Unit -1
Introduction to Energy Sources

World Energy Feature, Indian Energy Scenario, Conventional and non-conventional energy sources, Prospects of renewable energy sources.

Solar Energy Source: Introduction, Solar constant, radiation on Earth's surface, Radiation geometry, Radiation measurements, Radiation data, Average solar radiation, radiation on tilted surfaces

World Energy Feature

The world around us has changed significantly over the past 20 years. The following principal drivers have been shaping energy supply and use

(i) Sharp increase in the price of oil since 2001 after 15 years of moderate oil prices
(ii) Financial crisis and slow economic growth with drastic reduction in energy consumption in large economies
(iii) Shale gas in North America u Fukushima Daiichi nuclear accident
(iv) The volatile political situation in the energy supplying countries in the Middle East and North Africa, "The Arab Spring"
(v) Lack of global agreement on climate change mitigation u collapse of CO2 prices in the European Emissions Trading System
(vi) Exponential growth in renewables, in particular in Europe due to generous subsidies for producers which can become a problem instead of an opportunity
(vii) Deployment of 'smart' technologies u energy efficiency potential still remaining untapped
(viii) Growing public concerns about new infrastructure projects, including energy projects and their impact on political decision-making process
(ix) The supply and use of energy have powerful economic, social and environmental impacts. Not all energy is supplied on a commercial basis.
(x) Fuels, such as fuel wood or traditional biomass are largely non-commercial.
(xi) Fuel wood is playing a leading role in the developing countries, where it is widely used for heating and cooking.
(xii) Universal access to commercial energy still remains a target for the future. In many countries, especially in Africa and Asia, the pace of electrification lags far behind the growing demand.
(xiii) It is imperative to address this major challenge without further delays, in particular taking into account the impact access to electricity has on peoples' lives and well-being, economic growth and social development, including the provision of basic social services, such as health and education.

(xiv) Establishment of energy infrastructure in the least developed countries will need a major effort on behalf of the global energy community. It will also require political, legal and institutional structures, which today do not exist. Rising energy demand, declining public investment and the evolving role of the multilateral financial institutions need increased efforts by governments to change their roles in order to create an enabling business environment to attract private investment, both domestic and international.

Indian Energy Scenario

India ranks sixth in the world in total energy consumption, whereas more than 70% of its primary energy needs are being met through imports, mainly in the form of crude oil and natural Gas. Coming to the power generation in the country, India has increased installed power capacity from 1362 MW to over 112,058 MW since independence and electrified more than 500,000 villages. This achievement is impressive but not sufficient. The electricity consumption per capita for India is just 566 KWh and is far below most other countries or regions in the world. Even though 85% of villages are considered electrified, around 57% of the rural households and 12% of urban households, i.e. 84 million households in the country, do not have access to electricity. Electricity consumption in India is expected to rise to around 2280 BkWh by 2021-22 and around 4500 BkWh by2031-32. Figure 2 shows the Human Development Index (HDI) which is calculated from the literacy rate, infant mortality rate and GDP plotted against per capita electricity consumption.

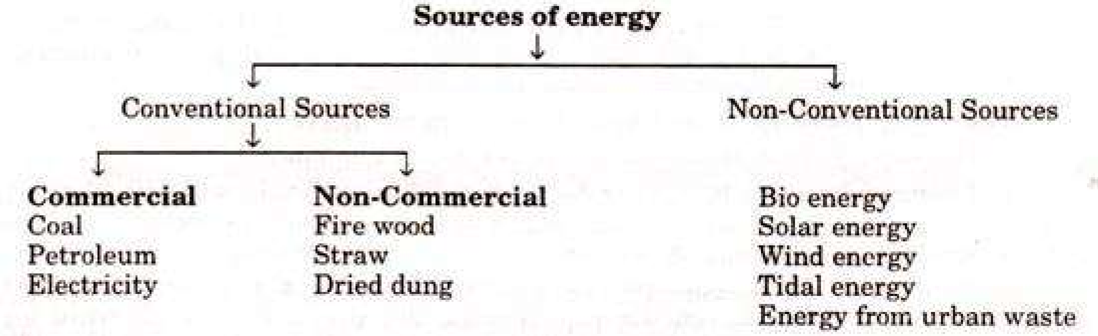
Conventional and Non-Conventional Sources of Energy

Energy is one of the most important component of economic infrastructure.
It is the basic input required to sustain economic growth. There is direct relation between the level of economic development and per capita energy consumption.

Simply speaking more developed a country, higher is the per capita consumption of energy and vice-versa. India's per capita consumption of energy is only one eighth of global average. This indicates that our country has low rate of per capita consumption of energy as compared to developed countries.

Two Main Sources of Energy:

The sources of energy are of following types:



1. Conventional Sources of Energy:

These sources of energy are also called non renewable sources. These sources of energy are in limited quantity except hydro-electric power.

These are further classified as commercial energy and non-commercial energy:

Commercial Energy Sources:

These are coal, petroleum and electricity. These are called commercial energy because they have a price and consumer has to pay the price to purchase them.

(a) Coal and Lignite:

Coal is the major source of energy. Coal deposits in India are 148790 million tonnes. Total lignite reserves found at Neyveli are 3300 million tonnes. In 1950-51, annual production of coal was 32 million tonnes. In 2005-06, annual production of coal was 343 million tonnes.

Lignite production was 20.44 million tonnes in 2005-06. According to an estimate, coal reserves in India would last about 130 years. India is now the fourth largest coal producing country in the world. Coal deposits are mainly found in Orissa, Bihar, Bengal and Madhya Pradesh. It provides employment to 7 lakh workers.

