DIGITAL NOTES

ON

NON-CONVENTIONAL SOURCES OF ENERGY

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DISCLAIMER

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SYLLABUS

UNIT – I

Principles of Solar Radiation: Role and potential of new and renewable source, the solar energy option, Environmental impact of solar power - Physics of the sun, the solar constant, extra-terrestrial and terrestrial solar radiation, Solar radiation on titled surface, Instruments for measuring solar radiation and sun shine, solar radiation data.

Solar Energy Collection: Flat plate and concentrating collectors, classification of concentrating collectors, orientation and thermal analysis, advanced collectors.

UNIT – II

Solar Energy Storage and Applications: Different methods, sensible, latent heat and stratified storage, solar ponds. Solar applications - solar heating/cooling techniques, solar distillation and drying, photovoltaic energy conversion.

Wind Energy: Sources and potentials, horizontal and vertical axis windmills, performance characteristics, Betz criteria.

UNIT – III

Bio-Mass: Principles of Bio-Conversion, Anaerobic/aerobic digestion, types of Bio-gas digesters, gas yield, combustion characteristics of biogas, utilization for cooking, I.C. Engine operation, and economic aspects.

UNIT – IV

Geothermal Energy: Resources, types of wells, methods of harnessing the energy, potential in India.

Ocean Energy: OTEC, Principles, utilization, setting of OTEC plants, thermodynamic cycles.

Tidal and Wave energy: Potential and conversion techniques, mini-hydel power plants, their economics.

UNIT – V

Direct Energy Conversion (DEC): Need for DEC, Carnot cycle, limitations, Principles of DEC. Thermoelectric generators, Seebeck, Peltier and Joule Thompson effects, figure of merit, materials, applications, MHD generators, principles, dissociation and ionization, hall effect, magnetic flux, MHD accelerator, MHD engine, power generation systems, electron gas dynamic conversion, economic aspects. Fuel cells, principle, faraday's laws, thermodynamic aspects, selection of fuels and operating conditions.

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UNIT – I

PRINCIPLES OF SOLAR RADIATION

ROLE AND POTENTIAL OF NEW AND RENEWABLE SOURCE

Attention of scientists and engineers all over the world has been drawn to develop alternative energy technologies, since the oil crisis in 1973. The commonly referred oil crisis is more of a crisis of prices; in addition to, of course:

1) Quick dwindling of fossil fuel reserves and
2) Increase in demand at an alarming rate. Realization of these two aspects led scientists and engineers look for alternatives.

Many options have been found and examined. Prominent among the options are as following:

1) Solar thermal.
2) Solar photovoltaic.
3) Wind energy.
4) Geothermal.
5) Tidal and wave energies.

Among these, solar energy is relatively more uniformly available. Also according to one estimate, the energy that reaches the Earth from 20 days of sunshine is equal to the energy stored in all of Earth's reserves of fossil fuels like, coal, petroleum, and natural gas.

In additions to the 'fuels' (commonly referred to as fossil fuels) referred above, two prominent, existing and fairly widely used, energy sources are the hydro-electric and the nuclear. though the potential of hydro-electric route is enormous, may not be available at a chosen location in addition to the other problems of huge land getting submerged and relocation of the people and other life forms in the area. Similarly, nuclear energy (particularly the breeder reactors) option holds a promise, though mired by safety issues and spread of pollutants. In this course on solar thermal energy, we shall not devote our attention to examining the merits and demerits of all possible future energy sources. Before we examine the solar option in detail, it is worthwhile to examine if there is any intrinsic reason for dependence on external energy resources to meet the needs of human beings, viz., food, shelter and clothing. Of course, the provision to fulfill the needs of other live forms also has to be made.

ALTERNATE (RENEWABLE, NON-CONVENTIONAL) ENERGY & THE SOLAR ENERGY OPTION

The terminology commonly heard, alternate energy sources, renewable energy sources, or non-conventional energy sources is somewhat misleading and certainly confusing. Strictly speaking, what is conventional today might have been non-conventional a hundred years back. Similarly, the alternate energy source leads to the question, ‘alternate’, to what? Renewable energy source gives the impression, that the source is perennial. Even, “solar energy” (and hence its manifestations) lasts a finite time, no matter how long this finite time is! Though we use these terms synonymously, we should understand the implication and distinction which is, many times, missed by the readers, speakers, as well as listeners. Commonly talked about alternate energy sources are, solar energy, wind energy, bio-mass, wave and tidal energy, and geothermal sources etc. Among these, solar energy appears to be the most promising.

The justification comes from the following considerations:

1) Nearly perennial.
2) Well distributed over the world (we may say, there is no bias for developed, developing or underdeveloped countries), predictable (though one may not be able to predict the solar radiation, say, on August 27th, 2012 at a location during 9.30 AM to 11.30 AM, one can work with likely averages for design purposes). By these features, one can guess the limitations of the other sources.
3) For example, wind energy, a manifestation of the solar, is about only 2% of the solar energy and is restricted to certain high wind velocity zones for harnessing. Of course, we do note, wind energy is a high grade energy source.

4) Wave and tidal energy are restricted by location as well as low efficiency.
5) Similarly, geothermal energy is not uniformly distributed and is limited like fossil fuels. Given that a promising (with already some proven success) option is the solar energy, we attempt to study the principles, applications and methods to predict the performance of the solar energy systems. We note at this stage that a solar energy system performance though depends on the 'solar collector performance, also highly depends on the system configuration.

ENVIRONMENTAL IMPACT OF SOLAR POWER

The sun provides a tremendous resource for generating clean and sustainable electricity without toxic pollution or global warming emissions.

The potential environmental impacts associated with solar power - land use and habitat loss, water use, and the use of hazardous materials in manufacturing can vary greatly depending on the technology, which includes two broad categories: photovoltaic (PV) solar cells or concentrating solar thermal plants (CSP). The scale of the system ranging from small, distributed rooftop PV arrays to large utility-scale PV and CSP projects also plays a significant role in the level of environmental impact.

Land Use: Depending on their location, larger utility-scale solar facilities can raise concerns about land degradation and habitat loss. Total land area requirements vary depending on the technology, the topography of the site, and the intensity of the solar resource. Estimates for utility-scale PV systems range from 3.5 to 10 acres per megawatt, while estimates for CSP facilities are between 4 and 16.5 acres per megawatt.

Unlike wind facilities, there is less opportunity for solar projects to share land with agricultural uses. However, land impacts from utility-scale solar systems can be minimized by siting them at lower-quality locations such as brown fields, abandoned mining land, or existing transportation and transmission corridors. Smaller scale solar PV arrays, which can be built on homes or commercial buildings, also have minimal land use impact.

Water Use: Solar PV cells do not use water for generating electricity. However, as in all manufacturing processes, some water is used to manufacture solar PV components.

Concentrating solar thermal plants (CSP), like all thermal electric plants, require water for cooling. Water use depends on the plant design, plant location, and the type of cooling system.

CSP plants that use wet-recirculating technology with cooling towers withdraw between 600 and 650 gallons of water per megawatt-hour of electricity produced. CSP plants with once-through cooling technology have higher levels of water withdrawal, but lower total water consumption (because water is not lost as steam). Dry-cooling technology can reduce water use at CSP plants by approximately 90 percent. However, the trade-offs to these water savings are higher costs and lower efficiencies. In addition, dry-cooling technology is significantly less effective at temperatures above 100 degrees Fahrenheit.

Many of the regions in the United States that have the highest potential for solar energy also tend to be those with the driest climates, so careful consideration of these water trade-offs is essential.

Hazardous Materials: The PV cell manufacturing process includes a number of hazardous materials, most of which are used to clean and purify the semiconductor surface. These chemicals, similar to those used in the general semiconductor industry, include hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, 1,1,1-trichloroethane, and acetone. The amount and type of chemicals used depends on the type of cell, the amount of cleaning that is needed, and the size of silicon wafer. Workers also face risks associated with inhaling silicon dust. Thus, PV manufactures must follow U.S. laws to ensure that workers are not harmed by exposure to these chemicals and that manufacturing waste products are disposed of properly.

Thin-film PV cells contain a number of more toxic materials than those used in traditional silicon photovoltaic cells, including gallium arsenide, copper-indium-gallium-diselenide, and cadmium-telluride. If not handled and disposed of properly, these materials could pose serious environmental or public health threats. However, manufacturers have a strong financial incentive to ensure that these highly valuable and often rare materials are recycled rather than thrown away.

Life-Cycle Global Warming Emissions: While there are no global warming emissions associated with generating electricity from solar energy, there are emissions associated with other stages of the solar life-cycle, including manufacturing, materials transportation, installation, maintenance, and decommissioning and dismantlement. Most estimates of life-cycle emissions for photovoltaic systems are between 0.07 and 0.18 pounds of carbon dioxide equivalent per kilowatt-hour.

Most estimates for concentrating solar power range from 0.08 to 0.2 pounds of carbon dioxide equivalent per kilowatt-hour. In both cases, this is far less than the lifecycle emission rates for natural gas (0.6-2 lbs of CO2E/kWh) and coal (1.4-3.6 lbs of CO2E/kWh).

PHYSICS/NATURE OF THE SUN [OR] PHYSICAL DESCRIPTION & REACTIONS OF THE SUN

Sun is a medium sized yellow star that may be considered as a sphere of intensely hot gaseous matter with an average diameter of 1.39 x 10^9 m at an average distance of 1.495 x 10^{11} m (or 1 Astronomical unit) from the earth. The sun coalesced from a cloud of gas and dust formed 4.5 billion years ago. Earth goes round the sun in an elliptic orbit as shown in Fig. 2.1.

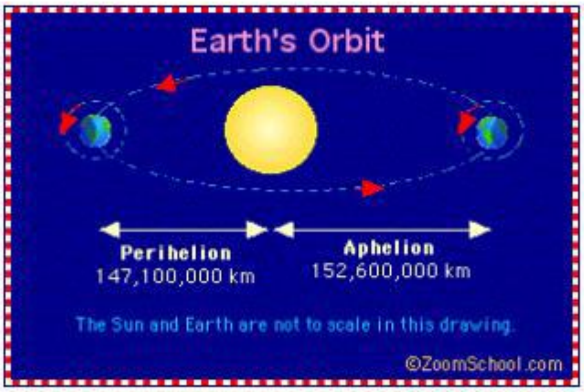


Fig. 2.1 The Perihelion and the Aphelion

The earth is closest to the sun at 1.471x10^{11} m, the perihelion around January 2 each year; it is farthest at 1.526 x10^{11} m around July 2 each year Sun, in effect is a continuous fusion reactor and the constituent gases are a containing vessel retained by gravitational forces. Most important fusion reaction is hydrogen combining to form helium. Energy is produced in the sun (and other stars also) by continuous fusion in which four nuclei of hydrogen fuse in a series of reactions involving other particles that continually appear and disappear in the course of the reactions, such as He3, nitrogen, carbon and other nuclei, but culminating in one nucleus of helium and two positrons. Resulting in a mass decrease.

$$4\ {}_1H^1 \longrightarrow {}_2He^4 + 2\ ({}_{+1}e^0) \qquad (2.1)$$

This reaction results in a mass decrease of about 0.0276 amu, corresponding to 25.7 MeV. The heat produced in these reactions maintains temperatures of the order of several million degrees in the core region of the sun and serves to trigger and sustain succeeding reactions.

Note: 1 amu (atomic mass unit) $=1.66\times10^{-27}$ kg

1 ev (electron volt) $= 1.6021\times10^{-19}$J

ΔE, the energy produced by a mass decrease of, Δm, is given by,

$$\Delta E(J) = \Delta m(kg)\, C^2,$$

Where C is the velocity of light.

$C = 3\times10^8$ m/s

The student may convince himself of the energy release per reaction, calculating in appropriate units

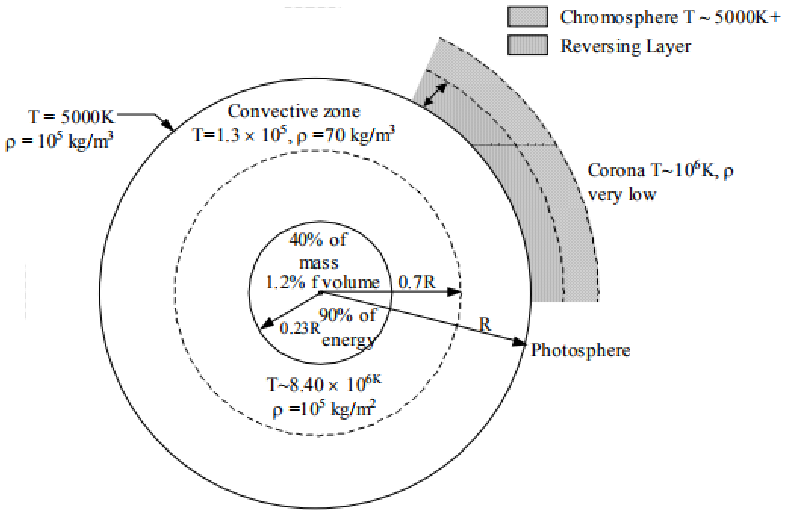


Fig. 2.2 Sun and its important zones

The Sun is made up of about 2 x 1030 kilograms of gas. It is composed of about 75% hydrogen and 25% helium. About 0.1% is metals made from hydrogen via nuclear fusion. It has been estimated that the sun has used up about half of its initial hydrogen available 4.5 billion years ago, i.e., the time of formation. A simple schematic of the sun is shown in Fig. 2.2. With reference to Fig. 2.2, 90 % of the energy is generated in the region $0 < r < 0.23$ Rsun, where Rsun is the radius of the sun. The temperature at 0.7 Rsun is the order of 130 x 10^3 K. From the region r > Rsun, convection process begins and is referred to as the convective zone. The upper layer of the convective zone is the photosphere, which is the source of most solar radiation. Other layers following the reversing layer (a layer of relatively cooler gases of several hundred km deep), are, chromosphere (has a depth of 10, 000 km with somewhat higher temperature and lower density) and lastly, the corona, of very low density and at a temperature of 106 K. Solar radiation is the composite result of several layers which absorb and emit at various wave lengths. For, thermal purposes it is adequate to consider the sun to be a blackbody at an effective temperature of 5762 K. This information is adequate for many solar energy calculations.

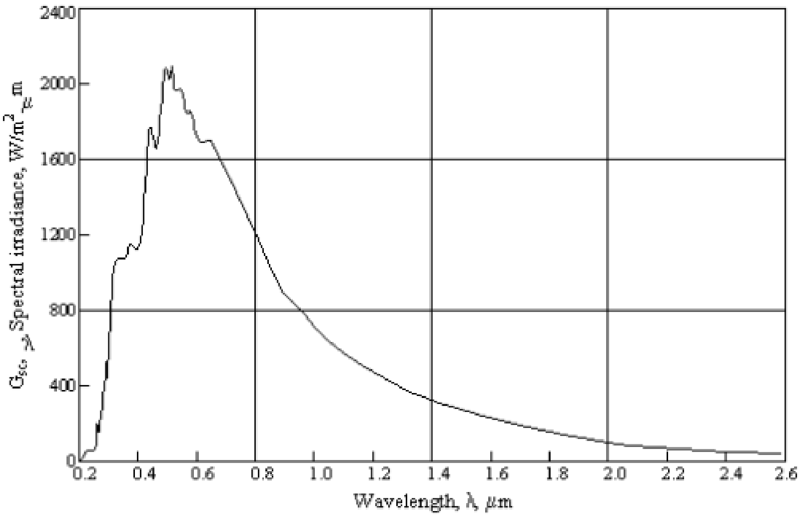


Fig.2.3 Spectral distribution of solar radiation.

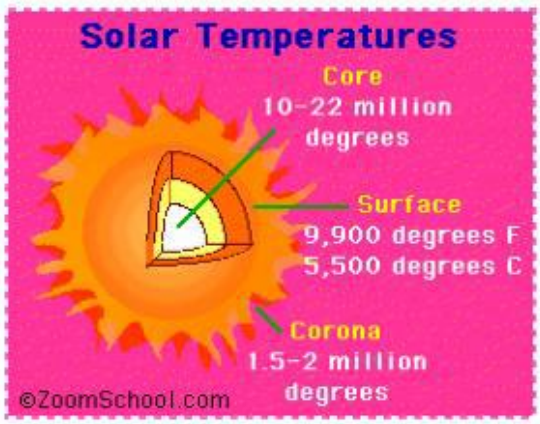


Fig. 2.4 Temperatures at different layers in the sun

The details of the sun's temperature are depicted in Fig. 2.4. The Sun's core can reach 5.5×10^6 °C to 12.5×10^6 °C. The estimates vary, the higher one going up to 40×10^6 °C. The surface temperature is approximately 5,500°C. The outer atmosphere of the sun goes up, to $1.5x10^{6}$ °C to $2x10^{6}$ °C degrees. The effective temperature of the sun is determined by measuring how much energy much energy (both heat and light) it emits.

THE SOLAR CONSTANT

The solar constant, Gsc, is the energy from the sun, per unit time, received on a unit area of surface perpendicular to the direction of propagation of the radiation at the earth's mean distance from the sun, if the earth's the atmosphere is fully transparent. It may be viewed on any unit surface normal to sun's rays on a sphere of radius equal to the sun-earth mean distance, thus alleviating the difficulty in imagining a fully transparent atmosphere around the earth. The recently reported value of the solar constant is 1367 W/m^2.

The physical idea can be obtained by considering the sun to be a sphere of diameter 1.39×10^{9} m, emitting as a black body at an effective temperature of 5762 K. The amount of radiation emitted by the sun As T4 would be σ, is the Stefan - Boltzman constant (= 5.67×10^{-8} W/m^2 σW.K4) and As is the surface area of the sun. The same amount of radiation passes through any sphere surrounding the sun as center. Thus, the surface of a sphere of radius equal to the sun-earth mean distance will experience intensity (W/m^2) inversely proportional to the square of the radius of the sphere enclosing the sun. This proportioning leads approximately to 1349 W/m^2.

The variation in the total radiation emitted by sun is less than use energy in large spectrum of the entire solar spectrum, and when the transmittance of atmosphere is a major uncertainty, the emitted energy by the sun may be considered as constant.

