas is sent-out through an outlet. The digested waste is used as fertilizer, because the digested waste has a high nutrient content, or it can be composted to further enhance nutrient content.

Types of Bio gas digesters and plants:

The classification of biogas plants depends upon the plants design and mode of working. Those are

1) Small scale biogas digester: These are again classified as

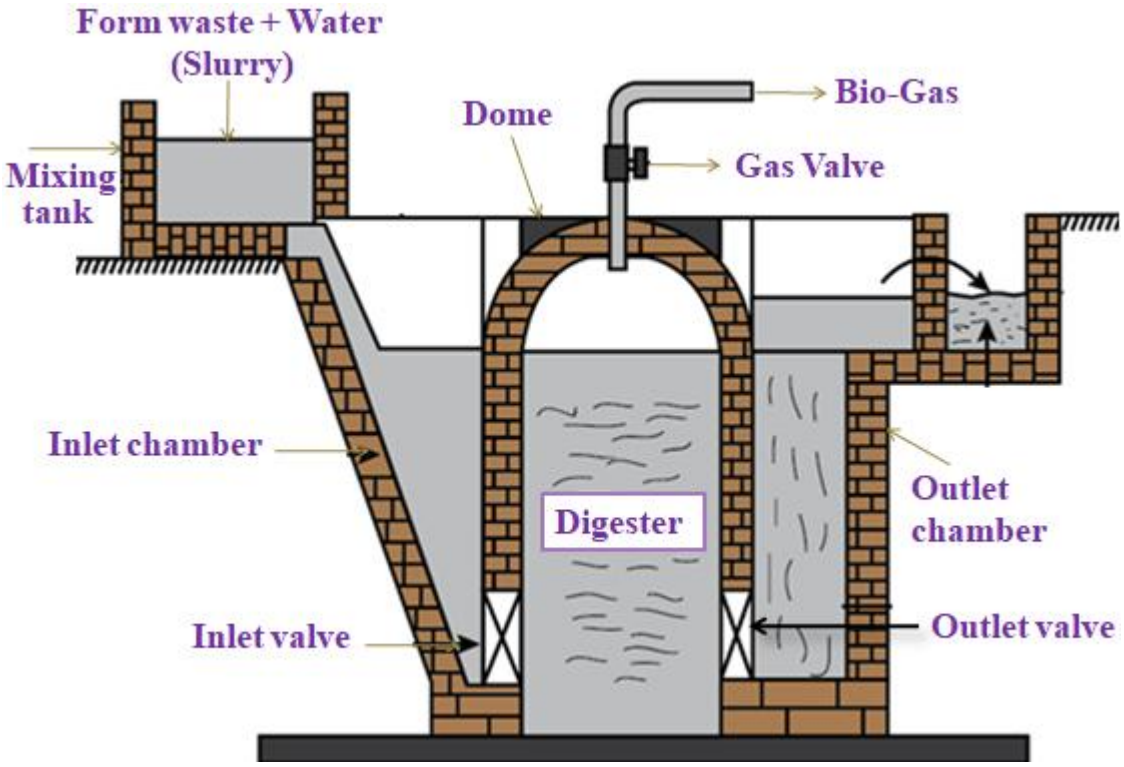
i) FixedDome Biogas Plant, ii) Floating Drum plant, iii) Ballon biogas plant

2) Industrial digesters: These are classified as (i) Continuous type plant, (ii) Batch type Plants

(iii) Semi-Batch type plant

Fixed Dome Biogas Plant:

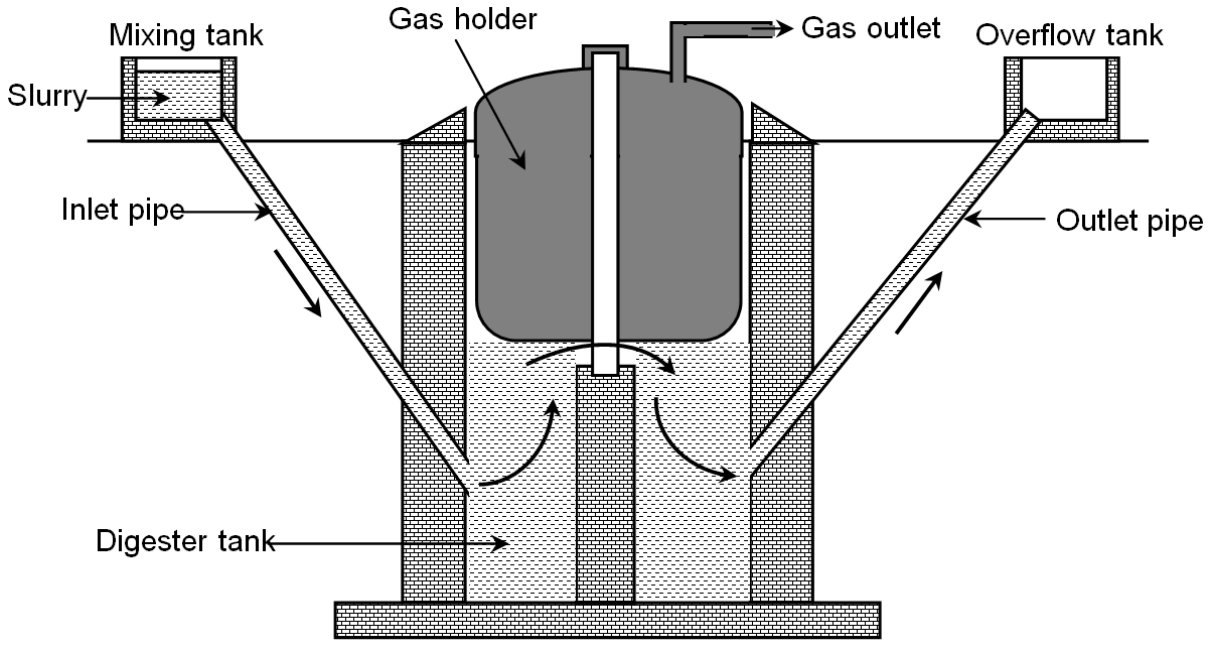
The basic structure of bio-gas plant is as shown in figure. At mixing tank, the farm waste and water are mixed to form a slurry. This slurry is fed into the digester. The digester is an air-tight chamber and oxygen is not present in it. Anaerobic bacteria in digester will decompose the slurry and produce the bio-gas. The bio-gas is sent-out through an outlet. The digested waste is used as fertilizer, because the digested waste has a high nutrient content, or it can be composted to further enhance nutrient content.



Advantages are the **relatively low construction costs**, the absence of moving parts and rusting steel parts. If well constructed, fixed dome plants have a long life span. The underground construction saves space and protects the digester from temperature changes.

Flating Drum Type Plants:

This also known as moving dome type biogas plants. The conventional movable drum type consists of an under-ground digester with an inlet on one side for feeding slurry and an outlet on the other side for removing digested slurry. The gas collects in a steel gas-holder (made with steel). The gas-holder floats either directly on the slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. When biogas is produced, the drum moves up and when it is consumed, the drum goes down.



Advantages:

(i) Constant gas pressure.
(ii) No problem of gas leakage
(iii) Higher gas production
(iv) Scum problem is less

Disadvantages: The main drawback of this is that metal cost is large and maintenance cost is also high.

Batch Type Biogas Plant:

Batch type biogas plants are used where daily supplies of raw waste materials are difficult to be obtained. A batch of digesters are loaded to capacity, sealed and given sufficient time in the digester for decomposation. After completion of the digestion, the residue is emptied and filled again. Gas production is uneven in this type of plant. This problem can also minimize by connecting batch loaded digester in series and fed at different times so that adequate biogas is available for daily use.

The salient features of batch-fed type biogas plants are:

(i) Gas production in batch type is uneven.
(ii) Batch type plants may have several digesters for continuous supply of gas.
(iii) Several digesters occupy more space.
(iv) This type of plants require large volume of digester, therefore, initial cost becomes high.

Continuous Type Biogas Plant:

In continuous type biogas plant, the supply of the gas is continuous and the digester is fed with biomass regularly. Continuous biogas plants may be single stage, double stage or multiple stage. Digestion of waste materials in a single chamber or digester is called single stage process, in two chambers or digester is called multi stage process.