(b) Oil and Natural Gas:

In these days oil is considered as the most important source of energy in India and the world. It is widely used in automobiles, trains, planes and ships etc. In India it is found in upper Assam, Mumbai High and in Gujarat. The resources of oil are small in India.

In 1950-51, the total production of oil in India was 0.3 million tonnes. It increased to 32.4 million tonnes in 2000-01. Despite tremendous increase in oil production. India still imports 70% of has oil requirements from abroad. In 1951, there was only one oil refinery in Assam.

After independence 13 such refineries were set up in public sector and their refining capacity was 604 lakh tonnes. After implementation of economic reforms, private refineries are also engaged in oil refining. As per current rate of consumption, oil reserves in India may last about 20 to 25 years.

Natural gas has been the most important source of energy since last two decades. It can be produced in two ways:

(i) With petroleum products as associated gas.

(ii) Free gas obtained from gas fields in Assam, Gujarat and Andhra Pradesh.

It is used in fertilizer and petro-chemical plants and gas based thermal power plants. Total production of natural gas was 31.96 billion cubic metre in 2003-04.

(c) Electricity:

Electricity is the common and popular source of energy. It is used in commercial and domestic purposes. It is used for lighting, cooking, air conditioning and working of electrical appliances like T.V., fridge and washing machine.

In 2000-01 agriculture sector consumed 26.8%, industrial sector 34.6% and 24% of electricity was used for domestic purposes and 7% was used for commercial purpose. Railways consumed 2.6% and miscellaneous consumption was 5.6%.

There are three main sources of power generation:

1. Thermal Power
2. Hydro-electric power
3. Nuclear Power

1. Thermal Power:

It is generated in India at various power stations with the help of coal and oil. It has been a major source of electric power. In 2004-05, its share in total installed capacity was 70 percent.

2. Hydro electric Power:

It is produced by constructing dams over overflowing rivers. For example Bhakra Nangal Project, Damodor Valley Project and Hirakud Project etc. In 1950-51, installed capacity of hydro-electricity was 587.4 MW and in 2004-05, it was 19600 MW.

3. Nuclear Power:

India has also developed nuclear power. Nuclear Power plants use uranium as fuel. This fuel is cheaper than coal. India has nuclear power plants at Tarapur, Kota (Rajasthan) Kalapakam (Chennai) Naroura (UP). Its supply accounts for only 3 percent of the total installed capacity.

Non-Commercial energy Sources:

These sources include fuel wood, straw and dried dung. These are commonly used in rural India. According to an estimate, the total availability of fuel wood in India was only 50 million tonnes a year. It is less than 50% of the total requirements. In coming years, there would be shortage of fire wood.

Agricultural wastes like straw are used as fuel for cooking purposes. According to one estimate agricultural waste used for fuel might be 65 million tonnes. Animal dung when dried is also used for cooking purposes. Total animal dung production is 324 million tonnes out of which 73 million tonnes are used as fuel for cooking purposes. The straw and dung can be used as valuable organic manure for increasing fertility of soil and in turn productivity.

2. Non-Conventional Sources of Energy:

Besides conventional sources of energy there are non-conventional sources of energy. These are also called renewable sources of energy. Examples are Bio energy, solar energy, wind energy and tidal energy.

Govt. of India has established a separate department under the Ministry of Energy called as the Department of Non-conventional Energy Sources for effective exploitation of non-conventional energy.

The various sources are given below:

1. Solar Energy:

Energy produced through the sunlight is called solar energy. Under this programme, solar photovoltaic cells are exposed to sunlight and in the form of electricity is produced. Photovoltaic cells are those which convert sun light energy into electricity. In year 1999-2000, 975 villages were illuminated through solar energy. Under Solar Thermal Programme, solar energy is directly obtained. Sunlight is converted into thermal power. Solar energy is used for cooking, hot water and distillation of water etc.

2. Wind Energy:

This type of energy can be produced by harnessing wind power. It is used for operating water pumps for irrigation purposes. Approximately 2756 wind pumps were set up for this purpose. In seven states, wind power operated power houses were installed and their installed capacity was 1000 MW. India has second position in wind power energy generation.

3. Tidal Energy:

Energy produced by exploiting the tidal waves of the sea is called tidal energy. Due to the absence of cost effective technology, this source has not yet been tapped.

4. Bio Energy:

This type of energy is obtained from organic matter.

It is of two kinds:

(i) Bio Gas:

Bio Gas is obtained from Gobar Gas Plant by putting cow dung into the plant. Besides producing gas this plant converts gobar into manure. It can be used for cooking, lighting and generation of electricity. 26.5 lakh bio gas plants had been established by the year 2003-04. They produce more than 225 lakh tonnes of manure. About 1828 large community bio gas plants have been established in the country.

(ii) Bio Mass:

It is also of a source of producing energy through plants and trees. The purpose of bio mass programme is to encourage afforestation for energy. So that fuel for the generation of energy based on gas technique and fodder for the cattle could be obtained, 56 MW capacity for the generation of bio mass energy has been installed.

5. Energy from Urban Waste:

Urban waste poses a big problem for its disposal. Now it can be used for generation of power. In Timarpur (Delhi) a power Ration of 3.75 capacity has been set up to generate energy from the garbage.

The Solar Constant

The Sun is considered to produces a constant amount of energy. At the surface of the Sun the intensity of the solar radiation is about 6.33×10^{7} W/m^2 (note that this is a power, in watts, per unit area in meters). As the Sun's rays spread out into space the radiation becomes less intense and by the time the rays reach the edge of the Earth's atmosphere they are considered to be parallel.