EXTRA-TERRESTRIAL SOLAR RADIATION

Solar radiation on a surface normal to sun's rays kept at a distance of sun-earth, (not the mean distance, but the actual distance as of, on that day, that time) G_{on}, will essentially be the solar constant, modified to take into account the varying distance between the sun and the earth. G_{on} is given by,

$$G_{on} = G_{sc}(1 + 0.033 \cos[360n/365]) \quad (3.1)$$

In Eq.(3.1), n is the day of the year, i.e., the sequential number of the day counting January 1 as 1.

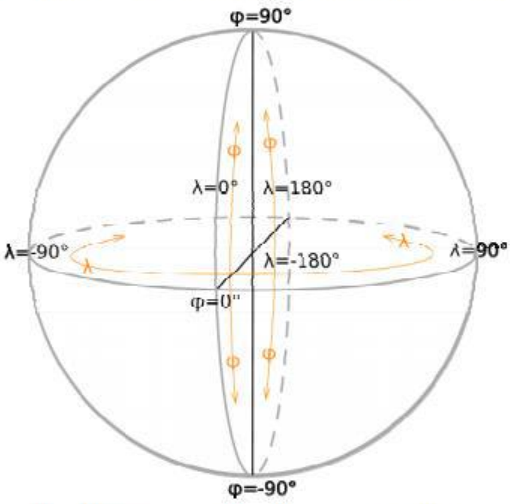


Fig. 3.1 Concept of latitude, φ and longitude λ

Different Angles:

Latitude and Longitude are the coordinates of a point (location) on earth's surface. A location on the earth's surface may be specified by latitude, longitude and elevation. Elevation, does not directly enter into calculation of different angles though may effect solar radiation received. The constant latitude and longitude lines, north pole, south pole and the equatorial plane are shown , is reckoned positive in the northern hemisphere and negative in the southernϕin Fig. 3.1. (Latitude, hemisphere. Longitudes, λ, is described along with "east" or "west", meaning that the location is situated to east or to west of the Greenwich meridian. Thus, the latitude varies from -900 to + 900 and the longitude varies from 00 to 1800 E or 00 to 1800 W.

The latitude of a point on the earth's surface is the angle between the equatorial plane and a line that passes through that point and is normal to the surface. The North Pole is 90° N; the South Pole is 90° S. The 0° parallel of latitude is designated the equator, the fundamental plane of all geographic coordinate systems. The Longitude λ, of a point on the earth's surface is the angle east or west from a reference meridian to another meridian that passes through that point. Latitude and longitude specify the position of any location on the planet, but do not account for altitude or depth.

TERRESTRIAL SOLAR RADIATION

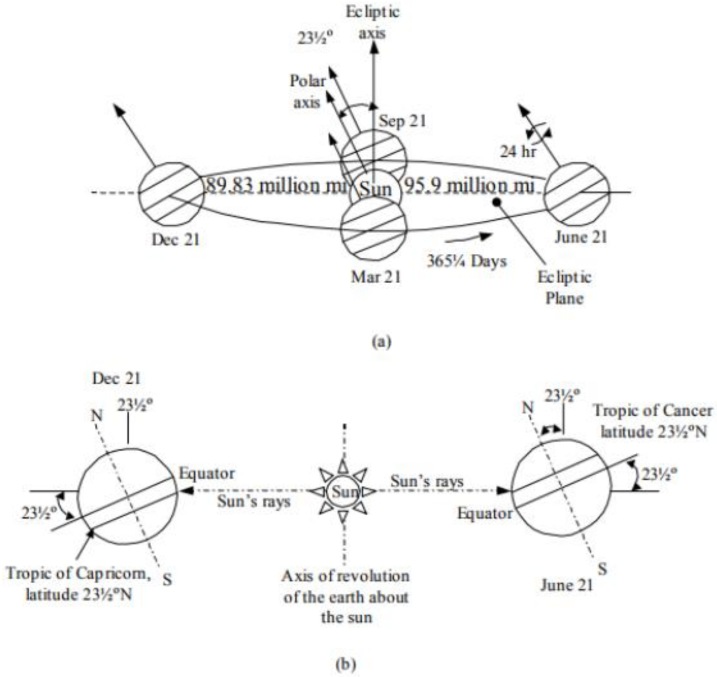


Fig. 3.2 Motion of the earth about the sun

Declination, is the angular position of the sun at solar noon with respect to the place of the equator.δ2. Declination, varies from - 23.450 to 23.450 , in degrees, for the day, n, of the year (counting Jan. 1 as 1),δ. can be calculated from

$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right) \tag{3.2}$$

Positions of the earth relative to sun at different times of the year are shown in Fig.3.2

3. *Solar Time* is the time based on the apparent angular motion of the sun across the sky, with *solar noon* being the time the sun crosses the meridian of the observer. Solar time is used in all sun angle relationships. The solar time in general deviates from the local clock time.

$$Solar\ time = Standard\ time \pm 4(\lambda_{st} - \lambda_{loc}) + E \tag{3.3}$$

In Eq.(3.3) λ_{st} is the longitude of the standard time and λ_{loc} is the longitude of the location under consideration. In Eq.(3.3) + sign is to be used for longitudes "WEST" and - sign for longitudes "EAST". E is equation of time, which is an additional correction due to perturbations in the earth's rate of rotation, which affect the time the sun crosses the observer's meridian. *E* in minutes can be calculated from

$$E = 9.87 \sin 2B - 7.53 \cos B - 1.5 \sin B \tag{3.4}$$

In Eq.(3.4),

$$B = \frac{360(n-81)}{364}\text{, where, } n \text{ is the day of the year, } 1 \le n \le 365\,. \qquad (3.5)$$

4. *Hour angle, ω,* is the angular displacement of the sun east or west of the local meridian due to rotation

SOLAR RADIATION ON TITLED SURFACE

Expressing the Basic components The solar radiation received by a tilted surface comprises of direct, diffuse and ground reflected components. A horizontal surface receives the direct and diffuse components of radiation while the tilted surface receives in addition, a ground reflected component if the surface 'sees' the ground. Since the direct component has a definite direction, first, the direct component will be estimated. The procedure describes to evaluate a factor, referred to as the tilt factor for direct radiation, which when multiplies the direct radiation available on a horizontal surface (commonly available form of data) yields the direct radiation on the tilted surface. Similarly the diffuse component shall be multiplied with a different factor. The ground reflected radiation would be the product of solar radiation on the horizontal surface, ground reflectivity and a view factor. On a day (Thus, if G is the intensity of solar radiation at an instant (defined by the hour angle) on a horizontal surface, it is conceivable that G comprises of, δ designated by the declination.

where G_b and G_d are the direct and diffuse components of intensity. The total radiation comprising of the three components at the instant on the tilted surface G_T can be formally expressed as,

$$G_T = G_b R_b + F_S G_d + F_g \rho_g G \qquad (8.2)$$

In Eq. (8.2) G_T is the radiation on the tilted surface, ρ_g is the ground reflectivity (usually 0.2 and 0.7 if the ground is snow covered) and R_b is the instantaneous tilt factor for direct radiation, defined as the ratio of direct radiation on the surface under consideration and the direct radiation on a horizontal surface. Thus,

$$R_b = G_{bT}/G_b \qquad (8.3)$$

F_s and F_g are the appropriate factors for sky diffuse and ground reflected components of radiation. Assuming an isotropic distribution of diffuse radiation, the factor F_s can be obtained as,

$$F_s = (1 + \cos\beta)/2 \qquad (8.4)$$

The view factor F_g for the ground reflected component of the radiation is given by,

$$F_g = (1 - \cos\beta)/2 \qquad (8.5)$$

Expression for Rb:

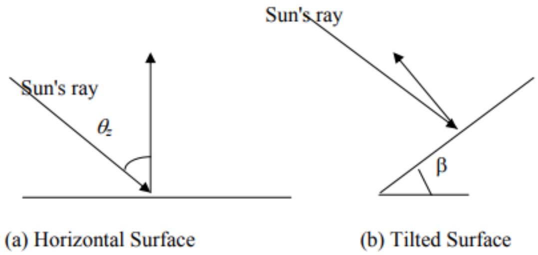


Fig.8.1 Direct radiation on horizontal and tilted surfaces

Consider a horizontal and a tilted surface as shown in Fig 8.1. Let Gb,n be the intensity of direct radiation z with the zenith.θon a plane perpendicular to the ray. The ray as shown in Fig.8.1 (a) makes an angle (the angle of incidence) with the outer normal to the tilted surface asθSimilarly, the ray makes an angle with the horizontal. From the geometry as shownβshown in Fig.8.1 (b). The tilted surface makes an angle in Fig.8.1, it follows,

$$G_b = G_{b,n}\cos\theta_z \ , \ G_{b,T} = G_{b,n}\cos\theta$$

Thus, R_b can be expressed as,

$$R_b = G_{bT}/G_b = \cos\theta/\cos\theta_z \qquad (8.6)$$

The expressions for $cos\theta$ are given by Eqs. (3.6) or (3.7). $cos\theta$ for south facing surfaces is given by Eq.(3.12). $cos\theta_z$ is expressed by Eq.(3.11). Using Eqs. (3.12) and (3.11) in Eq.(8.6), R_b for a south facing surface is given by,

$$R_b = \frac{\cos(\phi-\beta)\cos\delta\cos\omega + \sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta} \qquad (8.7)$$

Expression given by Eq. (8.7), strictly speaking is valid for an instant by the value of the hour angle ω employed. However, Eq. (8.7) can be used with no significant loss of accuracy for a time period of one hour $(\omega_1$ to $\omega_2)$ using $\omega = (\omega_1 + \omega_2)/2$.

INSTRUMENTS FOR MEASURING SOLAR RADIATION & SUN SHINE [OR] SOLAR RADIATION & SUN SHINE MEASURING INSTRUMENTS

There are two types of infrared detectors for solar radiation measurement. The difference is in the detectors, thermal detectors and photon detectors. Heating effect of incident radiation causing a change in some physical property of the detector is the principle underlying the thermal detectors. The time constant of the detectors should be small for responding to quick changes in the incident radiation. However, a quick response requires a long time constant and a low heat capacity. Fortunately, time constant of several seconds can be accepted in solar radiation measurements, since the systems in general massive and has long time constants. Photon detectors convert some of the incident radiation directly into electricity, which is proportional to the incident radiation. The detecting capability, in general, of photon detectors is one or two orders of magnitude greater. However, the penalty associated with photon detectors is that their spectral response is non-uniform.

Alternately, instruments to measure solar radiation broadly fall into three categories. They are, 1) measure global radiation 2) diffuse radiation and 3) direct radiation. It is easy to envisage that, it is best to measure normal incident direct radiation and in order to-do this, the instrument sensor needs to face the sun always. This calls for a tracking instrument with consequent inconvenience and additional equipment to follow the sun. Most often, global and diffuse components of radiation are measured and direct radiation measurements be used in checking the other two measurements. The instruments used to measure global radiation are referred to as, Pyranometers, and those used to measure diffuse radiation are referred to as pyranometers with shading ring which cuts off the direct radiation. The instruments that measure direct radiation are called pyrheliometers.

Pyranometers: Eppley pyranometer designed by Kimball and Hobbs, of US Weather Bureau has become the most widely used working Pyranometer’s. The Eppley Pyranometer's detector or the working surface consists of two concentric silver rings. The inner ring is coated with Parsons optical black lacquer and the outer one is coated with white magnesium oxide. The temperature difference between the two is an indication of the incident solar radiation and is measured by a thermopile. The sensor is placed inside a hermetically sealed spherical lamp bulb filled with dry air.

The detector is best when used to measure horizontal radiation. A reduction of 5% output is caused when the instrument is mounted vertically due to convective currents in the glass enclosure. The new Eppley pyranometer equipped with a thermister compensated electrical circuit reduced the temperature dependence and improved the cosine response.

Sunshine Recorder: The sunshine recorders essentially static do not require power supply and alleviate the difficulties faced by the recorders where uninterrupted power supply is not available. They are essentially, spherical lenses, which blacken a sensitive strip. The length of the charred portion of the strip is related to the solar radiation with the help of measurements made by alternate instruments. The empirical constants derived in the relations are expected to be valid for the type of climate for which they are derived. Though these recorders are only approximate, they are simple to use. Indeed, significant numbers of studies have been made in deriving reliable constants and examining their applicability for different climates.

Campbell-Stokes Recorder focuses solar radiation to burn a trace in a chart. Jordan Recorder focuses sunlight on to photographic paper. Marvin Recorder makes use of a thermoelectric switch to actuate a chronograph to trace the sunshine hours. The daily global solar radiation on a horizontal radiation H is related to the number of hours of bright sunshine (directly related to the length of the blackened portion of strip).

SOLAR ENERGY COLLECTION

Solar collectors are used to collect the solar energy and convert the incident radiations into thermal energy by absorbing them. This heat is extracted by flowing fluid (air or water or mixture with antifreeze) in the tube of the collector for further utilization in different applications.

Types of Solar Collectors: The collectors are classified as:

1) Non concentrating collectors.
2) Concentrating (focusing) collectors.

1) Non concentrating collectors: In these type, the collector area is the same as the absorber area. It is generally used for low & medium temperature requirements.

2) Concentrating (focusing) collectors: It have a larger interceptor than absorber. It is generally used for high temperature requirements.

FLAT PLATE COLLECTORS

Flat plate collector is most important part of any solar thermal energy system. It is simplest in design and both direct and diffuse radiations are absorbed by collector and converted into useful heat. These collectors are suitable for heating to temperature below 100C.

Flat plate collector absorbs both beam and diffuse components of radiant energy. The absorber plate is a specially treated blackened metal surface. Sun rays striking the absorber plate are absorbed causing rise of temperature of transport fluid. Thermal insulation behind the absorber plate and transparent cover sheets (glass or plastic) prevent loss of heat to surroundings.

The constructional details of flat plate collector is given below:

1) **Insulated Box:** The rectangular box is made of thin G.I sheet and is insulated from sides and bottom using glass or mineral wool of thickness 5 to 8 cm to reduce losses from conduction to back and side wall. The box is tilted at due south and a tilt angle depends on the latitude of location. The face area of the collector box is kept between 1 to 2 m^2.
2) **Transparent Cover:** This allows solar energy to pass through and reduces the convective heat losses from the absorber plate through air space. The transparent tampered glass cover is placed on top of rectangular box to trap the solar energy and sealed by rubber gaskets to prevent the leakage of hot air. It is made of plastic/glass but glass is most favorable because of its transmittance and low surface

degradation. However with development of improved quality of plastics, the degradation quality has been improved. The plastics are available at low cost, light in weight and can be used to make tubes, plates and cover but are suitable for low temperature application 70-120 C with single cover plate or up to 150C using double cover plate. The thickness of glass cover 3 to 4 mm is commonly used and 1 to 2 covers with spacing 1.5 to 3 cm are generally used between plates. The temperature of glass cover is lower than the absorber plate and is a good absorber of thermal energy and reduces convective and radiative losses of sky.

3) **Absorber Plate:** It intercepts and absorbs the solar energy. The absorber plate is made of copper, aluminum or steel and is in the thickness of 1 to 2 mm. It is the most important part of collector along with the tubes products passing the liquid or air to be heated. The plate absorbs the maximum solar radiation incident on it through glazing (cover plate) and transfers the heat to the tubes in contact with minimum heat losses to atmosphere. The plate is black painted and provided with selective material coating to increase its absorption and reduce the emission. The absorber plate has high absorption (80-95%) and low transmission/reflection.
4) **Tubes:** The plate is attached to a series of parallel tubes or one serpentine tube through which water or other liquid passes. The tubes are made of copper, aluminum or steel in the diameter 1 to 1.5 cm and are brazed, soldered on top/bottom of the absorber water equally in all the tubes and collect it back from the other end. The header pipe is made of same material as tube and of larger diameter. Now-a-days the tubes are made of plastic but they have low thermal conductivity and higher coefficient of expansion than metals.

Copper and aluminum are likely to get corroded with saline liquids and steel tubes with inhibitors are used at such places. Removal of Heat: These systems are best suited to applications that require low temperatures. Once the heat is absorbed on the absorber plate it must be removed fast and delivered to the place of storage for further use. As the liquid circulates through the tubes, it absorbs the heat from absorber plate of the collectors. The heated liquid moves slowly and the losses from collector will increase because of rise of high temperature of collector and will lower the efficiency. Flat-plate solar collectors are less efficient in cold weather than in warm weather. Factors affecting the Performance of Flat Plate Collector. The different factors affecting the performance of system are:

1) **Incident Solar Radiation:** The efficiency of collector is directly related with solar radiation falling on it and increases with rise in temperature.
2) **Number of Cover Plate:** The increase in number of cover plate reduces the internal convective heat losses but also prevents the transmission of radiation inside the collector. More than two cover plate should not be used to optimize the system.
3) **Spacing:** The more space between the absorber and cover plate the less internal heat losses. The collector efficiency will be increased. However on the other hand, increase in space between them provides the shading by side wall in the morning and evening and reduces the absorbed solar flux by 2-3% of system. The spacing between absorber and cover plate is kept 2-3 cm to balance the problem.
4) **Collector Tilt:** The flat plate collectors do not track the sun and should be tilted at angle of latitude of the location for an average better performance. However with changing declination angle with seasons the optimum tilt angle is kept $\Phi \pm 15^{o}$ The collector is placed with south facing at northern hemisphere to receive maximum radiation throughout the day.
5) **Selective Surface:** Some materials like nickel black (α= 0.89, ε= 0.15) and black chrome (α= 0.87, ε= 0.088), copper oxide (α= 0.89, ε= 0.17) etc. are applied chemically on the surface of absorber in a thin layer of thickness 0.1 µm. These chemicals have high degree of absorption (α) to short wave radiation (<4 µm) and low emission (ε) of long wave radiations (> 4 µm). The higher absorption of solar energy increase the temperature of absorber plate and working fluid. The top losses reduce and the efficiency of the collector increases. The selective surface should be able to withstand high temperature of 300-400 ^{o}C, cost less,

should not oxidize and be corrosive resistant. The property of material should not change with time.