In single stage process, the conversion of organic matter into bio-gas will takes place in one chamber only. This chamber is regularly feed with raw material while the spent residue keeps moving out. These plants are economic, simple and easy to operate. These plants are generally for small and medium size biogas plants.

In double stage process, acidogenic and methanogenic stage are physically separated into two chambers. In the first stage process, acid production is carried out in a separate chamber and only diluted acids are fed into the second chamber where biomethanation takes place and the bio-gas is collected from the second stage. The two stage biogas plants are costlier, difficult in operation and maintenance but they produce more gas. These plants are preferred for larger biogas plant system.

The important features of continous type biogas plants are:

(i) Gas production is continuous.

(ii) Retention period is less.

(iii) Less problems as compared to batch type.

(iv) Small digestion chambers are required.

Combustion characteristics of Bio-gas:

Bio gas is derived form the land fields, agriculature and forest waste and other sources of bio-mass. It is an environmentally friendly and a form of renewable energy source. The bio gas mainly consists of methane (CH_4), Corban di-oxide (CO_2) with small mixture of hydrozen sulfide and moisture. The molar friction of CO_2 is high which ranges form 40 to 60%, so bio gas is a low calorific value fuel. Due to high content of diluted gas CO_2, the combustion characteristics of bio gas are inferior to natural gas.

The bio gas is widely used as fuel for heating, power generation and vehicles. But bio gas possesses lower heating value than the convetional fuel. The electrical effiency of the bio gas decreases with decreasing CH_4 content.

Several experiements and numerical studies have been done to discuss the combustion characteristics of bio gas. In such studies hydrozen (H_2) is mixture with bio gas to improve the comburstion characteristics. Also, with the addition of H_2, the stability and the toal heat release of bio gas flame are improved,

To utilize the bio gas in IC engines, the unburnt component of CO_2 should be removed from bio gas. To upgrade the row bio gas and to increase CH_4 content in the bio gas, mechanical biological process is used. But this process is costlier, hence the direct usage of raw bio gas is more economical for engines or heat supply.

Economic Aspects of Bio gas: The Biogas programs and biogas units can serve the following purposes:

- The production of energy at low cost.
- Good growth in agriculture crop by the utilization of bio-fertilizer.
- The improvement of sanitation and hygiene.
- Conservation of tree, forest and reduction in soil erosion.
- Provision of skills enhancement and employment for rural areas
- Benefit for individual house holds.
- Low cost of bio gas plant (i.e production, running and capital) compared with conventional plants.
- Cost and benefit relation i.e the cost and benefits are directly related.

Geothermal energy

Defination: Geothermal energy means production of energy using the internal heat of the Earth's core i.e it uses the thermal energy from the earth's magma to create steam that drive the turbine and generate the electrical power using generator. Geothermal energy is called a renewable energy source because the water is replenished by rainfall, and the heat is continuously produced by the earth.

***Advantages*:**

i) *Renewable energy source*: Geothermal energy is called a renewable energy source because the water is replenished by rainfall, and the heat is continuously produced by the earth.

ii) *No fuel is required*: Since geothermal energy is a naturally occurring resource there is no fuel required.

iii) *It is a sustainable/stable energy source*: Geothermal provides a reliable source of energy as compared to other renewable resources such as wind and solar power. This is because the resource is always available to be tapped into, unlike with wind or solar energy.

iv) Since it is sustainable/stable energy source, it provide reliable power supply.

v) *Environmental friendly*: The Geothermal energy is more environmentally friendly than conventional fuel sources such as coal and other fossil fuels because the emissions from the geothermal power plant is low.

vi) *Huge potential*: It is currently estimated that geothermal power plants could provide between 0.0035 and 2 terawatts of power.

***Disadvantages*:**

i) The largest single disadvantage of geothermal energy is that it is location specific. Geothermal plants need to be built in places where the energy is accessible.

ii) The initial cost of this type of technology is more.

iii) Environmental side effects are more i.e Although geothermal energy does not typically release greenhouse gases, there are many of these gases stored under the Earth's surface which are released into the atmosphere during digging.

iv) Earthquakes: Geothermal energy also runs the risk of triggering earthquakes. This is due to alterations in the Earth's structure as a result of digging.