Fig. 1 The Sun's rays incident on the Earth.

I_0 = irradiance on a plane perpendicular to the Sun's rays

The *solar constant* (I_{SC}) is the average radiation intensity falling on an imaginary surface, perpendicular to the Sun's rays and at the edge of the Earth's atmosphere (figure 2.1). The word 'constant' is a little misleading since, because of the Earth's elliptical orbit the intensity of the solar radiation falling on the Earth changes by about 7% between January 1st, when the Earth is nearest the Sun, and July 3rd, when the Earth is furthest from the Sun (figure 1.2). A yearly average value is thus taken and the solar constant equals 1367 W/m^2. Even this value is inaccurate since the output of the sun changes by about ±0.25% due to Sun spot cycles.

The solar radiation intensity falling on a surface is called *irradiance* or *insolation* and is measured in W/m^2 or kW/m^2. The solar constant can be used to calculate the irradiance incident on a surface perpendicular to the Sun's rays outside and the Earth's atmosphere on any day of the year (i.e. as the distance between the Sun and Earth changes thought the year):

$$I_0 = I_{SC}\left[1 + 0.034\cos\left(2\pi\ \frac{n}{265.25}\right)\right]$$

Where:

I_0 = extraterrestrial (outside the atmosphere) irradiance on a plane perpendicular to the Sun's rays (W/m^2),

I_{SC} = the solar constant (1367 W/m^2),

n = the day of the year such that for January the 1st n = 1.

Fig. 2 shows the variation in I_0 over the course of a year. Most solar power calculations use I_0 as a starting point because, for any given day of the year it is the maximum possible energy obtainable from the Sun at the edge of the Earth's atmosphere.

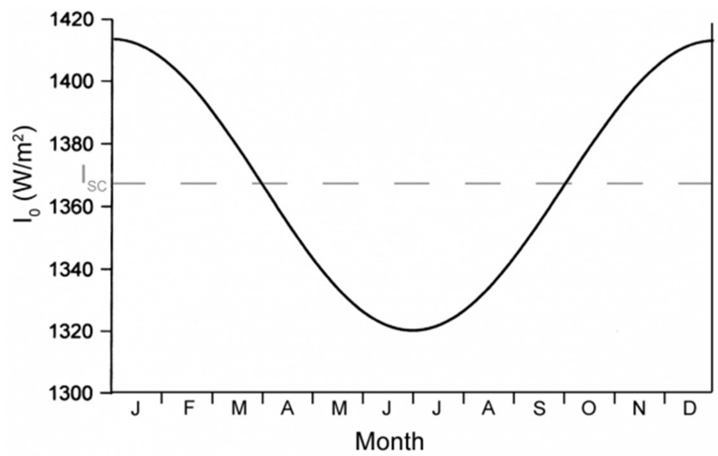


Fig. 2. The variation in Io over the course of a year.

The dashed line shows the value of the solar constant (Isc)

Solar Radiation on earth's surface

Solar radiation is becoming increasingly appreciated because of its influence of living matter and the feasibility of its application for useful purposes. It is a perpetual source of natural energy that, along with other forms of renewable energy, has a great potential for a wide variety of applications because it is abundant and accessible. The electromagnetic radiation emitted by the sun covers a very large range of wavelengths, from radio waves through the infrared, visible and ultraviolet to x-rays and gamma rays. However, 99 percent of the energy of solar radiation is contained in the wavelength band from 0.15 to 4µm, comprising the near ultraviolet, visible and near infrared regions of the solar spectrum, with a maximum at about 0.5µm. About 40 percent of the earth's surface on clear days is visible radiation within the spectral range .4 to .7µm, while 51 percent is infrared radiation in the spectral region .7 to 4µm.The total radiation emitted by the sun in unit time remains constant. The planet earth revolves around the sun in an elliptical orbit of very small eccentricity with the sun at one of the foci completing one revolution in one year. The axis of rotation of the earth is inclined at about 23.5 degrees with respect to the plane of orbital revolution and is directed always to a fixed point in space. As a consequence of this geometry of the sun and the earth, large seasonal variations occur in the amount of solar radiation received at different latitudes of the earth. The largest annual variations occur near the two poles and the smallest near the equator.

Of the entire quantity of radiant energy emitted by the sun's spherical surface, only a small fraction is actually intercepted by the planet earth. The amount of solar energy falling in unit time on unit area, held normal to the sun's rays outside the earth's atmosphere when the earth is the mean distance from the sun, is called the solar constant.

Solar radiation is the radiant energy emitted by the Sun in the form of electromagnetic waves. The sun emits vast amount of radiant energy. It is essential to drive directly or indirectly all biological and physical processes on the Earth. The earth is the only planet in the solar system, which receives an optimum amount of solar radiation that makes life sustainable on it. Solar spectrum resembles to that of a black body at approximately 5800K. 98% of the total emitted energy lies in the spectrum ranges from 250nm to 3000nm. About half of the radiation is in the visible. Short-wave part of the electromagnetic spectrum. The other half is mostly in the near-infrared part, with some in the ultraviolet part of the spectrum.

Solar radiation having wavelength less than 0.286nm (called ultraviolet) is absorbed by ozone layer in stratosphere. . The ultraviolet radiation not absorbed by the atmosphere is responsible for the change of color in skin pigments. The solar radiation, that traverses the atmosphere further, is subjected to scattering, reflection and absorption by air molecules, aerosols and clouds.