6) **Inlet Temperature:** With increase in inlet temperature of working fluid the losses increase to ambient. The high temperature fluid absorbed the less heat from absorber plate because of low temperature difference and increases the top loss coefficient. Therefore the efficiency of collector get reduced with rise in inlet temperature.
7) **Dust on cover Plate:** The efficiency of collector decreases with dust particles on the cover plate because the transmission radiation decreases by 1%. Frequent cleaning is required to get the maximum efficiency of collector.

Advantages of flat plate collectors:

1) It utilizes the both the beam as well as diffuse radiation for heating.
2) Requires less maintenance.

Disadvantages of flat plate collectors:

1) Large heat losses by conduction and radiation because of large area.
2) No tracking of sun.
3) Low water temperature is achieved.

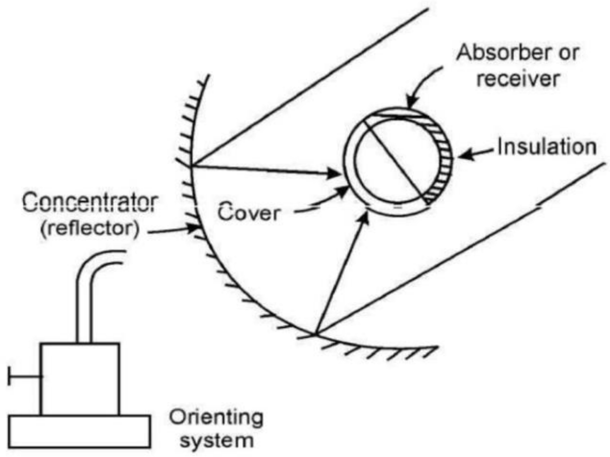
Applications of flat plate collector:

1) Solar water heating systems for residence, hotels, industry.
2) Desalination plant for obtaining drinking water from sea water.
3) Solar cookers for domestic cooking.
4) Drying applications.
5) Residence heating.

CONCENTRATING/FOCUSING COLLECTORS

Concentrating collector is a device to collect solar energy with high intensity of solar radiation on the energy absorbing surface. Such collectors use optical system in the form of reflectors or refractors. These collectors are used for medium (100-300^{o}C) and high-temperature (above 300^{o}C) applications such as steam production for the generation of electricity. The high temperature is achieved at absorber because of reflecting arrangement provided for concentrating the radiation at required location using mirrors and lenses. These collectors are best suited to places having more number of clear days in a year. The area of the absorber is kept less than the aperture through which the radiation passes, to concentrate the solar flux. These collectors require tracking to follow the sun because of optical system. The tracking rate depends on the degree of concentration ratio and needs frequent adjustment for system having high concentration ratio. The efficiency of these collectors lies between 50-70%. The collectors need more maintenance than FPC because of its optical system. The concentrating collectors are classified on the basis of reflector used; concentration ratio and tracking method adopted. FPC with Reflectors The mirrors are placed as reflecting surface to concentrate more radiations on FPC absorber. The fluid temperature is higher by 30°C than achieved in FPC. These collections utilize direct and diffuse radiation. Lens Focusing Type The fresnel lenses are used to concentrate the radiation at its focus. The lower side of lenses is grooved so that radiation concentrates on a focus line.

Schematic diagram of concentrating collector:



CLASSIFICATION/TYPES OF CONCENTRATING COLLECTORS

There are different types of concentrating (focusing) collectors. They are:

1) Point focus technology.
   i. Fresnel reflector based dish (ARUN dish).
   ii. Dual axis tracked paraboloid dish.
2) Line focus technology.

i. Parabolic Troughs Collectors (PTC).
ii. Linear Fresnel Reflector (LFR).

3) Non focusing technology.

i. Compound Parabolic Collectors (CPC).

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UNIT – II

SOLAR ENERGY STORAGE AND APPLICATIONS

SOLAR ENERGY STORAGE

Solar energy is available only during the sunshine hours. Consumer energy demands follow their own time pattern & the solar energy does not fully match the demand. As a result, energy storage is a must to meet the consumer requirement.

DIFFERENT METHODS: SENSIBLE, LATENT HEAT AND STRATIFIED STORAGE

1) Sensible heat storage.
2) Latent heat storage.
3) Stratified storage.

1) Sensible Heat Storage:

- Heating a liquid or solid which does not change phase comes under this category.
- Heat that causes a change in temperature in an object is called sensible heat.
- The quantity of heat stored is proportional to the temperature rise of the material.
- If T_1 and T_2 represent the lower and higher temperature, V the volume and ρ the density of the storage material, and C_p the specific heat, then the energy stored Q is given by:

$$Q = V\rho \int_{T1}^{T2} Cp \, dT$$

- For a sensible heat storage system, energy is stored by heating a liquid or a solid. Materials that are used in such a system include liquids like water, inorganic molten salts and solids like rock, gravel and refractories.
- The choice of the material used depends on the temperature level of its utilization. Water is used for temperature below 100 ^{0}C whereas refractory bricks can be used for temperature upto 1000 ^{0}C.

2) Latent Heat Storage:

- All pure substances in nature are able to change their state. Solids can become liquids (ice to water) and liquids can become gases (water to vapor) but changes such as these require the addition or removal of heat.
- In this system, heat is stored in a material when it melts, and heat is extracted from the material when it freezes.
- Heat can also be stored when a liquid changes to gaseous state, but as the volume change is large, such a system is not economic.
- Latent heat arises from the work required to overcome the forces that hold together atoms or molecules in a material. The regular structure of a crystalline solid is maintained by forces of attraction among its individual atoms, which oscillate slightly about their average positions in the crystal lattice.

3) Stratified Storage:

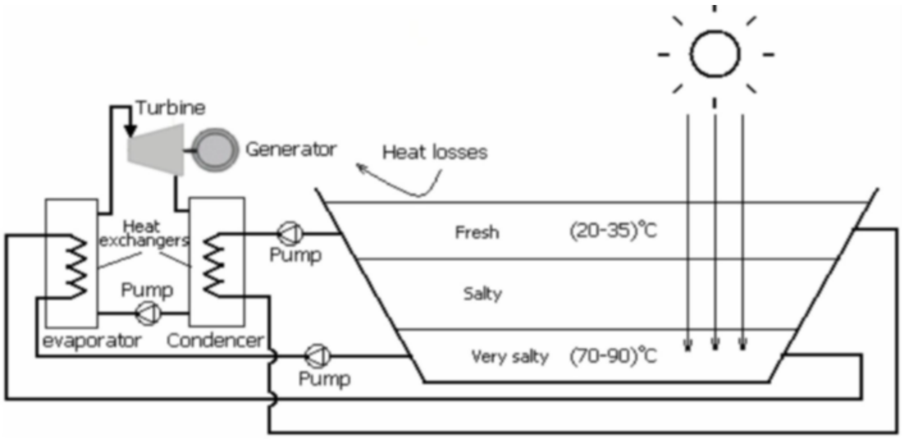
- A hot water storage tank (also called a hot water tank, thermal storage tank, hot water thermal storage unit, heat storage tank and hot water cylinder) is a water tank used for storing hot water for space heating or domestic use.

- An efficiently insulated tank can retain stored heat for days.

- Hot water tanks may have a built-in gas or oil burner system, electric immersion heaters, an external heat exchanger such as a central heating system, or heated water from another energy source such as a wood-burning stove.

SOLAR PONDS

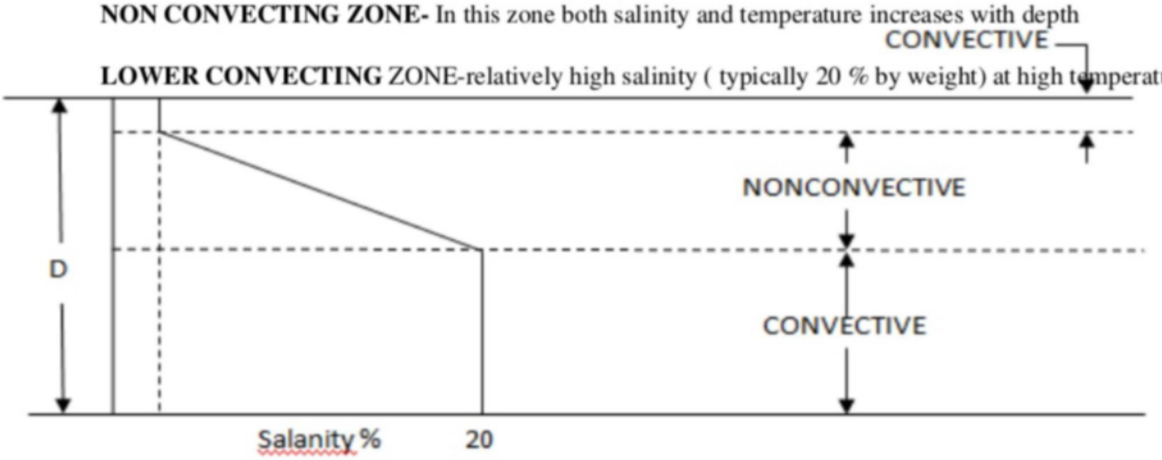
- Normal ponds receive sunlight a part of which is reflected at the surface, a part is absorbed and the remaining is transmitted to the bottom.
- Due to this the lower part gets heated up and the density decreases as a result of which it rises up and convection currents are set up.(As a result, the heated water reaches top layer and looses its heat by convection and evaporation).
- A natural or artificial body of water for collecting and absorbing solar radiation energy and storing it as heat.
- Thus a solar pond combines solar energy collection and sensible heat storage.
- They are large shallow bodies of water that are arranged so that the temperature gradient are reversed from the normal.
- This allows the use for collection and storage of solar energy which may under ideal conditions be delivered at temperature 40-50 `C above normal.
- It can be use for various applications, such as process heating, water desalination, refrigeration, drying and power generation.

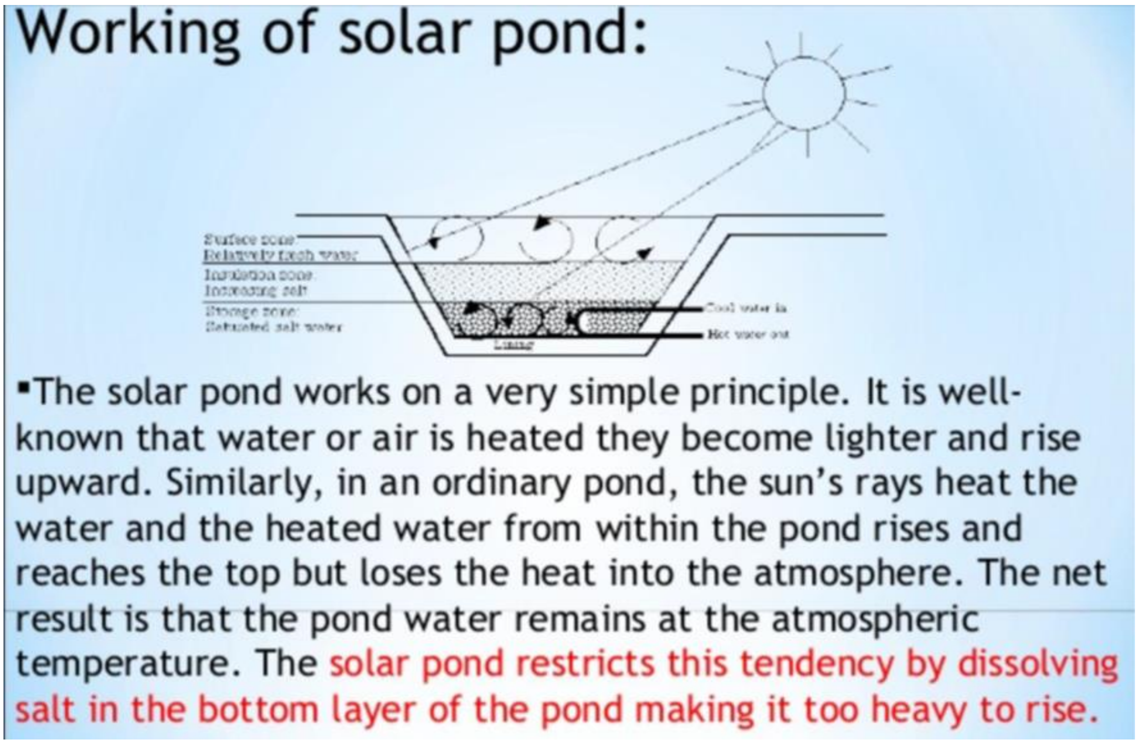


UPPER CONVECTIVE ZONE- This is a zone, typically 3 m thick, of almost low salinity which is almost close to ambient temperature.

NON CONVECTING ZONE- In this zone both salinity and temperature increases with depth

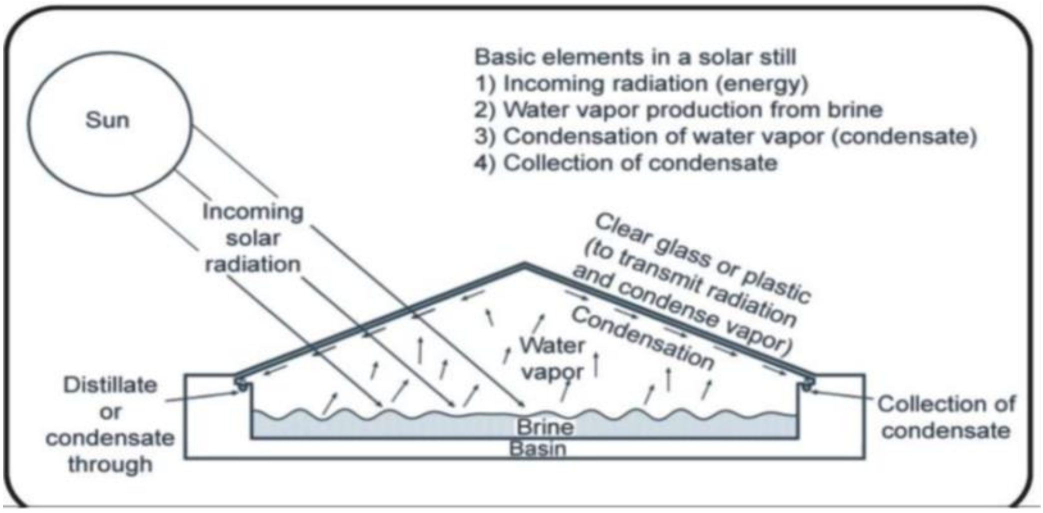
LOWER CONVECTING ZONE-relatively high salinity (typically 20 % by weight) at high temperature.





SOLAR DISTILLATION

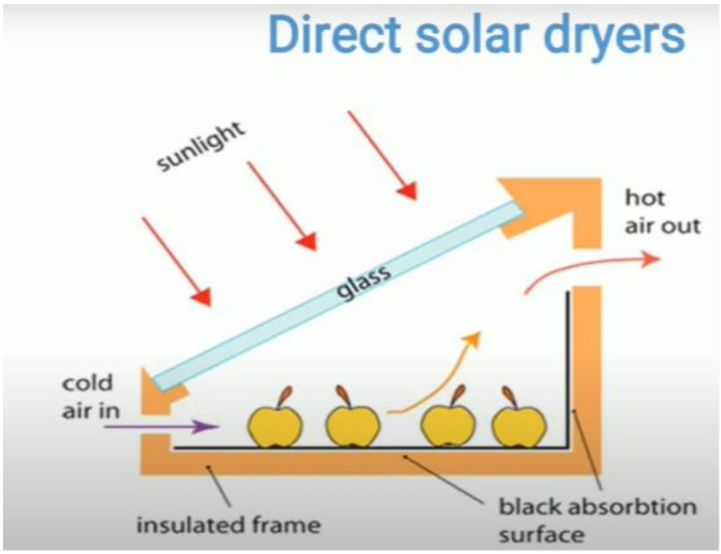
- Solar distillation is the use of solar energy to evaporate water and collect its condensate within the same closed system.
- water purification it can turn salt or brackish water into fresh drinking water.



SOLAR DRYING

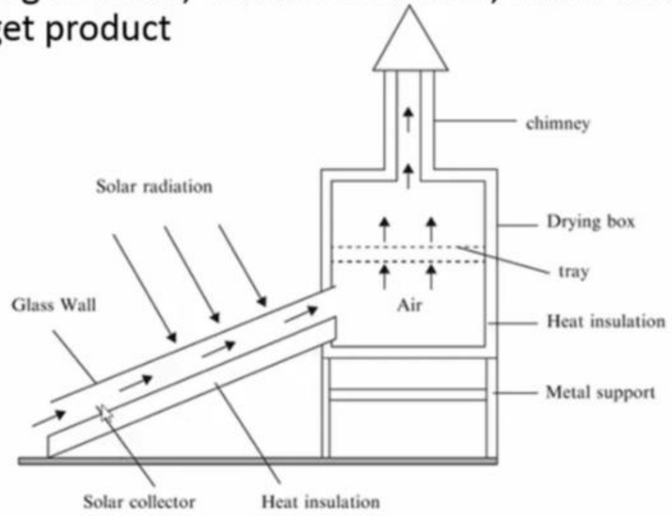
- Solar dryers are devices that use solar energy to dry the substances especially food.
- There are two general types of solar dryers

- direct dryer
- Indirect dryer



Indirect drying systems

- Uses absorbing surfaces, which heat the air, which is further passed over the target product



PHOTOVOLTAIC ENERGY CONVERSION

- Photovoltaic systems convert sunlight directly into electricity, and are potentially one of the most useful of the renewable energy technologies.
- Also known as solar cells, PV systems are already an important part of our lives. The simplest systems power many of the small calculators and wrist watches we use everyday.
- The conversion efficiency of a PV cell is the proportion of sunlight energy that the cell converts into electrical energy.
- A solar cell is essentially a semiconductor device fabricated in a manner which generates a voltage when solar radiation falls on it.
- Solar electricity systems capture the sun's energy using photovoltaic (PV) cells.
- The cells convert the sunlight into electricity, which can be used to run household appliances and lighting.
- A SOLAR CELL is a solid state electrical device that converts energy of light directly into electricity by Photoelectric Effect.