Geothermal fields: Geothermal energy is a form energy that is derived from the internal heat of the earth. It is a renewable energy source because the water is replenished by rainfalls and the heat is continuous produced inside the earth. Geothermal energy reserves from 0.5Km to the depth of 10Km.

The earth's surface **is classified** into three groups.

(1) *Non - thermal areas*: **Here the** temperature gradient **is** 10 – 40°C/km depth.

(2) Semi - thermal areas: Here the temperature gradient is 70°C per km depth.

(3) *Hyperthermal areas*: where the temperature gradients are many times greater than in non thermal areas.

Based on the above classification, the geothermal fields are classified as (i) **Hyper thermal fields** (ii) **Semi thermal fields.**

Hyper thermal fields: These field further classified as

(1) *Wet fields.* Where the water is pressurized and temperatures are above 100°C. When this fields are bring to the surface, a small amount of wet fields will converted into steam and a major part remains as the boiling water.

(2) *Dry fields.* They produce dry saturated steam or superheated steam at pressure above atmospheric.

Semi thermal fields: These fields has a capability of producing hot water at temperature above 100^0C.

Geothermal Energy Resources:

Geothermal energy is a form energy that is derived from the internal heat of the earth. It is a renewable energy source because the water is replenished by rainfalls and the heat is continuous produced inside the earth. Geothermal energy reserves from 0.5Km to the depth of 10Km. There are 4 major types of geothermal energy resources. Those are

(i) Hydrothermal resources
(ii) Geopressure resources
(iii) Hot Dry Rocks (HDR) resources
(iv) Magma resources

Vapor dominated Systems. In these systems the water is vaporized into steam and reaches the surface in a dry condition at about 200°C. This steam is the most suitable for use in turbo electric power plants, with the least cost. It suffer problems namely, the presence of corrosive gases and erosive material and environmental problems. These type of systems are very less in numbers; they are only five known sites in the world.

Liquid dominated Systems. In these systems the hot water circulating and is trapped from underground at a temperature range of 175 to 315°C.
This Hot water contains relatively large concentration of dissolved solids, hence the Power production is effected by these solids because they precipitate and cause scaling in pipes and heat exchanger surfaces, thus reducing flow and heat transfer.

Geopressured Systems. These resources occur in large, deep sedimentary basins. The reservoirs contain moderately high temperature water under very high pressure.
The geopressured resources are quite large: they could be used for the generation of electric power and the recovery of natural gas if suitable technology

Magma Resources. These consist of partially or completely molten rock, with temperatures in excess of 650°C.
These resources have a large geothermal energy content, but they are restricted to a relatively few locations.
Furthermore, the very high temperatures will make extraction of the energy a difficult technological problem.

Hot Dry Rocks (or Petrothermal Systems). These are very hot solid rocks occurring at moderate depths but to which water does not have access. In order to utilize this resource, means must be found for breaking up impermeable rock at depth.

Types of geothermal power plants or Methods of harnessing the geothermal energy:

There are three types of geothermal power plants. Those are

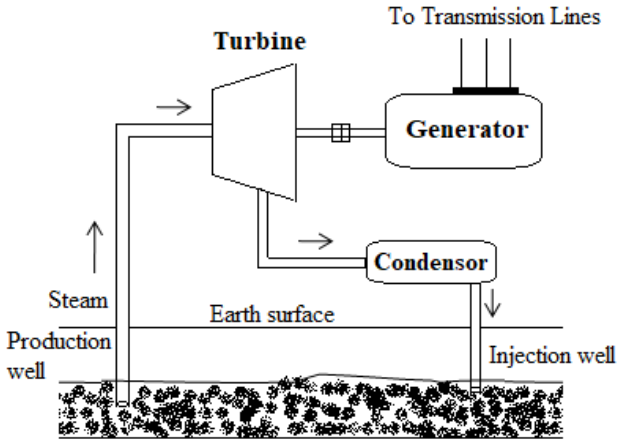
(i) Dry steam Power Plant. (ii) Flash steam Power Plant.