Types of Solar radiation

A. Direct solar radiation

The portion of the solar radiation which comes directly from the apparent solar disc, without reflection from other objects, is called direct or beam radiation. These radiations are received from the sun without change of radiation. Direct solar radiation at normal incidence, I, is the Angstrom compensated type for very accurate measurements and thermoelectric pyrheliometer for routine requirements.
The internationally accepted standard for direct solar radiation is the absolute cavity radiometer which has as detector a black body in the form of a receptacle. The thermoelectric pyrheliometer use thermopiles as sensors, the difference between the pyranometer and pyrheliometer being only in their angles of view, pyranometer having a view angle of 2π steradians, while pyrheliometer have an angle of view limited to the sun and 5 degree of the circum-solar sky.

B. Diffuse radiation

It is the solar radiation received from the sun after its direction has been changed by reflection and scattered by the atmosphere. Diffuse radiation is defined the solar radiation scattered by aerosols dust molecules. It does not have a unique direction. Diffuse solar or sky radiation or shortwave radiation from the sky received on a horizontal surface, D, is measured with a thermoelectric pyranometer provided with a suitable shading ring. Diffuse radiation forms about 17 percent of the global solar radiation with a clear sky and can be as high as 35 percent with hazy skies and 80 percent during the monsoon months.

C. Global Solar Radiation

Global Solar radiation or Total solar radiation is all solar radiation incidents on a surface, including scattered, reflected and direct. Total does not include radiation that has been absorbed by matter and then reemitted.

Diffuse solar radiation is the total solar radiation minus the direct radiation or beam radiation. The extra-terrestrial solar radiation is entirely direct or beam radiation. As that radiation passes through the earth atmosphere, it undergoes a complex interaction with the various components of the atmosphere. The major factors were scattering from molecules and dust particles, absorption by the atmosphere and refraction. A significant fraction of the radiation which reaches the surface of the earth is reflected and encounters a similar set of interactions; the remainder is absorbed by the surface of the earth.

The scattered radiation which reaches the observer from various parts of the sky dome is called diffuse radiation. Since the earth is surrounded by an atmosphere which contains various gaseous constituents, suspended dust and other minute solid and liquid particulate matter and clouds of various types, marked depletion of solar energy takes place during its passage through the atmosphere to the surface of the earth. One half of the scattered radiation is lost to space and the remaining half is directed downwards to the earth's surface from different directions as diffuse radiation. The effect of an increase in dust in the atmosphere is to decrease the direct solar radiation and increase the diffuse radiation.

In a cloudy atmosphere, considerable depletion of the direct solar radiation takes place. A large fraction is reflected back to space from the tops of clouds, another part transmitted downwards to the earth as diffuse radiation and a small fraction absorbed by the clouds. Clouds have greatest effect on the variation of solar radiation. A cloud between the observer and the sun blocks the direct radiation. Clouds elsewhere in the sky increase the diffuse radiation. Global solar radiation or shortwave radiation from the sun and the whole sky, received on a horizontal surface, G. is usually measured with a thermoelectric pyranometer coupled to a strip chart recorder or integrator printer. Pyranometer using silicon solar cells or bimetallic strips are not reliable and are not recommended for use, because of the limited spectral sensitivity of the former and the large temperature, azimuth and cosine errors and long response time of the latter.

SOLAR RADIATION MEASURING EQUIPMENTS

Experimental determination of the energy transferred to a surface by solar radiation requires instruments which will measure the heating effect of direct solar radiation and diffuse solar radiation .Measurement s are also made of beam radiation, which respond to solar radiation received from a very small portion of the circum solar sky. A total radiation type of instruments may be used for measuring diffuse radiation alone by shading the sensing element from the sun's direct rays.

CLASSIFICATIONS

pyrheliomeeter

A pyrheliometer is an instrument for measuring the intensity of direct solar radiation at normal incidence; it can either be a primary instrument or a secondary instrument scaled reference to a primary instrument. The latter have sometimes been called actionometers.

Pyrheliometer is a small telescope like device mounted on a drive mechanism that causes it to follow the sun through the day.

Pyranometer

A pyranometer is an instrument for the measurement of the solar radiation received form the whole hemisphere. It is suitable for the measurement of the global or sky radiation usually on a horizontal surface .Sometimes the term solarimeter is used instead of pyranometer. If shaded from the beam radiation by a shade ring, it measures diffuse radiation.

The pyranometer is sensitive to radiation from an entire hemisphere and is usually mounted so that the hemisphere is the sky dome.

The energy measured by a pyrheliometer is that energy which is available to a typical focusing solar energy collector system. The energy measured by the pyranometer is that energy which is available to a flat-plate collector system of horizontally mounted pyranometer measures the total amount of energy falling on the surface of the earth or a horizontal surface.

Pyrgeometer

A pyrgeometer is an instrument for the measurement of terrestrial radiation only.

Pyradiometer

A pyradiometer is an instrument for the measurement of both solar and terrestrial radiation, i.e. for net atmospheric radiation on a horizontal upward facing black surface at the ambient air temperature. These radiometers must be calibrated periodically against a standard. An accuracy of about 3% is then obtainable in good instruments.

Great care is needed when choosing a site for these radiometers, especially when the measurements are required for climatological studies in conjunction with measurements by other instruments over a large area. It is surprisingly difficult to find sites that have an uninterrupted view of the sky from the zenith to the horizon in all directions. Objects that stand above the horizontal plane of the instrument obscure part of the sky and influence the diffuse solar irradiance measured. Such objects may even obscure the beam solar irradiance for part of the day at some time in the year. It should also be remembered that a good site chosen at one time may become unsatisfactory later because nearby trees have grown taller, or because new buildings have been constructed.