Photoelectric effect:

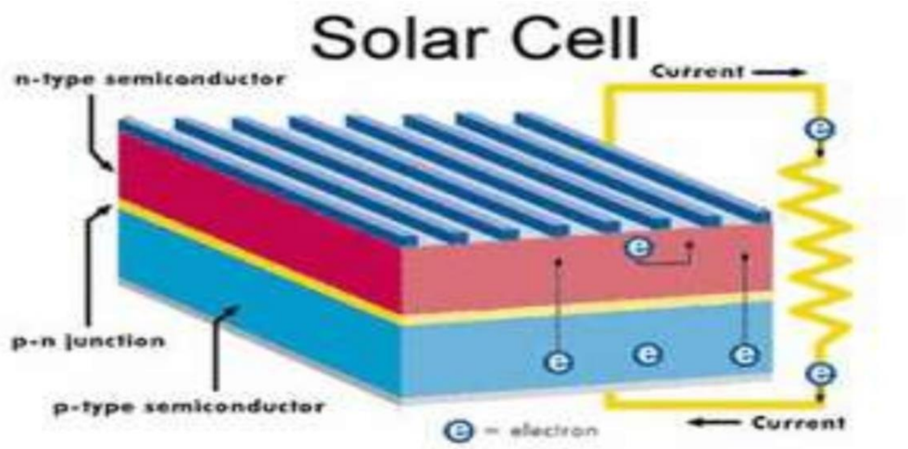
- When photons of light hit electrons in the silicon lattice and provide energy to flow. Introducing dopants such as boron and phosphorus into the silicon lattice provides a direction for the electrons to flow.
- Finally, electrons flowing from one cell into the next cell in a module *gain about 1/2 volt* from each cell.

A PV System typically consists of 3 basic components:

➢**PV cells** - Electricity is generated by PV cells, the smallest unit of a PV system.

➢**Modules -** PV cells are wired together to form modules which are usually a sealed, or encapsulated, unit of convenient size for handling.

➢**Arrays** – Groups of panels make up an array.



WIND ENERGY

The wind is a by-product of solar energy. Approximately 2% of the sun's energy reaching the earth is converted into wind energy. The surface of the earth heats and cools unevenly, creating atmospheric pressure zones that make air flow from high- to low-pressure areas.

The wind has played an important role in the history of human civilization. The first known use of wind dates back 5,000 years to Egypt, where boats used sails to travel from shore to shore. The first true windmill, a machine with vanes attached to an axis to produce circular motion, may have been built as early as 2000 B.C. in ancient Babylon. By the 10th century A.D., windmills with wind-catching surfaces having 16 feet length and 30 feet height were grinding grain in the areas in eastern Iran and Afghanistan.

The multi-vane "farm windmill" of the American Midwest and West was invented in the United States during the latter half of the l9th century. In 1889 there were 77 windmill factories in the United States, and by the turn of the century, windmills had become a major American export. Until the diesel engine came along, many transcontinental rail routes in the U.S. depended on large multi-vane windmills to pump water for steam locomotives.

Farm windmills are still being produced and used, though in reduced numbers. They are best suited for pumping ground water in small quantities to livestock water tanks. In the 1930s and 1940s, hundreds of thousands of electricity producing wind turbines were built in the U.S. They had two or three thin blades which rotated at high speeds to drive electrical generators. These wind turbines provided electricity to farms beyond the reach of power lines and were typically used to charge storage batteries, operate radio receivers and power a light bulb. By the early 1950s, however, the extension of the central power grid to nearly every American household, via the Rural Electrification Administration, eliminated the market for these machines. Wind turbine development lay nearly dormant for the next 20 years.

A typical modern windmill looks as shown in the following figure. The wind-mill contains three blades about a horizontal axis installed on a tower. A turbine connected to a generator is fixed about the horizontal axis.

Like the weather in general, the wind can be unpredictable. It varies from place to place, and from moment to moment. Because it is invisible, it is not easily measured without special instruments. Wind velocity is affected by the trees, buildings, hills and valleys around us. Wind is a diffuse energy source that cannot be contained or stored for use elsewhere or at another time.

nergy content in wind:-

power of wind stream = K.E of wind per unit time.

$$\therefore P_0 = \frac{1}{2} \dot{m} u_0^2 \quad \text{(watt)}$$

where,

$P_0 \rightarrow$ power of wind stream

$u_0 \rightarrow$ understurbed wind velocity.

$\dot{m} \rightarrow$ mass of air passes in a unit time from an area A with undisturbed wind velocity.

$= \rho A u_0$

$$\boxed{P_0 = \frac{1}{2} \rho A u_0^3}$$

Energy content in wind.

$$\boxed{E_0 = \int_0^t P_0 \, dt = \int_0^t \frac{1}{2} \cdot \rho A u_0^3 \, dt}$$

wind speed measurement are often taken at a hight of 10m from ground but the turbines often operate at a height above this.

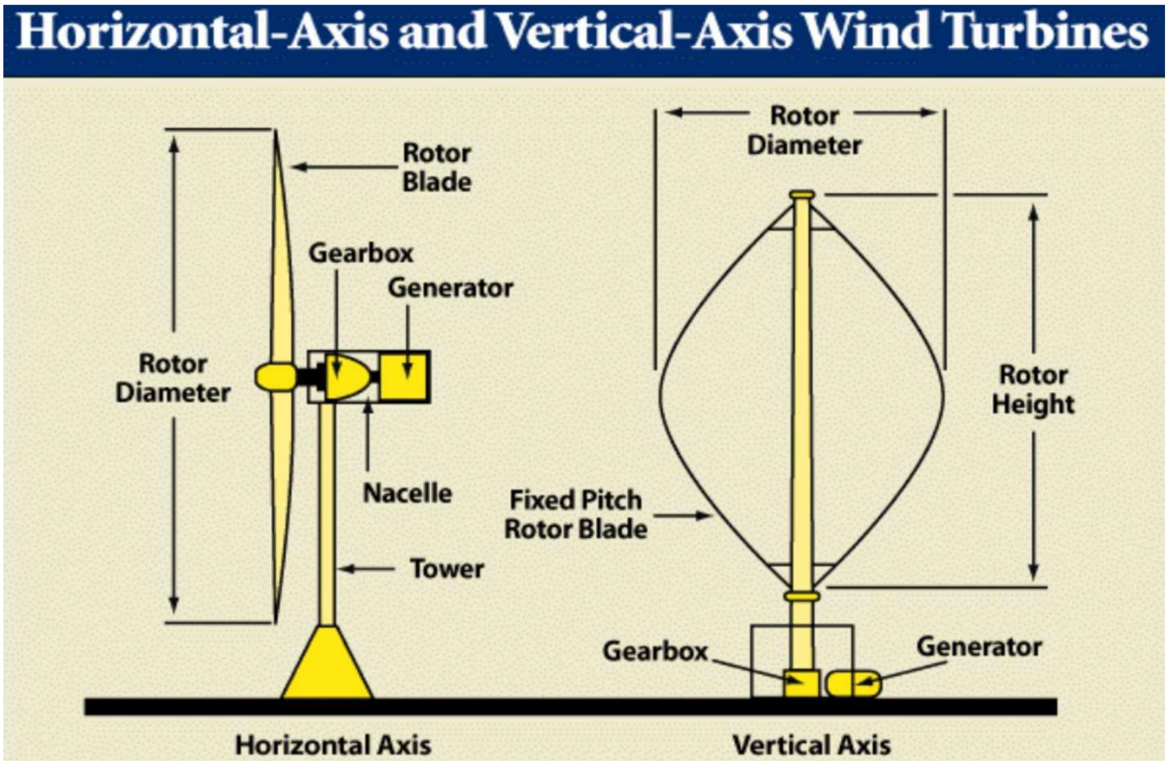
$$\boxed{\therefore \frac{u_2}{u_1} = \left(\frac{H_2}{H_1}\right)^{\alpha}}$$

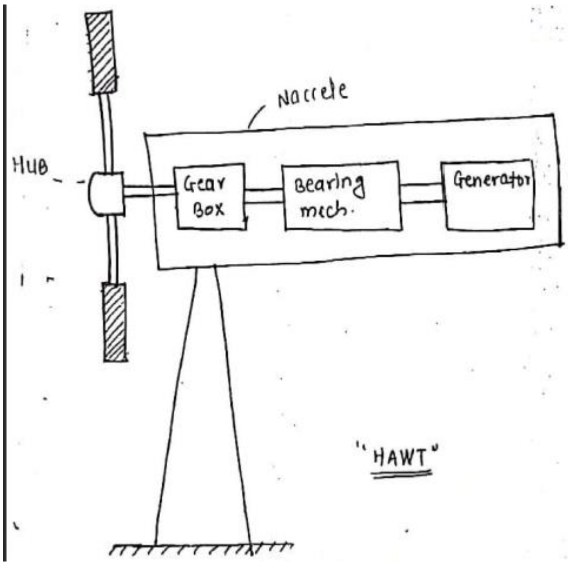
where, α = constant Depend on surface roughness and hight

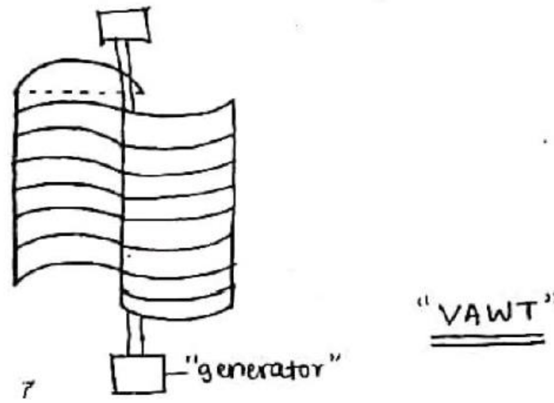
CLASSIFICATION OF WIND-MILLS: HORIZONTAL & VERTICAL AXIS WINDMILLS

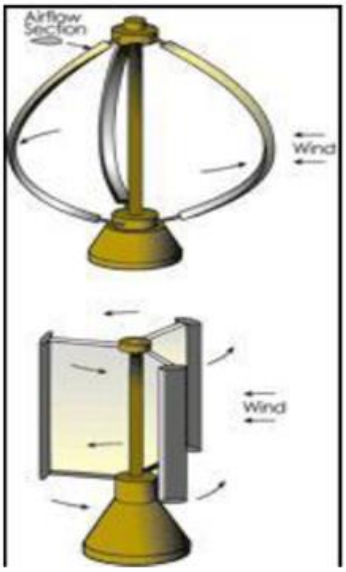
Wind turbines are classified into two general types: Horizontal axis and Vertical axis. A horizontal axis machine has its blades rotating on an axis parallel to the ground. A vertical axis machine has its blades rotating on an axis perpendicular to the ground. There are a number of available designs for both and each type has certain advantages and disadvantages. However, compared with the horizontal axis type, very few vertical axis machines are available commercially.

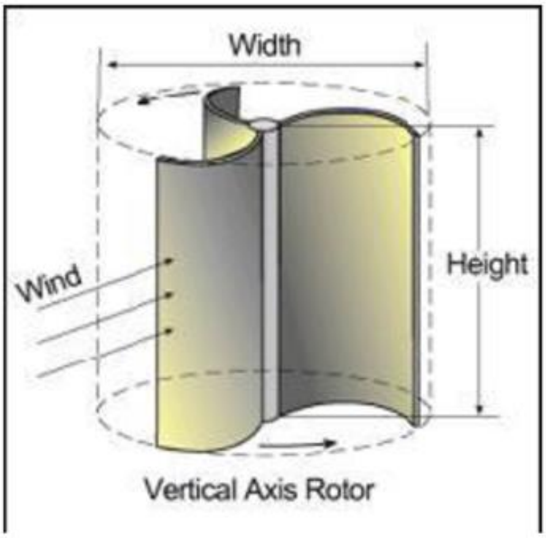
HAWT	VAWT.
1) Axis of wind machine rotor is Horizontal.	1) It is vertical.
2) commonly work over the lift force.	2) work over the drag force.
3) Naccele is on the top.	3) It is at the botom.
4) High maintainance cost is req--uired.	4) low maintainance cost.
5) Need Yaw mechanism for orienti--ng the m/c in the wind direction	5) No need of any mechanism.
6) Low solidity ratio. thats why need a starting torque.	6) High solidity ratio, thats why no need of any starting torque.
7) High energy available due to the hight.	7) less energy available due to less height.
8) suitable sides are costal areas. hill region.	8) can be used in the city as it required low wind speed.
9) Applⁿ:- •Electricity generation, •water pumping	9) Applⁿ:- •water pumping. •Electricity generation (Batory charging)











There is one more type of wind-mill called Cyclo-gyro wind-mill with very high efficiency of about 60%. However, it is not very stable and is very sensitive to wind direction. It is also very complex to build.

PERFORMANCE/OPERATING CHARACTERISTICS OF WIND MILLS

All wind machines share certain operating characteristics, such as cut-in, rated and cut-out wind speeds.

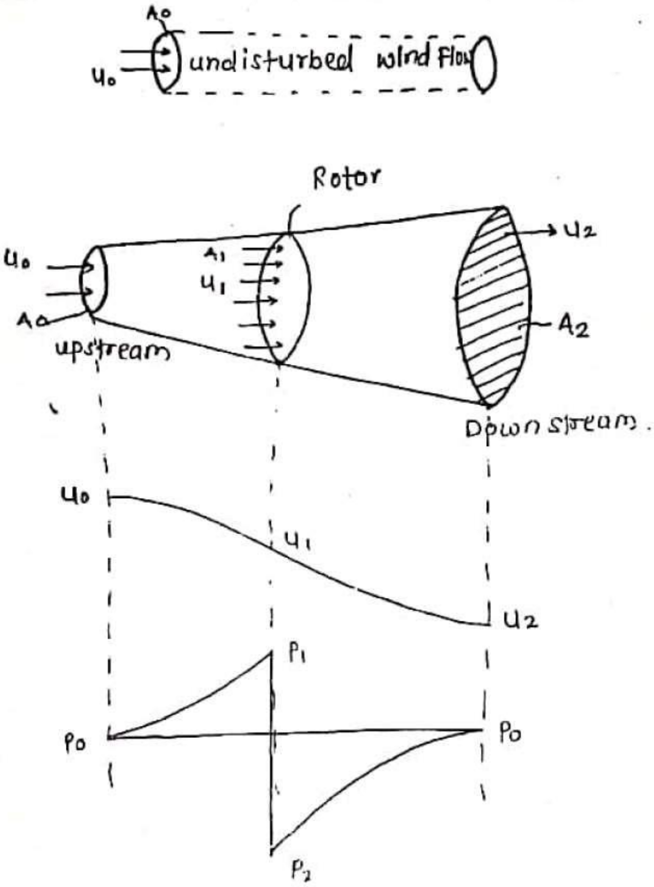
1) **Cut-in Speed:** Cut-in speed is the minimum wind speed at which the blades will turn and generate usable power. This wind speed is typically between 10 and 16 kmph.

2) **Rated Speed:** The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. For example, a "10 kilowatt" wind turbine may not generate 10 kilowatts until wind speeds reach 40 kmph. Rated speed for most machines is in the range of 40 to 55 kmph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases. The output of most machines levels off above the rated speed. Most manufacturers provide graphs, called "power curves," showing how their wind turbine output varies with wind speed.
3) **Cut-out Speed:** At very high wind speeds, typically between 72 and 128 kmph, most wind turbines cease power generation and shut down. The wind speed at which shut down occurs is called the cut-out speed. Having a cut-out speed is a safety feature which protects the wind turbine from damage. Shut down may occur in one of several ways. In some machines an automatic brake is activated by a wind speed sensor. Some machines twist or "pitch" the blades to spill the wind. Still others use "spoilers," drag flaps mounted on the blades or the hub which are automatically activated by high rotor rpm's, or mechanically activated by a spring loaded device which turns the machine sideways to the wind stream. Normal wind turbine operation usually resumes when the wind drops back to a safe level.

BETZ CRITERIA

Betz Limit: It is the flow of air over the blades and through the rotor area that makes a wind turbine function. The wind turbine extracts energy by slowing the wind down. The theoretical maximum amount of energy in the wind that can be collected by a wind turbines rotor is approximately 59%. This value is known as the Betz limit. If the blades were 100%

Power extraction from Betz model:



u_0 = velocity at upstream
u_1 = velocity at rotor.
u_2 = velocity at downstream

mass flow rate.

$$\dot{m} = \rho A_0 u_0 = \rho A_1 u_1 = \rho A_2 u_2 \quad \text{—} \; (1)$$

Axial thrust on the rotor

$$F_A = \dot{m}\,(u_0 - u_2) \quad \text{—} \; (2)$$

Power extracted by turbine.

$$P_T = F_A . u_1$$

$$P_T = \dot{m} u_1 (u_0 - u_2) \quad \text{—} \; (3)$$

Power extraction can be written as

$$P_T = \frac{1}{2} \dot{m} \, (u_0^2 - u_2^2) \quad \text{— (4)}$$

$$(3) = (4)$$

$$\cancel{\dot{m}} u_1 \, (u_0 - u_2) = \frac{1}{2} \cancel{\dot{m}} (u_0^2 - u_2^2)$$

$$\boxed{u_1 = \frac{(u_0 + u_2)}{2}} \quad \text{— (5)}$$

minimum possible value of u_1 is when $u_2 = 0$

$$\boxed{u_1 = \frac{u_0}{2}}$$

According to the linear momentum theory wind speed through the turbine rotor can't be less than 1/2 the speed of upstream wind.

Interference Factor :- (a)

$$a = \frac{u_0 - u_1}{u_0} \quad \text{— (6)}$$

$$a u_0 = u_0 - u_1$$

$$u_1 = u_0 - a u_0$$

$$u_1 = u_0 (1 - a) \quad \text{— (7)}$$

$$u_1 = \frac{u_0 + u_2}{2}$$

by eq^n (5)

Put u_1 in eq^n (6)

$$a = \frac{u_0 - \left(\frac{u_0 + u_2}{2}\right)}{u_0}$$

$$a = \frac{u_0 - u_2}{2 u_0} \quad \text{— (8)}$$

$$P_T = \dot{m} u_1 (u_0 - u_2)$$

$$P_T = \rho A_1 u_1 \cdot u_1 (u_0 - u_2)$$

by eq^n 7, 8

$$P_T = \rho \cdot A_1 [u_0(1-a)]^2 \cdot 2au_0$$

$$P_T = \rho \cdot A_1 \cdot u_0^2 (1-a)^2 \cdot 2au_0$$

$$P_T = 4a(1-a)^2 \cdot \frac{1}{2} \rho \cdot A \cdot u_0^3$$

$$C_p = 4a(1-a)^2$$

→ Power coieffficent.