(iii) Binary cycle Power Plant. (iv) Hybrid Power plant

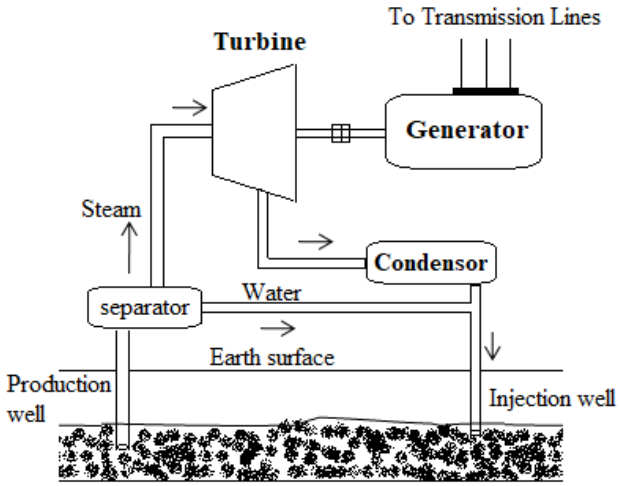
Dry steam Power Plant:

To generate power from geothermal energy, wells are dug a mile deep into the earth to pump the steam and hot water to the surface, which can then be used to drive turbines connected to electricity generators. The dry steam geothermal plant has two separate wells to the extract the dry steam from the reservoir under the earth's surface; those are (i) **Production well** (ii) **Injection well**.

In this power plant, the steam is supplied directly to the turbine in the power plant from underground wells, that turns the generator to generate electricity. The steam come out from the geothermal well is at a temperature of up to 150ºC. This is one of the oldest techniques of geothermal electricity.



Dry steam plant



Flash steam plant

***Flash steam Power Plant*:**

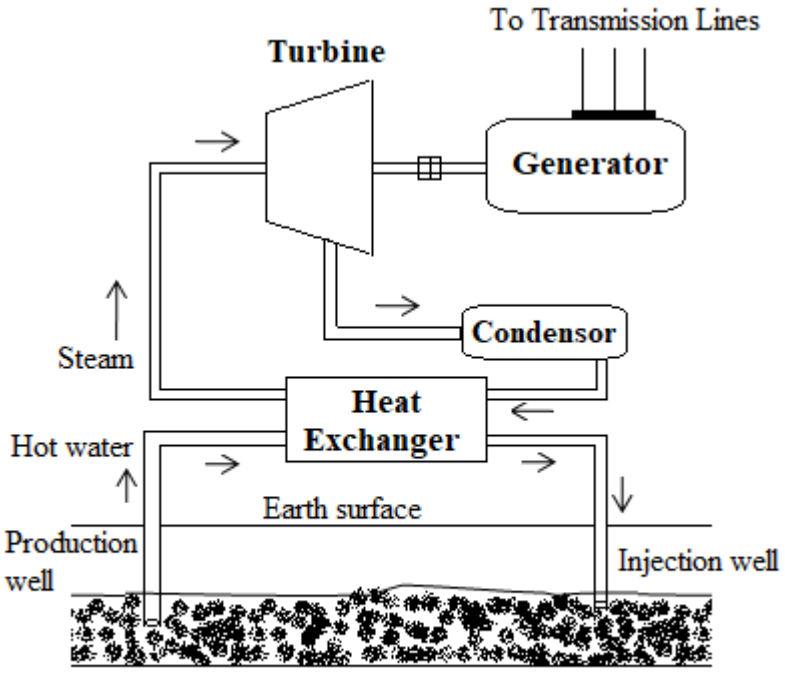
The flash steam geothermal plant has two separate wells to the extract the hot water from the reservoir under the earth's surface; those are (i) **Production well** (ii) **Injection well**.

In this power plant, the hot water in well under high pressure is drawn to a region of lower pressure. This pressure will vaporizes the hot water and emits steam at high temperature. The steam is then separated from the water and used to power a turbine - generator. Any leftover water and condensed steam are injected back into the well, making this a sustainable resource. The temperatures of the hot water is greater than 182°C.

***Binary cycle power plant*:**

The binary cycle geothermal plant has two separate wells to the extract the water at low temparature from the reservoir under the earth's surface; those are (i) **Production well** (ii) **Injection well**.