Solar Radiation Geometry

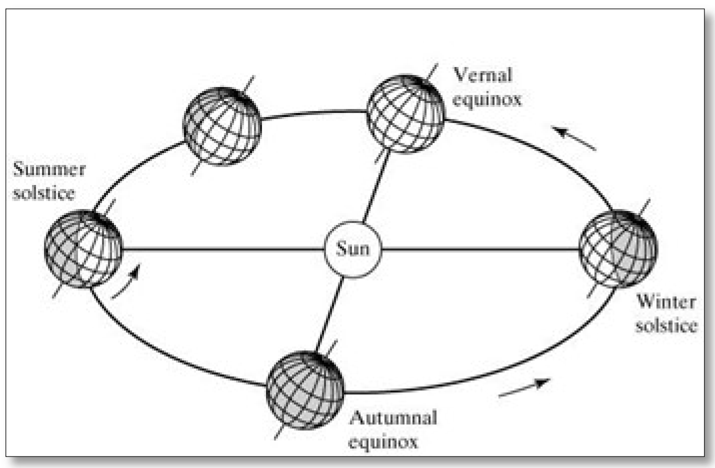
The sun is the source of most energy on the earth and is a primary factor in determining the thermal environment of a locality. It is important for engineers to have a working knowledge of the earth's relationship to the sun. They should be able to make estimates of solar radiation intensity and know how to make simple solar radiation measurements. They should also understand the thermal effects of solar radiation and know how to control or utilize them.

The earth is nearly spherical with a diameter of about 7,900 miles (12.7 x 10^3 km). It makes one rotation about its axis every 24 hours and completes a revolution about the sun in a period of approximately 365 1/4 days. The earth revolves around the sun in a nearly circular path, with the sun located slightly off center of the circle. The earth's mean distance to the sun is about 9.3 x 10^7 miles (1.5 x 10^8 km). Around January 1, the earth is closest to the sun while on around July 1 it is most remote, about 3.3% farther away. Since the intensity of solar radiation incident upon the top of the atmosphere varies inversely with the square of the earth-sun distance, the earth receives about seven per cent more radiation in January than in July. The earth's axis of rotation is tilted 23.5 degrees with respect to its orbit about the sun. The earth's tilted position is of profound significance. Together with the earth's daily rotation and yearly revolution, it accounts for the distribution of solar radiation over the earth's surface, the changing length of hours of daylight and darkness, and the changing of the seasons.

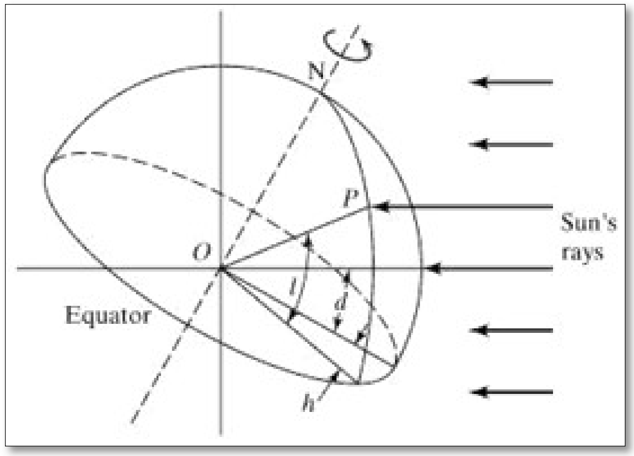
Figure 1 shows the effect of the earth's tilted axis at various times of the year. Figure 2 shows the position of the earth relative to the sun's rays at the time of winter solstice. At the winter solstice (around December 22), the North Pole is inclined 23.5 degrees away from the sun. All points on the earth's surface north of 66.5 degrees north latitude are in total darkness while all regions within 23.5 degrees of the South Pole receive continuous sunlight. At the time of the summer solstice (around June 22), the situation is reversed. At the times of the two equinoxes (around March 22 and September 22), both poles are equidistant from the sun and all points on the earth's surface have 12 hours of daylight and 12 hours of darkness.

BASIC EARTH-SUN ANGLES

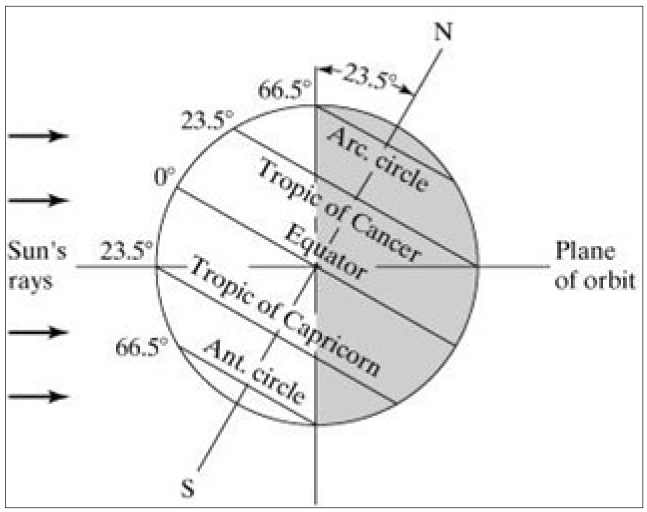
The position of a point P on the earth's surface with respect to the sun's rays is known at any instant if the latitude, l, and hour angle, h, for the point, and the sun's declination angle, d, are known. Figure 3 shows these fundamental angles. Point P represents a location on the northern hemisphere.