↓

Power extraction from maximum available wind energy.

$$P_T = C_p \cdot P_0$$

To maximize the power extraction

$C_p \rightarrow$ max.

$$\frac{dc_p}{da} = 0.$$

$$\frac{d}{da}\left(4a(1-a)^2\right) = 0$$

$$4a \cdot 2(1-a)(-1) + (1-a)^2 \cdot 4 = 0$$

$$(1-a)\left[-8a + 4 - 4a\right] = 0$$

$$(1-a)(4-12a) = 0$$

$$\boxed{a=1}, \quad \boxed{a = 1/3}$$

$$a = \frac{u_0 - u_1}{u_0}$$

$$1 = \frac{u_0 - u_1}{u_0}$$

$$\boxed{u_1 = 0} \times$$

$$u_1 = u_0(1-a)$$

$$u_1 = u_0(1 - 1/3) = 2u_0/3$$

$$a = \frac{u_0 - u_2}{2u_0}$$

$$1/3 = \frac{u_0 - u_2}{2u_0}$$

$$\boxed{u_2 = u_0/3}$$

$$C_{pmax} = 4 \cdot \tfrac{1}{3}\left(1-\tfrac{1}{3}\right)^2 \quad \ldots \quad (a = \tfrac{1}{3})$$

$$= \tfrac{4}{3} \cdot \tfrac{4}{9}$$

$$= \tfrac{16}{27}$$

$$C_{pmax} = 0.593$$

$$= 59.3\ \%$$

It means that for maximum power extraction upstream wind speed is reduced to 2/3 at turbine and further reduced 1/3rd at downstream.

Betz limit said a limit like carnot means a wind energy conversion device can't have a efficency grater than 59.3 %

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UNIT – III

BIO-MASS

INTRODUCTION

Biomass is an organic matter from plants, animals and micro organisms grown on land and water and their derivatives. the energy obtained from biomass is called biomass energy.

Energy from biomass: Energy from biomass can be obtained by using the following methods:

1) Combustion.
2) Anaerobic digestion.
3) Pyrolysis.
4) Hydrolysis and ethanol fermentation.
5) Gasifier.

1) Combustion: 'combustion' is the process, now in commercial operation, that uses biomass to produce energy. Direct combustion requires biomass with a moisture content around 15 % or less, so it may require drying prior to combustion for most of the crops.

2) Anaerobic digestion: The biogas plants using anaerobic digestion are simple in construction with low capital outlay.

3) Pyrolysis: 'pyrolysis' is an irreversible change brought about by action of heat in the absence of oxygen; the energy splits the chemical bonds and leaves the energy stored in biomass. It may yield either soild, liquid or gaseous fuel.

4) Hydrolysis and Ethanol Fermentation: the process of hydrolysis converts cellulose to alcohols through fermentation. Ethyl alcohol can be produced from variety of sugar by fermentation with yeasts.

5) Gasifier: Pyrolysis-gasification is a promising conversion technology. It appears to be economically competitive with natural gas, using biomass wastes.

Photosynthesis: The preparation of food by the leaves of green plant and micro- organisms in presence of sunlight, chlorophyll, water and "CO_2" is called photosynthesis. In this process, the CO_2 from the atmosphere combines with water and light energy to produce carbohydrates (i.e.., sugars, starches etc..) and oxygen.

$$6CO_2 + 6H_2O \xrightarrow[\text{photosyntesis}]{\text{sun light}} C_6H_{12}O_6 + 6O_2$$

Biomass does not add CO_2 to the atmosphere as it absorbs the same amount of carbon in growing the plants as it is released when consumed as fuel. It is superior fuel as the energy produced by biomass is ' carbon cycle neutral'.

PRINCIPLES OF BIO-CONVERSION [OR] BIOMASS CONVERSION PROCESS

The following process are used for the biomass conversion to energy or to biofuels:

1) Densification.
2) Combustion and incineration.
3) Thermo-chemical conversion.
4) Biochemical conversion.

1) Densification: In this process bulky biomass is reduced to a better volume-to weight ratio by compressing in a die at a high temperature and pressure. The biomass pressed into briquettes or pellets (easier to transport and store) can be used as clean fuel in domestic chulhas, bakeries and hotels.

2) Combustion and incineration:

Combustion: combustion is the process of burning in presence of oxygen to produce heat (utilized for cooking, space heating, industrial purposes and for electricity generation), light and by products. This method is very inefficient with heat losses to 30 to 90 % of the original energy contained in the biomass.

Incineration: It is process of burning completely the solid masses to 'ashes' by high temperature oxidation. "Incineration" is a special process which is used for incinerating municipal solid waste to reduce the volume of solid refuse (90 percent) and to produce heat steam and electricity.

3) Thermo- chemical conversion: It is process to decompose biomass with various combinations of temperatures and pressures. Thermo- chemical conversion takes the following two forms:

i. **Gasification:** It is the process of heating the biomass with limited oxygen to produce 'low heating value' or by reacting it with steam and oxygen at high pressure and temperature to produce 'medium heating value gas'. The output gas is known as "producer gas", a mixture of H_2 (15-20%), CO (10 to 20%), CH_4(1 to 5%), CO_2 (9 to 12%) and N_2 (45 to 55%).

ii. **Liquification:** Biomass can be liquified fast or flash pyrolysis, called "pyrolytic oil" which is dark brown liquid of low viscosity and a mixture of hydrocarbons.

4) Biochemical Conversion: In biochemical conversion there are two principal conversion process:

i. **Anaerobic digestion:** This process involves 'microbial digestion' of biomass and is done in the 'absence of oxygen'. This process and end products depend upon the micro-organisms cultivated under culture conditions. (An anaerobe is a micro-organisms that can live and grow without external oxygen or air; it extracts oxygen by decomposing the biomass at low temperatures up to 65c, in presence of moisture).

ii. **Fermentation:** Fermentation is the process of decomposition of organic matter by micro-organisms especially bacteria and yeasts. It is a well established and widely used technology for the conversion of grains and sugar crops into ethanol (ethyl alcohol).

Fig. 6.1, shows the biomass and conversion technologies and products.

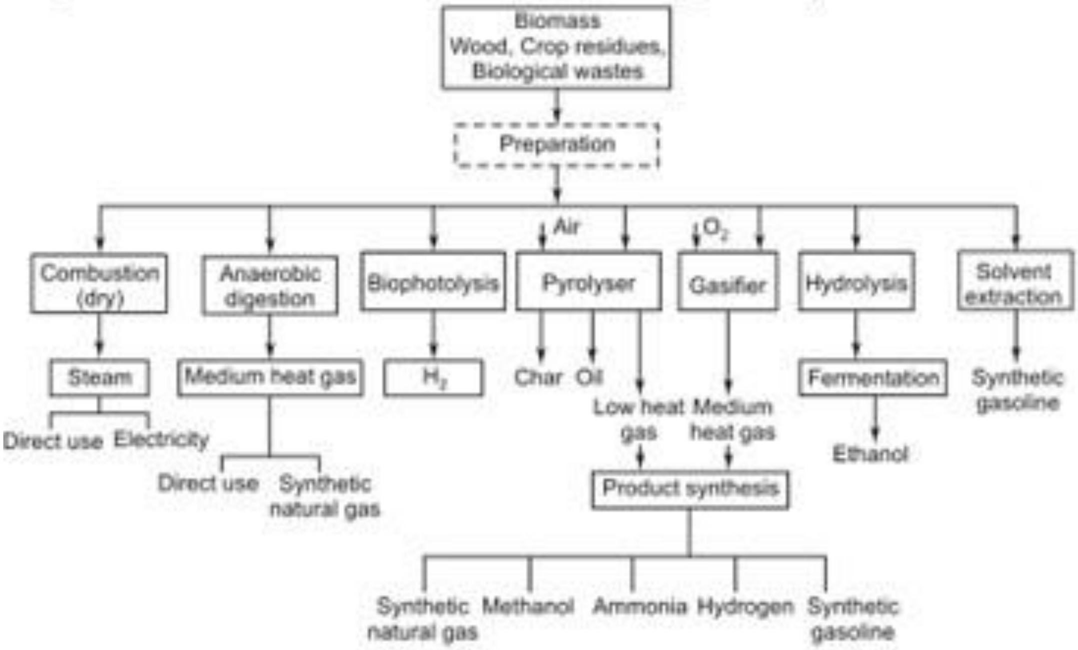

Fig. 6.1. Biomass conversion technologies and products .

ANAEROBIC DIGESTION

Anaerobic Digestion is a biochemical degradation process that converts complex organic material, such as animal manure, into methane and other by-products.

Anaerobic digester (commonly referred to as an AD) is a device that promotes the decomposition of manure or "digestion" of the organics in manure to simple organics and gaseous biogas products. Biogas is formed by the activity of anaerobic bacteria. Microbial growth and biogas production are very slow at ambient temperatures. These bacteria occur naturally in organic environments where oxygen is limited. Biogas is comprised of about 60% methane, 40% carbon dioxide, and 0.2 to 0.4% of hydrogen sulfide. Manure is regularly put into the digester after which the microbes break down the manure into biogas and a digested solid. The digested manure is then deposited into a storage structure. The biogas can be used in an engine generator or burned in a hot water heater. AD systems are simple biological systems and must be kept at an operating temperature of 100 degrees F in order to function properly. The first methane digester plant was built at a leper colony in Bombay, India. Biogas is very corrosive to equipment and requires frequent oil changes in an engine generator set to prevent mechanical failure. The heating value of biogas is about 60% of natural gas and about ¼ of propane. Because of the low energy content and its corrosive nature of biogas, storage of biogas is not practical.

TYPES OF BIO-GAS DIGESTERS

There are two major types of biogas designs promoted in India:

1) Floating Drum.
2) Fixed Dome

The **floating drum** is an old design with a mild-steel, Ferro-cement or fiberglass drum, which floats along a central guide frame and acts as a storage reservoir for the biogas produced. The **fixed dome** design is of Chinese origin and has dome structure made of cement and bricks. It is a low-cost alternative to the floating drum, but requires high masonry skills and is prone to cracks and gas leakages. Family biogas plants come in different size depending on the availability of dung and the quantity of biogas required for cooking. The average size of the family is 5-6 persons, and thus biogas plant of capacity 2-4 m^3 is adequate. The biomass requirement is estimated to be 1200 liters for a family.

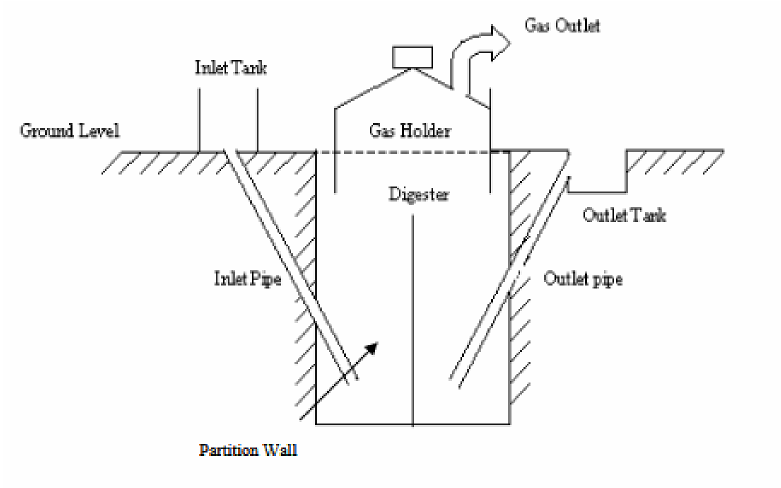

Figure 2: Floating Gasholder drum design (a conventional Indian design)

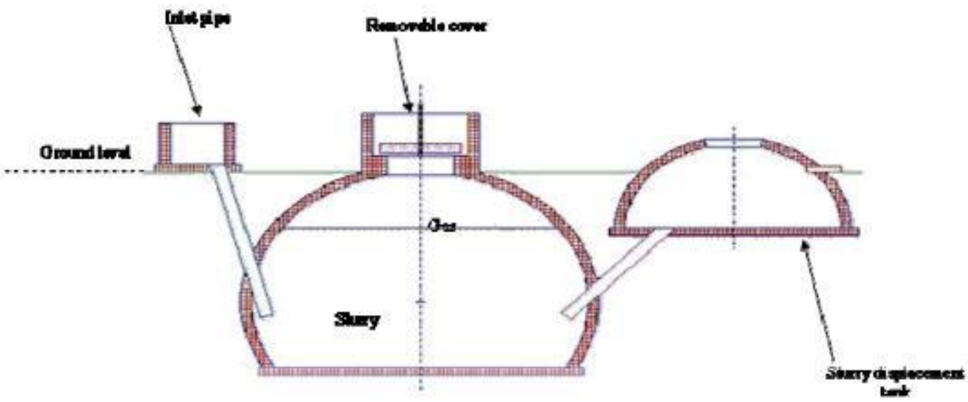

Figure 3: Spherical shaped fixed - dome plant

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UNIT – IV

GEOTHERMAL ENERGY

The word geothermal comes from the Greek words geo (earth) and thermo (heat). So, geothermal energy is heat from within the earth. We can use the steam and hot water produced inside the earth to heat buildings or generate electricity. Geothermal energy is a renewable energy source because the water is replenished by rainfall and the heat is continuously produced inside the earth.

Geothermal energy is generated in the earth's core, about 4,000 miles below the surface. Temperatures hotter than the sun's surface are continuously produced inside the earth by the slow decay of radioactive particles, a process that happens in all rocks. The earth has a number of Different layers: The core itself has two layers: a solid iron core and an outer core made of very hot melted rock, called magma. The mantle which surrounds the core and is about 1,800 miles thick. It is made up of magma and rock.

The crusts the outermost layer of the earth, the land that forms the continents and ocean floors. It can be three to five miles thick under the oceans and 15 to 35 miles thick on the continents. The earth's crust is broken into pieces called plates. Magma comes close to the earth’s surface near the edges of these plates. This is where volcanoes occur. The lava that erupts from volcanoes is partly magma. Deep underground, the rocks and water absorb the heat from this magma. The temperature of the rocks and water get hotter and hotter as you go deeper underground. People around the world use geothermal energy to heat their homes and to produce electricity by digging deep wells and pumping the heated underground water or steam to the surface. Or, we can make use of the stable temperatures near the surface of the earth to heat and cool buildings.

Where is Geothermal Energy found?

Most geothermal reservoirs are deep underground with no visible clues showing aboveground. Geothermal energy can sometimes find its way to the surface in the form of: volcanoes and fumaroles (holes where volcanic gases are released) hot spring sand geysers. The most active geothermal resources are usually found along major plate boundaries where earthquakes and volcanoes are concentrated. Most of the geothermal activity in the world occurs in an area called the Ring of Fire. This area rims the Pacific Ocean. When magma comes close to the surface it heats ground water found trapped in porous rock or water running along fractured rock surfaces and faults. Such hydrothermal resources have two common ingredients: water (hydro) and heat (thermal). Naturally occurring large areas of hydrothermal resources are called geothermal reservoirs. Geologists use different methods to look for geothermal reservoirs. Drilling a well and testing the temperature deep underground is the only way to be sure a geothermal reservoir really exists. Most of the geothermal reservoirs in the United States are located in the western states, Alaska, and Hawaii. California is the state that generates the most electricity from geothermal energy. The Geysers dry steam reservoir in northern California is the largest known dry steam field in the world. The field has been producing electricity since 1960.

Uses of Geothermal Energy: Some applications of geothermal energy use the earth's temperatures near the surface, while others require drilling miles into the earth. The three main uses of geothermal energy are:

1) Direct Use and District Heating Systems which use hot water from springs or reservoirs near the surface.
2) Electricity generation in a power plant requires water or steam at very high temperature (300 to 700 degrees Fahrenheit). Geothermal power plants are generally built where geothermal reservoirs are located within a mile or two of the surfaces.
3) Geothermal heat pumps use stable ground or water temperatures near the earth's surface to control building temperatures above ground.

TYPES OF WELLS

Drilled wells

- It is constructed by either cable tool (percussion) or rotary-drilling machines. Drilled wells that penetrate unconsolidated material require installation of casing and a screen to prevent inflow of sediment and collapse.
- They can be drilled more than 1,000 feet deep. The space around the casing must be sealed with grouting material of either neat cement or bentonite clay to prevent contamination by water draining from the surface downward around the outside of the casing.

DRIVEN WELLS

- Driven wells are constructed by driving a small-diameter pipe into shallow water-bearing sand or gravel. Usually a screened well point is attached to the bottom of the casing before driving.
- These wells are relatively simple and economical to construct, but they can tap only shallow water and are easily contaminated from nearby surface sources because they are not sealed with grouting material. Hand-driven wells usually are only around 30 feet deep; machine-driven wells can be 50 feet deep or more.