This type of power plant will operate on water at lower temperatures of ***about 107°C -182°C***. These plants use the heat from the hot water to boil a *working fluid (*usually an organic compound with a low boiling point). The working fluid is vaporized in a *heat exchanger* and used to turn a turbine. The water is then injected back into the ground to be reheated.



Binary cycle plant

The water and the working fluid are *kept separated* during the whole process, so there are little or no air emissions.

Hybrid power plant: It is a combination of flash and binary systems and is used for plants where the geothermal reserves produce both steam and water.

Types of Geothermal wells:

To generate power from geothermal energy, wells are dug a mile deep into the earth to pump the steam and hot water the surface, which can then be used to drive turbines connected to electricity generators.

The geothermal power plants drill two separate wells to the extract the hot water from the reservoir under the earth's surface; those are (i) **Production well** (ii) **Injection well**.

Production well: A production well is drilled into a known geothermal reservoir to exctract the geothermal energy that is available in the form of hot water or steam or magma.

***Injection well*:** The injection well in the geothermal plants is used for returning the geothermal fluids (condensated steam) back into the geothermal reservoir after energy extraction.

The Geothermal well are further classified as three types. Those are

(i) Temperature/Geothermal Gradient (TG) Wells

(ii) Slim Wells (iii) Commercial Grade Wells

Temperature/Geothermal Gradient (TG) Wells: In this wells, the temperature/geothermal gradient will increases with increase in earth depth. It indicates that the heat flowing from the Earth's warm interior to its surface. On average, the temperature increases by about 25°C for every Km of depth. This difference in temperatures drives the flow of geothermal energy and allows humans to use this energy for heating and electricity generation. The main features of these type of wells is

- These type of well for dig for less depth i.e <500m.
- The diameter of the well is less.
- Drilled with light truck-mounted rotary or diamond core rigs.

Slim Wells: This well is designed to reduce the drilling exploration cost for geothermal energy. The diameter of these wells is small i.e less than 6". The features of these wells is

- The slim wells are friendlier to the environment since there is less surface disturbance.
- Less noise and air pollution compared to a conventional large size well bcz it generate Smaller footprint.
- There is less drilling fluid exposed to the surface and less heavy duty equipment and materials used.
- The overall project cost is less i.e typically 30% to 50% of the cost of a full sized well.
- Useful as reservoir monitoring wells.

Commercial Grade Wells: These well is designed to collect the for geothermal energy for commercial applications. The commercial grade wells are subdivided into two wells. Those are (i) Supply well and (ii) Injection/return well. The features are

- Designed to be very robust and long-lived.
- It is not always clear.
- These are used for space heating/cooling, Generation of electrical power, Industrial process heat.

Potential of Geothermal Energy in India:

Geothermal energy is a form energy that is derived from the internal heat of the earth. It is a renewable energy source because the water is replenished by rainfalls and the heat is continuous produced inside the earth. Geothermal energy available from 0.5Km to the depth of 10Km. Geothermal energy is a renewable and reliable source of energy. An average geothermal plant generates about 122 kg of CO_2 per MWh whereas an average coal-based plant generates 1000 kg per KWh.

Geothermal power has considerable potential for growth. The amount of heat within 10Km of the earth's surface is estimated to contain **50,000 times more energy** than all oil and gas resources. India has seven geothermal provinces and number of geothermal springs. In India, exploration and study of geothermal fields started in 1970. The Geological Survey of India (GSI) has identified 350 geothermal energy locations in the country. The estimated potential for geothermal energy in India is **about 10GW**.

The promising geothermal sites for direct heat use applications are Rajgir in Bihar, Manikaran in Himachal Pradesh, Surajkund in Jharkhand, Tapoban in Uttarakhand and Sohana region in Haryana. The six major geothermal regions/provinces in India are

i) Himalayan region: Himachal Pradesh, Jammu & Kashmir, etc.

ii) Areas of Faulted blocks: Aravalli belt, Naga-Lushi, West coast regions and Son-Narmada lineament.

iii) Volcanic Arc: Andaman and Nicobar Arc (Barren Island).

iv) Deep sedimentary basin of Tertiary age: Cambay basin in Gujarat.

v) Radioactive region: Surajkund, Hazaribagh, and Jharkhand.

vi) Cratonic region: Peninsular India.