The earth's revolution about the sun



Position of the earth in relation to the sun's rays at time of winter solstice



Latitude, hour angle, and sun's declination angle

The latitude, l, is the angular distance of the point P north (or south) of the equator. It is the angle between the line OP and the projection of *OP* on the equatorial plane. Point *O* represents the center of the earth. The calculation of the various solar angles, performed later in this chapter, can be simplified by the adoption of a consistent sign convention. As part of this sign convention, north latitudes are positive and south latitudes are negative.

The hour angle, h, is the angle measured in the earth's equatorial plane between the projection of *OP* and the projection of a line from the center of the sun to the center of the earth. At solar noon, the hour angle is zero. The hour angle expresses the time of day with respect to solar noon. One hour of time is represented by $360 \div 24 = 15$ degrees of hour angle. As part of the convention, the hour angle is negative before solar noon and positive after solar noon.

The sun's declination angle, d, is the angular distance of a sun's rays north (or south) of the equator. It is the angle between a line extending from the center of the sun to the center of the earth and the projection of this line upon the earth's equatorial plane. The declination is positive when the sun's rays are north of the equator and negative when they are south of the equator. At the time of the winter solstice, the sun's rays are 23.5 degrees south of the earth's equator (d = -23.5°). At the time of the summer solstice, the sun's rays are 23.5 degrees north of the earth's equator (d = 23.5°). At the equinoxes, the sun's declination is zero.

The equation used to calculate the declination angle in radians on any given day is given by

$$\delta = 23.45\frac{\pi}{180}\sin\left[2\pi\left(\frac{284+n}{36.25}\right)\right]$$

where ‘n’ is the day of the year.

The Hour Angle

The hour angle is described in figure 1.6 and it is positive during the morning, reduces to zero at solar noon and becomes increasingly negative as the afternoon progresses. Two equations can be used to calculate the hour angle when various angles are know (not that δ changes from day to day and α and A change with time throughout the the day):

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

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

Where:

ω = the hour angle;

α = the altitude angle;

A_Z = the solar azimuth angle;

δ = the declination angle;

φ = observer’s latitude.

At solar noon the hour angle equals zero and since the hour angle changes at 15° per hour it is a simple matter to calculate the hour angle at any time of day. The hour angles at sunrise and sunset (ω_S) are very useful quantities to know. Numerically these two values have the same value however the sunrise angle is negative and the sunset angle is positive. Both can be calculated from:

$$\cos\omega_S = -\tan\phi\tan\delta$$

This equation is derived by substituting α= 0 into equation 3.8. ω_S can be used to find the number of daylight hours (N) for a particular day using the next equation, where ω_S is in radians:

$$N = \frac{2\omega_S}{15}\times\frac{180}{\pi}$$

There are always 4380 hours of daylight per year (non-leap years) everywhere on the globe.

For equation 3.4 beyond φ = ± 66.55°:(tan δ – tan φ) ≥ 1 there is no sunset, i.e. 24 hours of daylight; (tan δ – tan φ) ≤ 1 there is no sunrise, i.e. 24 hours of darkness.

If a surface is tilted from the horizontal the Sun may rise over its edge after it has rise over the horizon. Therefore the surface may shade itself for some of the day. The sunrise and sunset angles for a titled surface (ω_S‘) facing the equator (i.e. facing due south in the northern hemisphere) are given by:

$$\cos\omega' = -\tan(\phi - \beta)\tan\delta$$

where:

β = the angle of inclination of the surface from the horizontal.

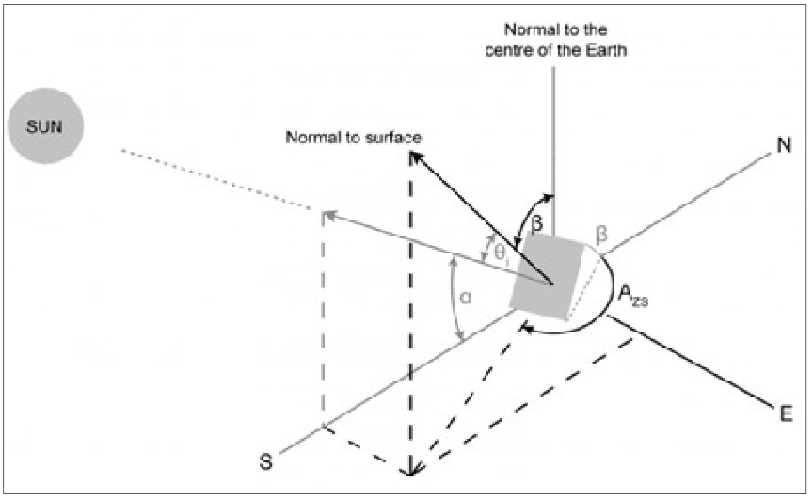


Figure 3.2: A tilted surface that is not facing the equator.

Equation may give the sunrise angle for the tilted surface that indicates that the Sun rises over the edge of the surface before it has appeared over the horizon. This situation is obviously wrong and a check must be made to find the actual sunrise angle over the tilted plane (ω_0): $\omega_0 = min\{\omega_S, \omega'_S\}$

For a titled surface facing the equator the sunrise and sunset angles are still numerically equal with the sunrise angle being positive and the sunset angle being negative. When a surface is inclined from the horizontal but not facing the equator, calculating the sunrise and sunset angles over the edge of the surface is complex. Such a surface is shown in figure 3.2. For such a surface the sunrise and sunset angles (ω_S”) will not be numerically equal and the following procedure must be followed:

$$\omega'_S = \cos^{-1}\left[\frac{ab \pm \sqrt{a^2 - b^2 + 1}}{a^2 + 1}\right]$$