DUG WELLS

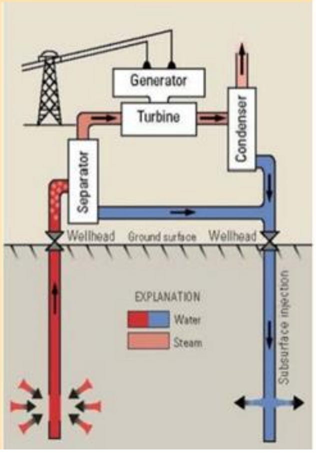
- Historically, dug wells were excavated by hand shovel to below the water table until incoming water exceeded the digger's bailing rate. The well was lined with stones, bricks, tile, or other material to prevent collapse, and was covered with a cap of wood, stone, or concrete tile.
- Because of the type of construction, bored wells can go deeper beneath the water table than can hand-dug wells. Dug and bored wells have a large diameter and expose a large area to the aquifer. These wells are able to obtain water from less-permeable materials such as very fine sand, silt, or clay.
- Disadvantages of this type of well are that they are shallow and lack continuous casing and grouting, making them subject to contamination

METHODS OF HARNESSING THE ENERGY

- Flashed steam plant
- Dry steam plant
- Binary power plant
- Hybrid power plant

Flashed steam plant

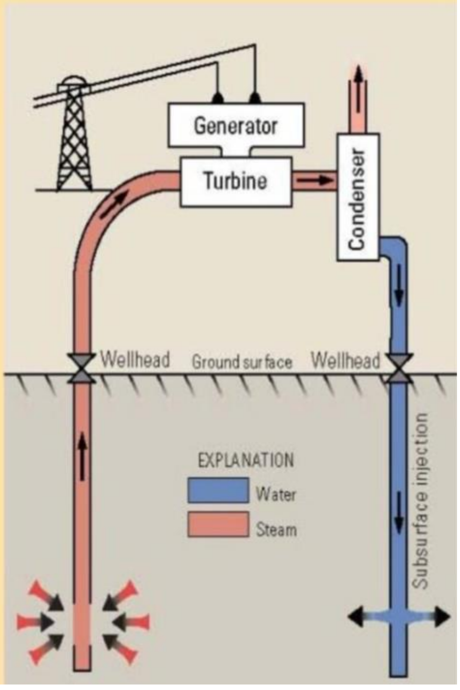
- Hot water at high pressure when released from deep reservoir forms high pressure steam (flashed steam).
- This steam drives turbines.
- This is most common type of plant operating today.



Flashed steam plant

Dry steam plant

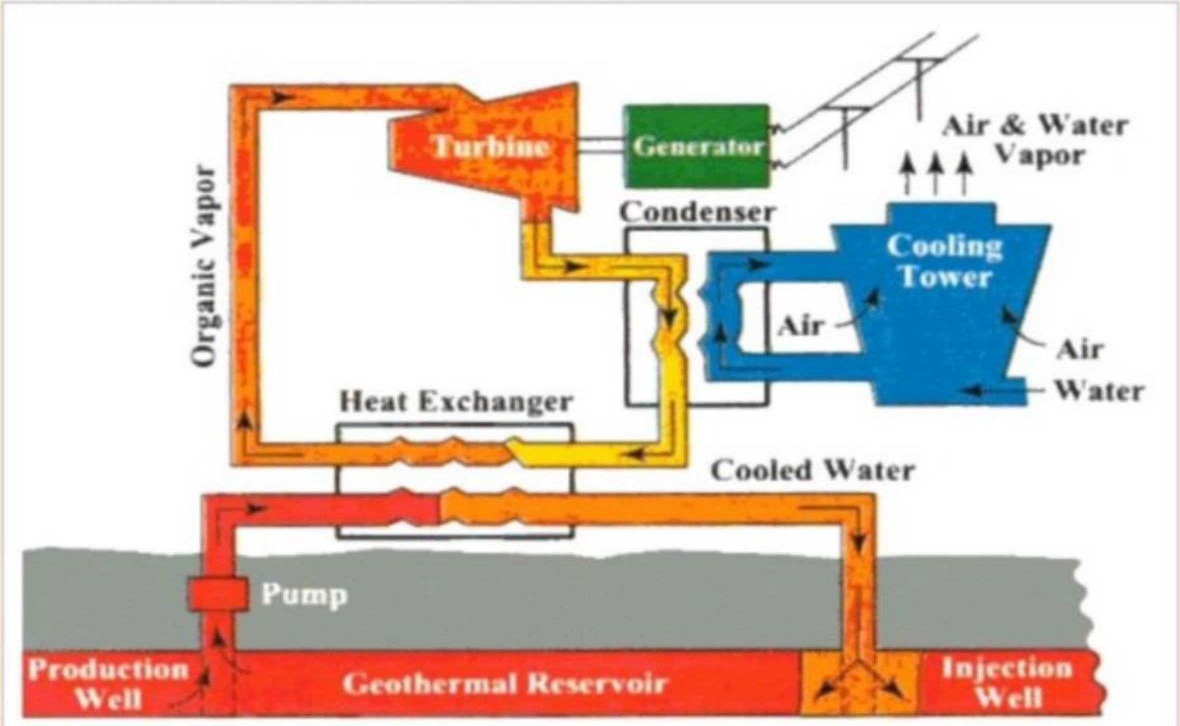
- Usually geysers are the main source of dry steam.
- Reservoirs which produce steam with small quantity of water use this type of plant.
- A rock catcher is used to protect turbine from rocks coming along with steam.



Binary power plant

- In this the geothermal water is passed through a heat exchanger where its heat is transferred to a secondary liquid.
- Liquids having lower boiling point are used as secondary liquid such as isobutene, isopentane or ammonia–water mixture.
- The vapour of secondary liquid are used to rotate turbines.
- The binary system is useful in geothermal reservoirs which are relatively low in temperature.
- Heat loss is minimum as system is completely closed.

Schematic of binary cycle geothermal power plant



Hybrid power plant

- It uses both boiling water as well as steam.
- Steam is directly is used as used in flashed steam plant.
- While energy of hot water is used through secondary liquid as used in Binary system.

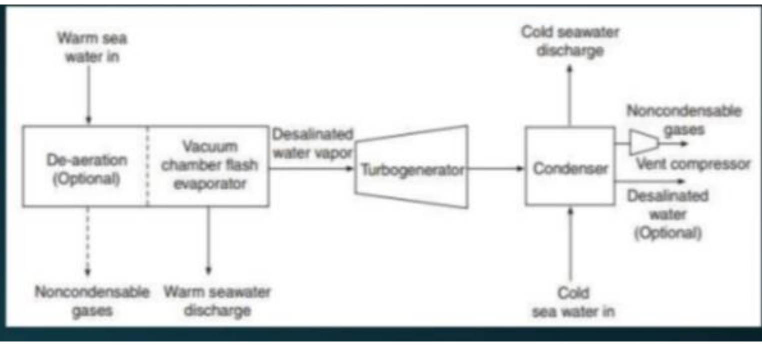
OCEAN ENERGY

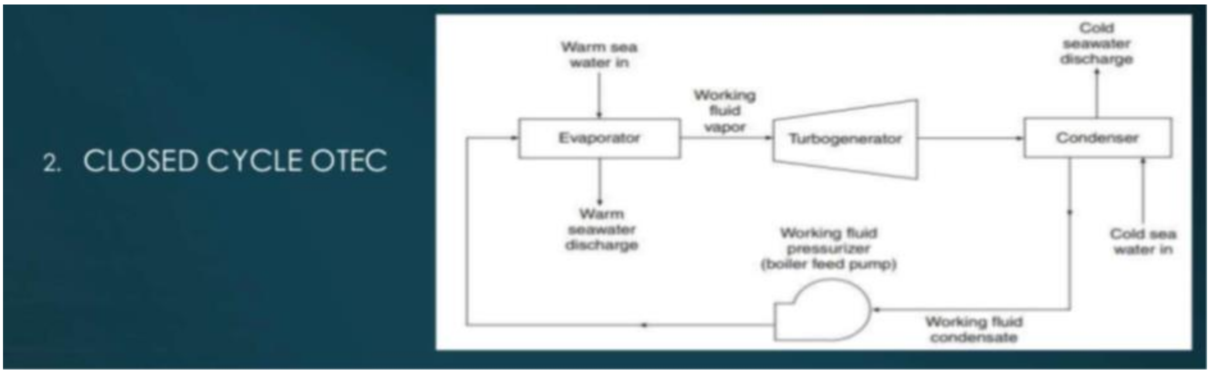
OCEAN THERMAL ENERGY CONVERSION (OTEC)

- Ocean Thermal Energy Conversion (OTEC) is a process that can produce electricity by using the temperature difference between deep cold ocean water and warm tropical surface waters. OTEC plants pump large quantities of deep cold seawater and surface seawater to run a power cycle and produce electricity. OTEC is firm power (24/7), a clean energy source, environmentally sustainable and capable of providing massive levels of energy.
- Recently, higher electricity costs, increased concerns for global warming, and a political commitment to energy security have made initial OTEC commercialization economically attractive in tropical island communities where a high percentage of electricity production is oil based. Even within the US, this island market is very large; globally it is many times larger. As OTEC technology matures, it should become economically attractive in the southeast US.

TYPES

1. OPEN CYCLE OTEC





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

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

Benefits of OTEC:

- The distinctive feature of OTEC is the potential to provide baseload electricity, which means day and night (24/7) and year-round. This is a big advantage for for instance tropical islands that typically has a small electricity network, not capable of handling a lot of intermittent power.
- Next to producing electricity, OTEC also offers the possibility of co-generating other synergistic products, like fresh water, nutrients for enhanced fish farming and seawater cooled greenhouses enabling food production in arid regions. Last but not least, the cold water can be used in building air-conditioning systems. Energy savings of up to 90% can be realized.
- The vast baseload OTEC resource could help many tropical and subtropical (remote) regions to become more energy self-sufficient

PRINCIPLES OF OTEC

- Ocean Thermal Energy Conversion (OTEC) is a marine renewable energy technology that harnesses the solar energy absorbed by the oceans to generate electric power. The sun's heat warms the surface water a lot more than the deep ocean water, which creates the ocean's naturally available temperature gradient, or thermal energy.
- OTEC uses the ocean's warm surface water with a temperature of around 25°C (77°F) to vaporize a working fluid, which has a low-boiling point, such as ammonia. The vapor expands and spins a turbine coupled to a generator to produce electricity. The vapor is then cooled by seawater that has been pumped from the deeper ocean layer, where the temperature is about 5°C (41°F). That condenses the working fluid back into a liquid, so it can be reused. This is a continuous electricity generating cycle.

UTILIZATION OF OTEC

- **Fresh Water**: The first by-product is fresh water. A small hybrid 1 MW OTEC is capable of producing some 4,500 cubic meters of fresh water per day, enough to supply a population of 20,000 with fresh water. OTEC-produced fresh water compares very favourably with standard desalination plants, in terms of both quality and production costs.
- **Food:** A further by-product is nutrient rich cold water from the deep ocean. The cold "waste" water from the OTEC is utilised in two ways. Primarily the cold water is discharged into large contained ponds, near shore or on land, where the water can be used for multi-species mariculture producing harvest yields which far surpass naturally occurring cold water upwelling zones, just like agriculture on land.
- **Cooling:** The cold water is also available as chilled water for cooling greenhouses, such as the Seawater Greenhouse or for cold bed

SETTING OF OTEC PLANTS

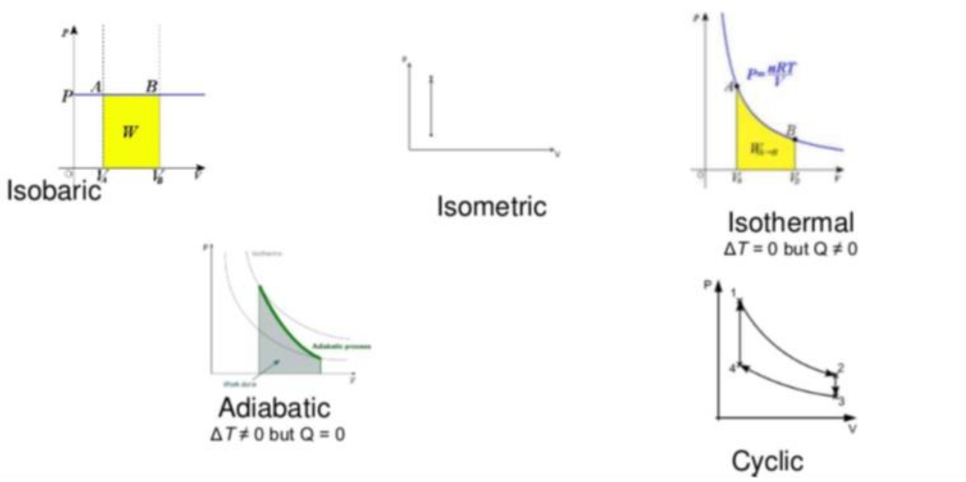
Requirements:

- Feasibility of technology and operational necessities
- Status of the technology and its future market potential
- Contribution of the technology to protection of the environment
- Climate
- Financial requirements and costs
- Clean Development Mechanism market status

THERMODYNAMIC CYCLES

- A thermodynamic cycle is a series of thermodynamic processes which returns a system to its initial state.
- Properties depend only on the thermodynamic state and thus do not change over a cycle.
- Variables such as heat and work are not zero over a cycle, but rather depend on the process. The first law of thermodynamics dictates that the net heat input is equal to the net work output over any cycle.
- The repeating nature of the process path allows for continuous operation, making the cycle an important concept in thermodynamics.

DIFFERENT PROCESSES



TIDAL ENERGY

- ❖ Tidal power, also called **TIDAL ENERGY**, is a form of **HYDROPOWER** which converts the energy of tides into the useful form of power, mainly in electricity.
- ❖ Tides are the waves caused due to gravitational pull of the moon and sun.
- ❖ Ocean tides are the periodic rise and fall of ocean water level occurs twice in each lunar day.

- ❖ Time interval between a consecutive low tide and high tide is 6.207 hrs.
- ❖ Tidal range is the difference between the consecutive high tide and low tide.
- ❖ During high tide, the water flow into the dam and during low tide water flow out which result in moving the turbine.
- ❖ Although not yet widely used, tidal power has potential for future electricity generation. Tides are more predictable than wind energy and solar power.

Advantages of Tidal Energy

❖ It is an inexhaustible source of energy.
❖ Tidal energy is environment friendly energy and doesn't produce greenhouse gases.
❖ As 71% of Earth's surface is covered by water, there is scope to generate this energy on large scale.
❖ Efficiency of tidal power is far greater as compared to coal, solar or wind energy. Its efficiency is around 80%.
❖ Tidal Energy doesn't require any kind of fuel to run.
❖ The life of tidal energy power plant is very long.

Disadvantages of Tidal Energy

❖ Cost of construction of tidal power plant is high.
❖ There are very few ideal locations for construction of plant and they too are localized to coastal regions only.
❖ Intensity of sea waves is unpredictable and there can be damage to power generation units.
❖ Influences aquatic life adversely and can disrupt migration of fish.
❖ The actual generation is for a short period of time. The tides only happen twice a day so electricity can be produced only for that time.
❖ Usually the places where tidal energy is produced are far away from the places where it is consumed. This transmission is expensive and difficult.

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UNIT – V

DIRECT ENERGY CONVERSION (DEC)

INTRODUCTION

- Transformation of one type of energy (such as sunlight) to another energy (such as electricity) without passing through an intermediate stage (such as steam to spin generator turbines).
- The fuel cell, another electrochemical producer of electricity, was developed by William Robert Grove.
- Thermoelectric generators are devices that covert heat directly into electricity.
- In a solar cell, radiant energy drives electrons across a potential difference at a semiconductor junction in which the concentrations of impurities are different on the two sides of the junction.

Types of DEC:

1) Thermo electric power generation.
2) Thermo ionic power generation.
3) Magneto hydro dynamic systems.
4) Photovoltaic power systems.
5) Fuel cells.
6) Thermo nuclear fusion power generation.

These are explained in the below sections.

NEED FOR DEC

In direct energy conversion system energy source directly converted into electricity without and working fluid or steam. Direct conversion systems have no moving parts.

1) No conversion of energy into mechanical and to electricity.
2) Less loss in conversion process.
3) More efficient process.
4) Cost also reduced but technology required to improve in this way.

CARNOT CYCLE

A Carnot gas cycle operating in a given temperature range is shown in the T-s diagramming Fig. 4.1(a). One way to carry out the processes of this cycle is through the use of steady-state, steady flow devices as shown in Fig. 4.1(b). The isentropic expansion process 2-3 and the isentropic compression process 4-1 can be simulated quite well by a well-designed turbine and compressor respectively, but the isothermal expansion process 1-2 and the isothermal compression process 3-4 are most difficult to achieve. Because of these difficulties, a steady-flow Carnot gas cycle is not practical. The Carnot gas cycle could also be achieved in a cylinder-piston apparatus (reciprocating engine) as shown in Fig. 4.2(b). The Carnot cycle on the p-v diagram is as shown in Fig. 4.2(a), in which processes 1-2 and 3-4 are isothermal while processes 2-3and 4-1 are isentropic. We know that the Carnot cycle efficiency is given by the expression.

$$\eta_{th} = 1 - \frac{T_L}{T_H} = 1 - \frac{T_4}{T_1} = 1 - \frac{T_3}{T_2}$$

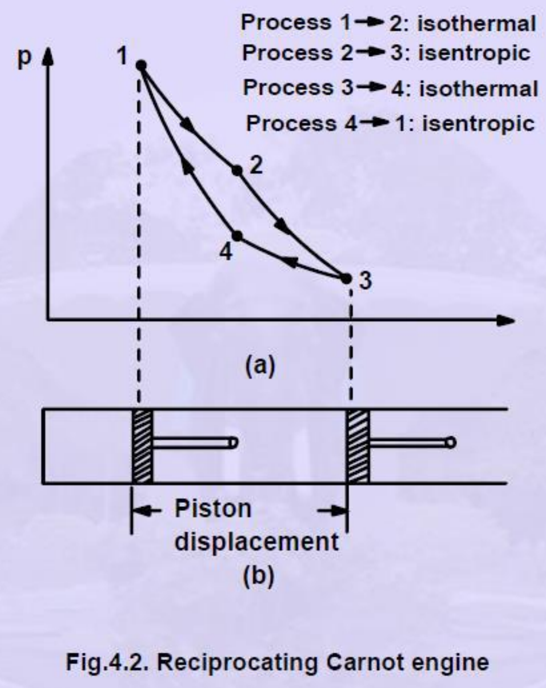


Fig.4.2. Reciprocating Carnot engine

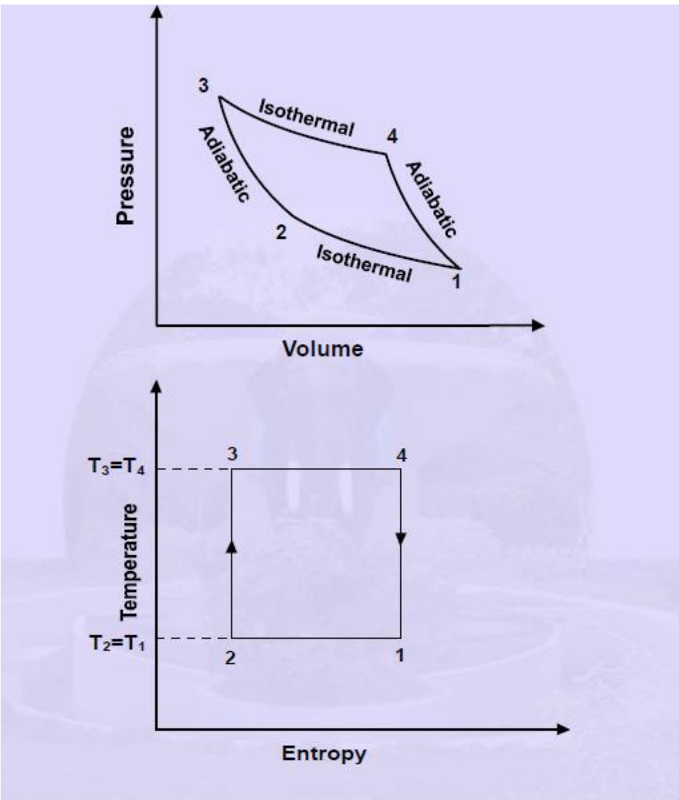


Fig.4.3. Carnot cycle on p-v and T-s diagrams

LIMITATIONS OF CARNOT CYCLE

1) Isothermal process is possible if it is very slow and
2) Isentropic process is possible if it very fast.
3) This alternate combination of very fast, very slow, very fast and very slow is not possible to achieve in actual practice and these are thus the limitations of this cycle.

THERMOELECTRIC GENERATORS (TEG) [OR] SEE BECK GENERATOR

A thermoelectric generator (TEG), also called a See beck generator, is a solid state device that converts heat flux (temperature differences) directly into electrical energy through a phenomenon called the See beck effect (a form of thermoelectric effect). Thermoelectric generators function like heat engines, but are less bulky and have no moving parts. However, TEGs are typically more expensive and less efficient.

Thermoelectric generators could be used in power plants in order to convert waste heat into additional electrical power and in automobiles as automotive thermoelectric generators (ATGs) to increase fuel efficiency. Another application is radioisotope thermoelectric generators which are used in space probes, which has the same mechanism but use radioisotopes to generate the required heat difference.

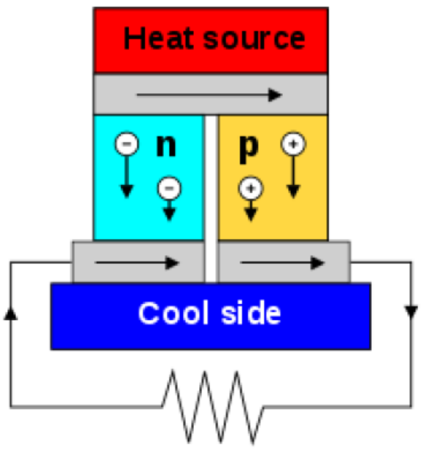
Thermoelectric power generators consist of three major components: thermoelectric materials, thermoelectric modules and thermoelectric systems that interface with the heat source.

Thermoelectric materials:

Thermoelectric materials generate power directly from heat by converting temperature differences into electric voltage. These materials must have both high electrical conductivity (σ) and low thermal conductivity (κ) to be good thermoelectric materials. Having low thermal conductivity ensures that when one side is made hot, the other side stays cold, which helps to generate a large voltage while in a temperature gradient. The measure of the magnitude of electrons flow in response to a temperature difference across that material is given by the See beck coefficient (S). The efficiency of a given material to produce a thermoelectric power is governed by its "figure of merit" $zT = S^2\sigma T/\kappa$.

For many years, the main three semiconductors known to have both low thermal conductivity and high power factor were bismuth telluride (Bi_2Te_3), lead telluride (PbTe), and silicon germanium (SiGe). These materials have very rare elements which make them very expensive compounds.

Today, the thermal conductivity of semiconductors can be lowered without affecting their high electrical properties using nanotechnology. This can be achieved by creating nanoscale features such as particles, wires or interfaces in bulk semiconductor materials. However, the manufacturing processes of nano-materials is still challenging.



A thermoelectric circuit composed of materials of different Seebeck coefficient (p-doped and n-doped semiconductors), configured as a thermoelectric generator.

Thermoelectric module: A thermoelectric module is a circuit containing thermoelectric materials which generates electricity from heat directly. A thermoelectric module consists of two dissimilar thermoelectric materials joined at their ends: an n-type (negatively charged); and a p-type (positively charged) semiconductors. A direct electric current will flow in the circuit when there is a temperature difference between the two materials. Generally, the current magnitude is directly proportional to the temperature difference.

In application, thermoelectric modules in power generation work in very tough mechanical and thermal conditions. Because they operate in very high temperature gradient, the modules are subject to large thermally induced stresses and strains for long periods of time. They also are subject to mechanical fatigue caused by large number of thermal cycles.

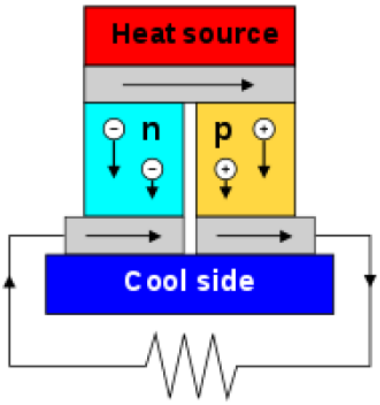
Thus, the junctions and materials must be selected so that they survive these tough mechanical and thermal conditions. Also, the module must be designed such that the two thermoelectric materials are thermally in parallel, but electrically in series. The efficiency of a thermoelectric module is greatly affected by the geometry of its design.

Thermoelectric system: Using thermoelectric modules, a thermoelectric system generates power by taking in heat from a source such as a hot exhaust flue. In order to do that, the system needs a large temperature gradient, which is not easy in real-world applications. The cold side must be cooled by air or water. Heat exchangers are used on both sides of the modules to supply this heating and cooling.

There are many challenges in designing a reliable TEG system that operates at high temperatures. Achieving high efficiency in the system requires extensive engineering design in order to balance between the heat flow through the modules and maximizing the temperature gradient across them. To do this, designing heat exchanger technologies in the system is one of the most important aspects of TEG engineering. In addition, the system requires to minimize the thermal losses due to the interfaces between materials at several places. Another challenging constraint is avoiding large pressure drops between the heating and cooling sources.

After the DC power from the TE modules passes through an inverter, the TEG produces AC power, which in turn, requires an integrated power electronics system to deliver it to the customer.

SEEBECK EFFECT



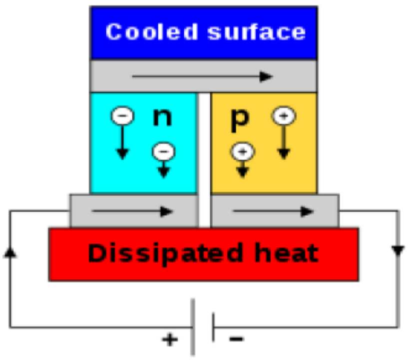
A thermoelectric circuit composed of materials of different Seebeck coefficients (p-doped and n-doped semiconductors), configured as a thermoelectric generator. If the load resistor at the bottom is replaced with a voltmeter, the circuit then functions as a temperature-sensing thermocouple.

The Seebeck effect is the conversion of heat directly into electricity at the junction of different types of wire. It is named after the Baltic German physicist Thomas Johann Seebeck, who in 1821 discovered that a compass needle would be deflected by a closed loop formed by two different metals joined in two places, with a temperature difference between the joints. This was because the electron energy levels in each metal shifted differently and a potential difference between the junctions created an electrical current and therefore a magnetic field around the wires. Seebeck did not recognize that there was an electric current involved, so he called the phenomenon "thermomagnetic effect". Danish physicist Hans Christian Orsted rectified the oversight and coined the term "thermoelectricity".

The Seebeck effect is a classic example of an electromotive force (emf) and leads to measurable currents or voltages in the same way as any other emf. Electromotive forces modify Ohm's law by generating currents even in the absence of voltage differences (or vice versa); the local current density is given by where is the local voltage, and is the local conductivity. In general, the See beck effect is described locally by the creation of an electromotive field. where is the See beck coefficient (also known as thermo power), a property of the local material, and is the temperature gradient The See beck coefficients generally vary as function of temperature and depend strongly on the composition of the conductor. For ordinary materials at room temperature, the See beck coefficient may range in value from −100 μV/K to +1,000 μV/K

If the system reaches a steady state, where, then the voltage gradient is given simply by the emf: This simple relationship, which does not depend on conductivity, is used in the thermocouple to measure a temperature difference; an absolute temperature may be found by performing the voltage measurement at a known reference temperature. A metal of unknown composition can be classified by its thermoelectric effect if a metallic probe of known composition is kept at a constant temperature and held in contact with the unknown sample that is locally heated to the probe temperature. It is used commercially to identify metal alloys. Thermocouples in series form a thermopile. Thermoelectric generators are used for creating power from heat differentials.

PELTIER EFFECT



The Seebeck circuit configured as a cooler. The Peltier effect is the presence of heating or cooling at an electrified junction of two different conductors and is named after French physicist Jean Charles Athanase Peltier, who discovered it in 1834. When a current is made to flow through a junction between two conductors, A and B, heat may be generated or removed at the junction. The Peltier heat generated at the junction per unit time is where and are the Peltier coefficients of conductors A and B, and is the electric current (from A to B). The total heat generated is not determined by the Peltier effect alone, as it may also be influenced by Joule heating and thermal-gradient effects.

The Peltier coefficients represent how much heat is carried per unit charge. Since charge current must be continuous across a junction, the associated heat flow will develop a discontinuity if and are different. The Peltier effect can be considered as the back-action counterpart to the Seebeck effect (analogous to the back-emf in magnetic induction): if a simple thermoelectric circuit is closed, then the Seebeck effect will drive a current, which in turn (by the Peltier effect) will always transfer heat from the hot to the cold junction. The close relationship between Peltier and Seebeck effects can be seen in the direct connection between their coefficients:

A typical Peltier heat pump involves multiple junctions in series, through which a current is driven. Some of the junctions lose heat due to the Peltier effect, while others gain heat. Thermoelectric heat pumps exploit this phenomenon, as do thermoelectric cooling devices found in refrigerators.

JOULE THOMPSON EFFECT

In different materials, the Seebeck coefficient is not constant in temperature, and so a spatial gradient in temperature can result in a gradient in the Seebeck coefficient. If a current is driven through this gradient, then a continuous version of the Peltier effect will occur. This Thomson effect was predicted and subsequently observed by Lord Kelvin (William Thomson) in 1851. It describes the heating or cooling of a current-carrying conductor with a temperature gradient.

If a current density is passed through a homogeneous conductor, the Thomson effect predicts a heat production rate per unit volume where is the temperature gradient, and is the Thomson coefficient. The Thomson coefficient is related to the Seebeck coefficient as (see below). This equation, however, neglects Joule heating and ordinary thermal conductivity.

This relation expresses a subtle and fundamental connection between the Peltier and Seebeck effects. It was not satisfactorily proven until the advent of the Onsager relations, and it is worth noting that this second Thomson relation is only guaranteed for a time-reversal symmetric material; if the material is placed in a magnetic field or is itself magnetically ordered (ferromagnetic, antiferromagnetic, etc.), then the second Thomson relation does not take the simple form shown here.

The Thomson coefficient is unique among the three main thermoelectric coefficients because it is the only one directly measurable for individual materials. The Peltier and Seebeck coefficients can only be easily determined for pairs of materials; hence, it is difficult to find values of absolute Seebeck or Peltier coefficients for an individual material.

If the Thomson coefficient of a material is measured over a wide temperature range, it can be integrated using the Thomson relations to determine the absolute values for the Peltier and Seebeck coefficients. This needs to be done only for one material, since the other values can be determined by measuring pairwise Seebeck coefficients in thermocouples containing the reference material and then adding back the absolute Seebeck coefficient of the reference material. For more details on absolute Seebeck coefficient determination, see Seebeck coefficient.

FIGURE OF MERIT

The potential of a material for thermoelectric applications is determined in large to a measure of the material’s dimensionless figure of merit

$$ZT = \frac{\alpha^2 \sigma T}{\kappa} = \frac{\alpha^2 T}{\rho \kappa}$$

where, α is the Seebeck coefficient, σ the electrical conductivity, ρ the electrical resistivity, and κ the total thermal conductivity ($\kappa = \kappa_L + \kappa_E$; the lattice and electronic contributions respectively.

MATERIALS SELECTION CRITERIA

The good thermoelectric materials should possess:

1) Large Seebeck coefficients.
2) High electrical conductivity.
3) Low thermal conductivity.

The examples for thermoelectric materials are:

1) Bismuth Telluride (Bi_2Te_3).
2) Lead Telluride (PbTe).
3) Silicon Germanium (SiGe).
4) Bismuth-Antimony (Bi-Sb).

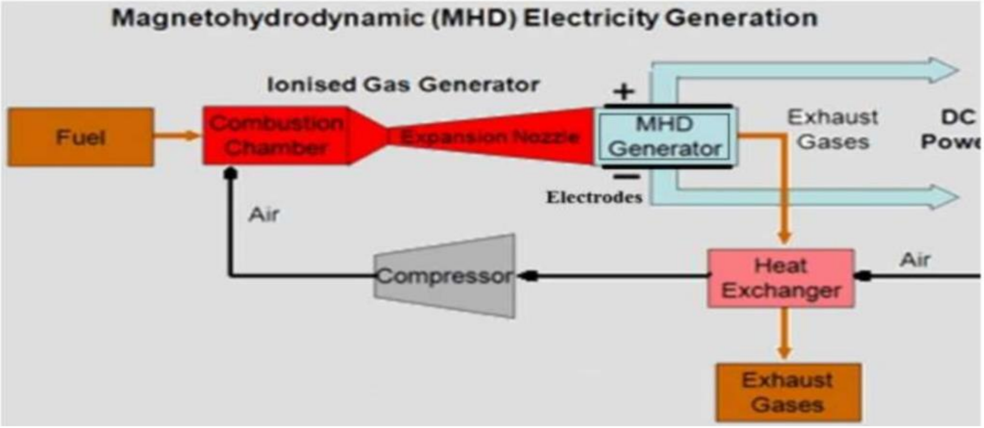
MAGNETOHYDRODYNAMIC (MHD) GENERATORS

A magneto hydrodynamic generator (MHD generator) is a magneto hydrodynamic device that transforms thermal energy and kinetic energy into electricity. MHD generators are different from traditional electric generators in that they operate at high temperatures without moving parts. MHD was developed because the hot exhaust gas of an MHD generator can heat the boilers of a steam power plant, increasing overall efficiency. MHD was developed as a topping cycle to increase the efficiency of electric generation, especially when burning coal or natural gas. MHD dynamos are the complement of MHD propulsions, which have been applied to pump liquid metals and in several experimental ship engines.

An MHD generator, like a conventional generator, relies on moving a conductor through a magnetic field to generate electric current. The MHD generator uses hot conductive plasma as the moving conductor. The mechanical dynamo, in contrast, uses the motion of mechanical devices to accomplish this. MHD generators are technically practical for fossil fuels, but have been overtaken by other, less expensive technologies, such as combined cycles in which a gas turbine's or molten carbonate fuel cell's exhaust heats steam to power a steam turbine.

Natural MHD dynamos are an active area of research in plasma physics and are of great interest to the geophysics and astrophysics communities, since the magnetic fields of the earth and sun are produced by these natural dynamos.

MHD GENERATOR



Types of MHD:

1) Open Cycle (OC) MHD.
2) Closed Cycle (CC) MHD.
   i. Seeded inert gas system.
   ii. Liquid metal system.

Temperature of CC MHD plants is very less compared to OC MHD plants. It's about 1400^{o}C.

1) Open cycle (OC) MHD:

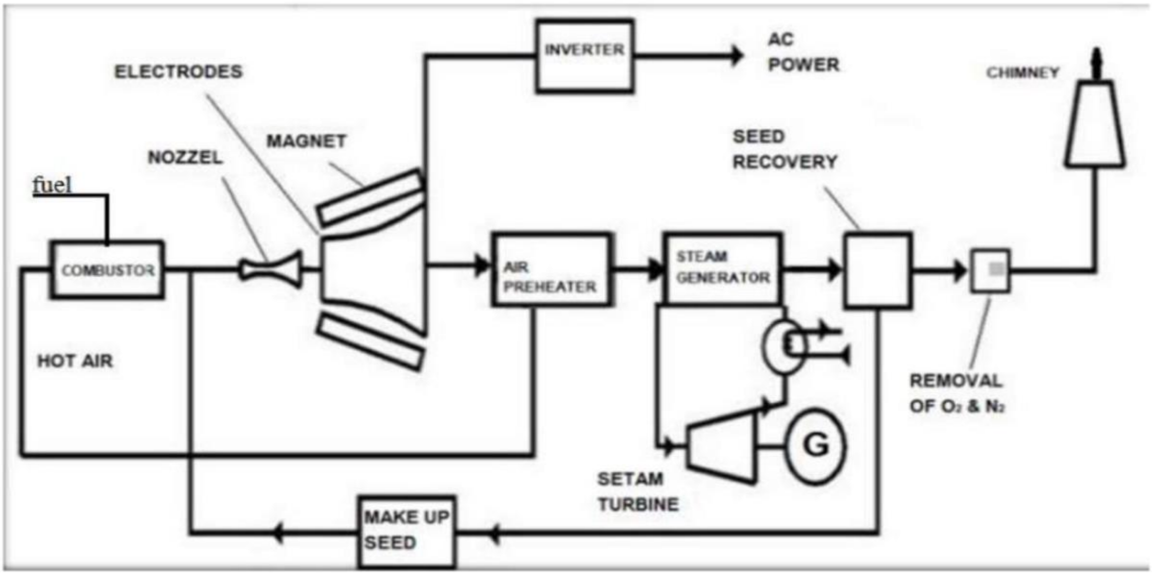
- The fuel used maybe oil through an oil tank or gasified coal through a coal gasification plant
- The fuel (coal, oil or natural gas) is burnt in the combustor or combustion chamber.
- The hot gases from combustor is then seeded with a small amount of ionized alkali metal (cesium or potassium) to increase the electrical conductivity of the gas.
- The seed material, generally potassium carbonate is injected into the combustion chamber, the potassium is then ionized by the hot combustion gases at temperature of roughly 2300' c to 2700'c.