Where:

$$a = \frac{\cos\phi}{\sin A_{ZS}\tan\beta} + \frac{\sin\phi}{\sin A_{ZS}}\ b = \tan\delta\left[\frac{\cos\phi}{\tan A_{AZ}} - \frac{\sin\phi}{\sin A_{AZ}\tan\beta}\right]$$

Equation 3.7 gives two solutions because of the ± sign, one is the sunset angle and the other is the sunrise angle. Then c0 is checked as before:

$$\omega_0 = \min\{\omega_S, \omega_S''\}$$

2.10.2 The Altitude Angle

The altitude angle (α) is described in figure 1.7 and can be calculated from:

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

2.10.3 The Azimuth Angle

The azimuth angle is described in figure 1.7 and can be calculated from the following equation:

$$\sin\alpha = \frac{\sin\omega\cos\delta}{\sin\theta_Z} = \frac{\sin\omega\cos\delta}{\cos\alpha}$$

The azimuth angle at sunrise (A_{SR}) can be calculated from:

$$\sin A_{SR} = -\sin\omega_S\cos\delta$$

2.10.4 Angle Of Incidence

The angle of incidence (θ_i) of the Sun on a surface tilted at an angle from the horizontal (β) and with any surface azimuth angle (A_{ZS}) can be calculated from (when A_{ZS} is measured clockwise from north):

$$Cos\ \theta_I = Sin\ \delta\, Sin\ \phi\, Cos\beta + Sin\ \delta\, Cos\ \phi\, Sin\ \beta\, Cos\ A_{zs} + Cos\ \delta\, Cos\ \phi\, Cos\beta\ Cos\ \omega - Cos\ \delta\, Sin\ \phi\ Sin\beta\ Cos\ A_{zs}\, Cos\omega - Cos\ \delta\ Sin\ A_{zs}\ Sin\ \beta\ Sin\ \omega$$

This horrible equation can be simplified in a number of instances. When the surface is flat (i.e. horizontal) β=0, cos β = 1, sin β = 0. Therefore equation 3.11 becomes:

$$\cos\theta_i = \cos\theta_Z = \cos\delta\cos\phi\cos\omega + \sin\delta\sin\phi$$

When the surface is tilted towards the equator (facing south in the northern hemisphere):

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

Solar Energy collectors : Principle of conversion of energy, Flat plate collector, Transmissivity of cover system, Collector energy balance equation, Thermal Analysis of FPC, Useful heat gain, Focusing collectors, advantages and disadvantages, Factors affecting collector performance.

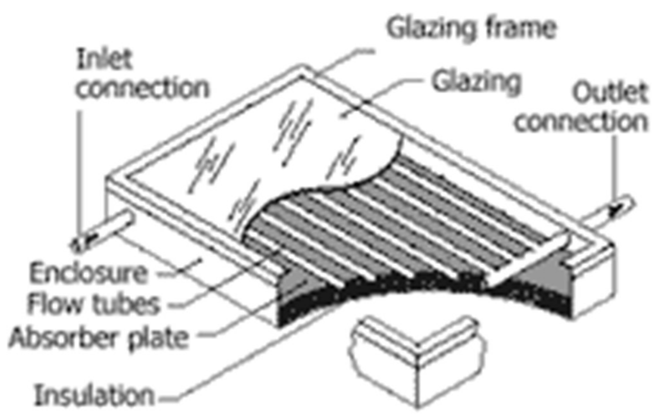
Application of Solar Energy: Solar Water Heating, Heating and Cooling of Buildings, Thermo electric conversion, Power generation, PV cells, Solar distillation, Pumping, Cooking, Hydrogen production.

Principle of conversion of energy

Conversion of Solar Energy (Solar Radiation) into Thermal Energy Solar radiation (energy) impinging on solid bodies increases the oscillation of atoms (absorption of the solar radiation) à heat energy is being generated à irradiance depends on the position of the sun = sunset (latitude, season) and direction (azimuth, deviance to the south) The atoms of black colour are only loosely bound to each other à very intense oscillation of atoms à very good conversion of solar radiation into heat energy The conversion of solar radiation into heat energy takes place inside the absorber of solar panels. The absorption of “short wave” radiation results in an emission of “long wave” heat radiation (infra-red radiation). Absorptance = 1 (100%) à radiation is entirely absorbed Actual absorption of solar radiation with the black absorber: 92% - 98% Actual emission of heat radiation with black bodies: 75% - 85% à “selective” surface coating of absorbers reduces emissions to only 3-5% (especially titaniumoxinitrid-coating on copper or aluminium and ceramic coatings)

Flat plate collectors

A typical flat-plate collector is a metal box with a glass or plastic cover (called glazing) on top and a dark-colored absorber plate on the bottom. The sides and bottom of the collector are usually insulated to minimize heat loss.



Sunlight passes through the glazing and strikes the absorber plate, which heats up, changing solar energy into heat energy. The heat is transferred to liquid passing through pipes attached to the absorber plate. Absorber plates are commonly painted with "selective coatings," which absorb and retain heat better than ordinary black paint. Absorber plates are usually made of metal—typically copper or aluminum—because the metal is a good heat conductor. Copper is more expensive, but is a better conductor and less prone to corrosion than aluminum. In locations with average available solar energy, flat plate collectors are sized approximately one-half- to one-square foot per gallon of one-day's hot water use.

Applications: The main use of this technology is in residential buildings where the demand for hot water has a large impact on energy bills. This generally means a situation with a large family, or a situation in which the hot water demand is excessive due to frequent laundry washing.