- To attain such high temperatures, the compressed air is used to burn the coal in the combustion chamber, must be adequate to at least 1100^0c.

- A lower preheat temperature would be adequate if the air is enriched in oxygen. An alternative is used to compress oxygen alone for combustion of fuel, little or no preheating is then required. The additional cost of oxygen might be balanced by saving on the preheater.

- The hot pressurized working fluid leaving the combustor flows through a convergent divergent nozzle. In passing through the nozzle, the random motion energy of the molecules in the hot gas is largely converted into directed, mass of energy. Thus , the gas emerges from the nozzle and enters the MHD generator unit at a high velocity.

OPEN CYCLE



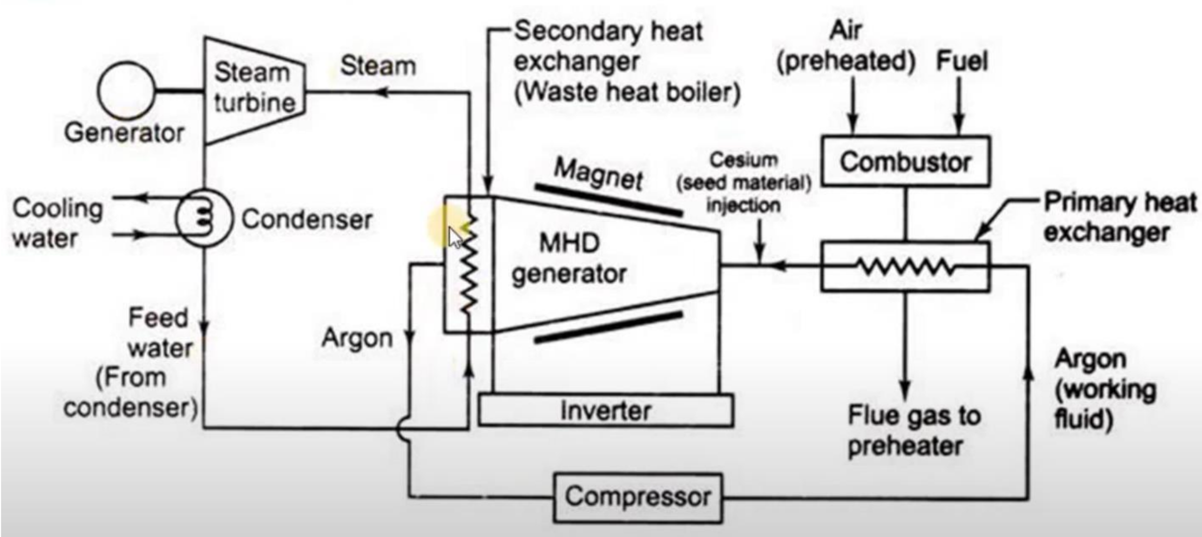
2) Closed Cycle MHD (Seeded Inert gas system):

- In a closed cycle system the carrier gas operates in the form of Brayton cycle. In a closed cycle system the gas is compressed and heat is supplied by the source, at essentially constant pressure, the compressed gas then expands in the MHD generator, and its pressure and temperature fall. After leaving this generator heat is removed from the gas by a cooler, this is the heat rejection stage of the cycle. Finally the gas is recompressed and returned for reheating.

- The complete system has three distinct but interlocking loops. On the left is the external heating loop. Coal is gasified and the gas is burnt in the combustor to provide heat. In the primary heat exchanger, this heat is transferred to a carrier gas argon or helium of the MHD cycle. The combustion products after passing through the air preheater and purifier are discharged to atmosphere.

- Because the combustion system is separate from the working fluid, so also are the ash and flue gases. Hence the problem of extracting the seed material from fly ash does not arise. The flue gases are used to preheat the incoming combustion air and then treated for fly ash and sulfur dioxide removal, if necessary prior to discharge through a stack to the atmosphere.

- The loop in the center is the MHD loop. The hot argon gas is seeded with cesium and resulting working fluid is passed through the MHD generator at high speed. The dc power out of MHD generator is converted in ac by the inverter and is then fed to the grid.



3) Closed Cycle MHD (Liquid metal system):

- When a liquid metal provides the electrical conductivity, it is called a liquid metal MHD system.

- An inert gas is a convenient carrier

- The carrier gas is pressurized and heated by passage through a heat exchanger within combustion chamber. The hot gas is then incorporated into the liquid metal usually hot sodium to form the working fluid. The latter then consists of gas bubbles uniformly dispersed in an approximately equal volume of liquid sodium.

- The working fluid is introduced into the MHD generator through a nozzle in the usual ways. The carrier gas then provides the required high direct velocity of the electrical conductor.

- After passage through the generator, the liquid metal is separated from the carrier gas. Part of the heat exchanger to produce steam for operating a turbine generator. Finally the carrier gas is cooled, compressed and returned to the combustion chamber for reheating and mixing with the recovered liquid metal. The working fluid temperature is usually around 800'c as the boiling point of sodium even under moderate pressure is below 900'c.

- At lower operating temp, the other MHD conversion systems may be advantageous from the material standpoint, but the maximum thermal efficiency is lower. A possible compromise might be to use liquid lithium, with a boiling point near 1300'c as the electrical conductor lithium is much more expensive than sodium, but losses in a closed system are less.

PRINCIPLES

The Lorentz Force Law describes the effects of a charged particle moving in a constant magnetic field. The simplest form of this law is given by the vector equation.

$$\mathbf{F} = Q \cdot (\mathbf{v} \times \mathbf{B})$$

Where, F is the force acting on the particle; Q is the charge of the particle; v is the velocity of the particle, and B is the magnetic field.

The vector F is perpendicular to both v and B according to the right hand rule.

IONIZATION OF GAS

Various methods for ionizing the gas are available, all of which depend on imparting sufficient energy to the gas. The ionization can be produced by thermal or nuclear means. Materials such as potassium carbonate or cesium are often added in small amounts, typically about 1% of the total mass flow to increase the ionization & improve the conductivity, particularity combustion of gas plasma.

HALL EFFECT

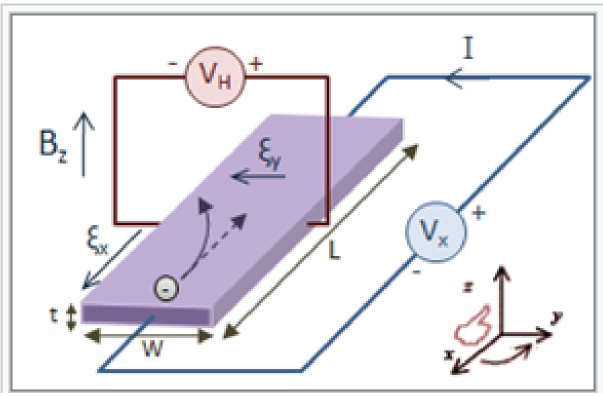
Hall effect is the production of a voltage difference (the Hall voltage) across an electrical conductor, transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current. It was discovered by Edwin Hall in 1879. For clarity, the original effect is sometimes called the ordinary Hall effect to distinguish it from other "Hall effects" which have different physical mechanisms.

The Hall coefficient is defined as the ratio of the induced electric field to the product of the current density and the applied magnetic field. It is a characteristic of the material from which the conductor is made, since its value depends on the type, number, and properties of the charge carriers that constitute the current.

The hall voltage represented as VH is given by:

$$V_H = IB/qnd$$

Here, I is the current flowing through the sensor; B is the magnetic Field Strength; q is the charge; n is the number of charge carriers per unit volume; d is the thickness of the sensor.



Applications of Hall Effect: Hall effect principle is employed in the following cases:

1) Magnetic field sensing equipment.
2) For the measurement of direct current, Hall effect Tong Tester is used.
3) It is used in phase angle measurement.
4) Proximity detectors.
5) Hall effect Sensors and Probes.
6) Linear or Angular displacement transducers.
7) For detecting wheel speed and accordingly assist the anti lock braking system.

FUEL CELLS

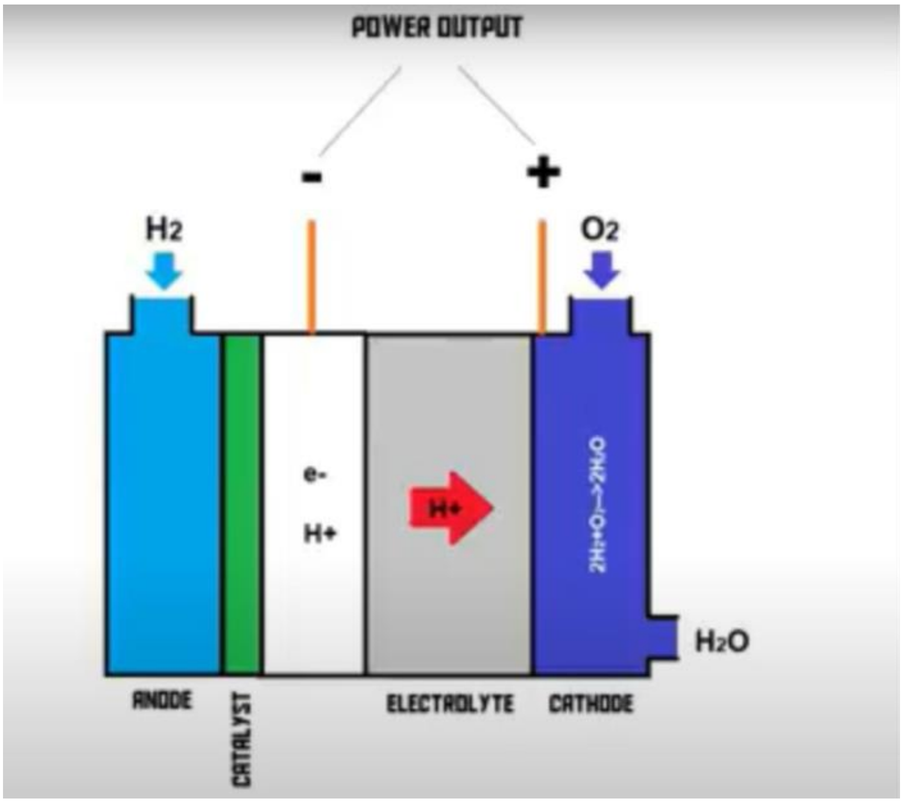
A fuel cell is an electrochemical cell that converts the chemical energy from a fuel into electricity through an electrochemical reaction of hydrogen fuel with oxygen or another oxidizing agent. Fuel cells are different from batteries in requiring a continuous source of fuel and oxygen (usually from air) to sustain the chemical reaction, whereas in a battery the chemical energy comes from chemicals already present in the battery. Fuel cells can produce electricity continuously for as long as fuel and oxygen are supplied.

The first fuel cells were invented in 1838. The first commercial use of fuel cells came more than a century later in NASA space programs to generate power for satellites and space capsules. Since then, fuel cells have been used in many other applications. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. They are also used to power fuel cell vehicles, including forklifts, automobiles, buses, boats, motorcycles and submarines.

There are many types of fuel cells, but they all consist of an anode, a cathode, and an electrolyte that allows positively charged hydrogen ions (protons) to move between the two sides of the fuel cell. At the anode a catalyst causes the fuel to undergo oxidation reactions that generate protons (positively charged hydrogen ions) and electrons. The protons flow from the anode to the cathode through the electrolyte after the reaction. At the same time, electrons are drawn from the anode to the cathode through an external circuit, producing direct current electricity. At the cathode, another catalyst causes hydrogen ions, electrons, and oxygen to react, forming water.

Fuel cells are classified by the type of electrolyte they use and by the difference in start up time ranging from 1 second for proton exchange membrane fuel cells (PEM fuel cells, or PEMFC) to 10 minutes for solid oxide fuel cells (SOFC). Individual fuel cells produce relatively small electrical potentials, about 0.7 volts, so cells are "stacked", or placed in series, to create sufficient voltage to meet an application's requirements. In addition to electricity, fuel cells produce water, heat and, depending on the fuel source, very small amounts of nitrogen dioxide and other emissions. The energy efficiency of a fuel cell is generally between 40–60%; however, if waste heat is captured in a cogeneration scheme, efficiencies up to 85% can be obtained. A related technology is flow batteries, in which the fuel can be regenerated by recharging. The fuel cell market is growing, and in 2013 Pike Research estimated that the stationary fuel cell market will reach 50 GW by 2020.

Construction:



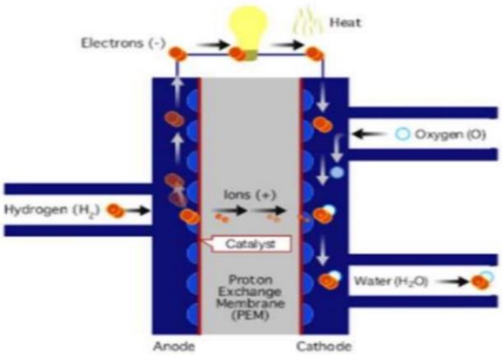
PARTS OF A FUEL CELL

- Anode
  - Negative post of the fuel cell.
  - Conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit.
  - Etched channels disperse hydrogen gas over the surface of catalyst.
- Cathode
  - Positive post of the fuel cell
  - Etched channels distribute oxygen to the surface of the catalyst.
  - Conducts electrons back from the external circuit to the catalyst
  - Recombine with the hydrogen ions and oxygen to form water.
- Electrolyte
  - Proton exchange membrane.
  - Specially treated material, only conducts positively charged ions.
  - Membrane blocks electrons.
- Catalyst
  - Special material that facilitates reaction of oxygen and hydrogen
  - Usually platinum powder very thinly coated onto carbon paper or cloth.
  - Rough & porous maximizes surface area exposed to hydrogen or oxygen
  - The platinum-coated side of the catalyst faces the PEM.

WORKING

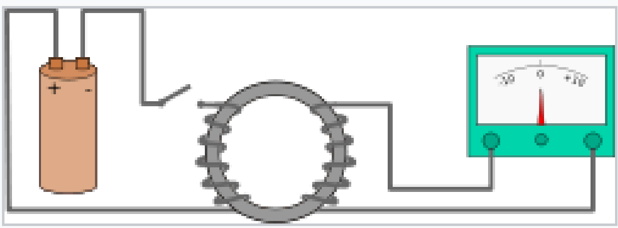
- A fuel cell generates electrical power by continuously converting the chemical energy of a fuel into electrical energy by way of an electrochemical reaction. The fuel cell itself has no moving parts, making it a quiet and reliable source of power. Fuel cells typically utilize hydrogen as the fuel, and oxygen (usually from air) as the oxidant in the electrochemical reaction. The reaction results in electricity, by-product water, and by-product heat.

- When hydrogen gas is introduced into the system, the catalyst surface of the membrane splits hydrogen gas molecules into protons and electrons. The protons pass through the membrane to react with oxygen in the air (forming water). The electrons, which cannot pass through the membrane, must travel around it, thus creating the source of DC electricity.

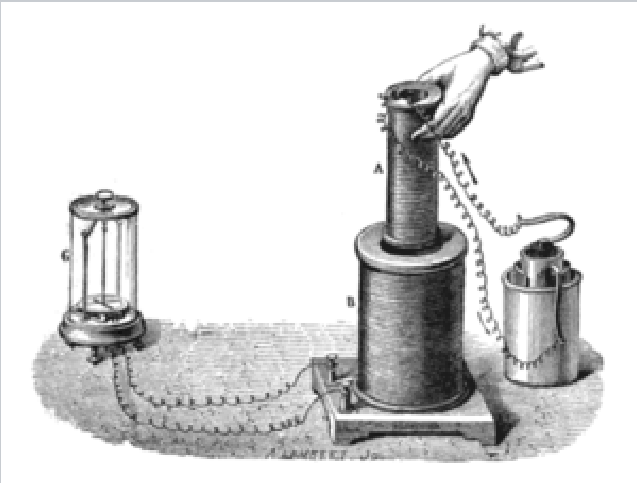


FARADAY'S LAWS

Faraday's law of induction is a basic law of electromagnetism predicting how a magnetic field will interact with an electric circuit to produce an electromotive force (EMF) a phenomenon called electromagnetic induction. It is the fundamental operating principle of transformers, inductors, and many types of electrical motors, generators and solenoids. The Maxwell–Faraday equation is a generalization of Faraday's law, and is listed as one of Maxwell's equations.



A diagram of Faraday's iron ring apparatus. The changing magnetic flux of the left coil induces a current in the right coil.[3]



Faraday's experiment showing induction between coils of wire: The liquid battery *(right)* provides a current which flows through the small coil *(A)*, creating a magnetic field. When the coils are stationary, no current is induced. But when the small coil is moved in or out of the large coil *(B)*, the magnetic flux through the large coil changes, inducing a current which is detected by the galvanometer *(G)*.[14]

Qualitative statement: The most widespread version of Faraday's law states: The induced electromotive force in any closed circuit is equal to the negative of the time rate of change of the magnetic flux enclosed by the circuit. This version of Faraday's law strictly holds only when the closed circuit is a loop of infinitely thin wire, and is invalid in other circumstances as discussed below. A different version, the Maxwell–Faraday equation (discussed below), is valid in all circumstances.

Faraday's law of induction makes use of the magnetic flux Φ_B through a hypothetical surface Σ whose boundary is a wire loop. Since the wire loop may be moving, we write $\Sigma(t)$ for the surface. The magnetic flux is defined by a surface integral:

$$\Phi_B = \iint_{\Sigma(t)} \mathbf{B}(\mathbf{r}, t) \cdot d\mathbf{A},$$

where dA is an element of surface area of the moving surface $\Sigma(t)$, B is the magnetic field (also called "magnetic flux density"), and $B \cdot dA$ is a vector dot product (the infinitesimal amount of magnetic flux through the infinitesimal area element dA). In more visual terms, the magnetic flux through the wire loop is proportional to the number of magnetic flux lines that pass through the loop.