Commercial applications include car washes, military laundry facilities and eating establishments. The technology can also be used for space heating if the building is located off-grid or if utility power is subject to frequent outages. Solar water heating systems are most likely to be cost effective for facilities with water heating systems that are expensive to operate, or with operations such as laundries or kitchens that require large quantities of hot water.

Unglazed liquid collectors are commonly used to heat water for swimming pools. Because these collectors need not withstand high temperatures, they can use less expensive materials such as plastic or rubber. They also do not require freeze-proofing because swimming pools are generally used only in warm weather or can be drained easily during cold weather.

Transmissivity of the Cover System

The transmissivity of the cover system of a collector can be obtained with adequate accuracy by considering reflection – refraction and absorption separately and is given by the product form,

$$\tau = \tau_r \, \tau_a \quad \ldots \quad (4.57)$$

Where,

$\tau_r \rightarrow$ Transmissivity obtained by considering only reflection and refraction and

$\tau_a \rightarrow$ Transmissivity obtained by considering only absorption.

Transmissivity based on reflection – refraction

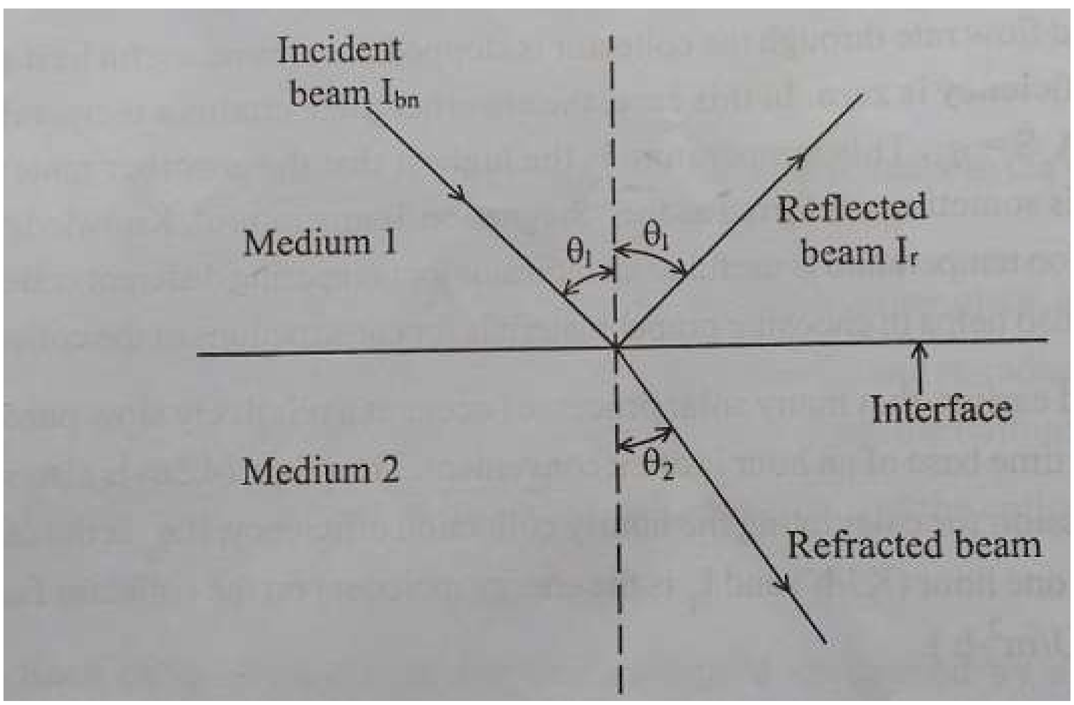
When a beam of light of intensity Ibn travelling through a transparent medium 1 strikes the interface separating it from another transparent medium 2. It is reflected and refracted as shown in the Figure. The reflected beam has a reduced indensity Ir and has a direction such that the angle of reflection is equal to the angle of incidence. On the other hand, the directions of the incident and refracted beams are related to each other by Snell's Law which states that,

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

Where, θ_1 → Angle of incidence,

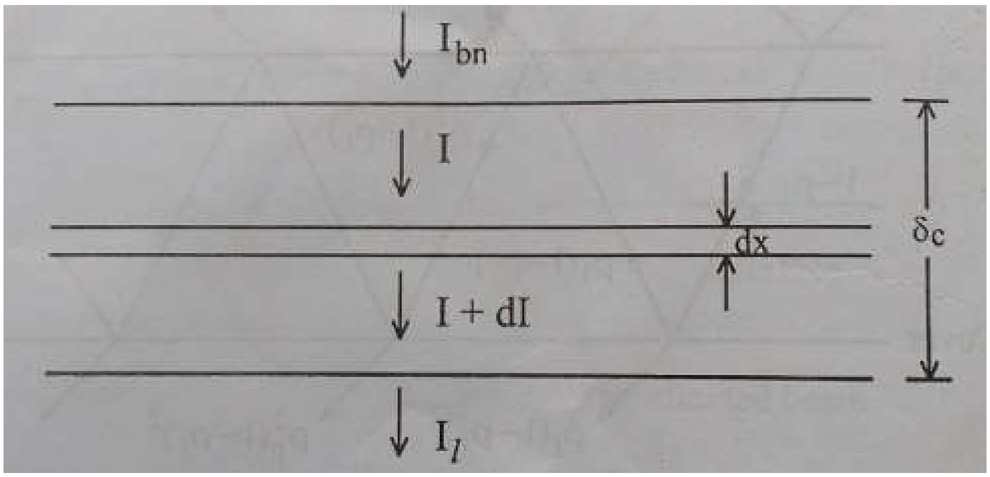
θ_2 → Angle of refraction, and

n_1, n_2 → Refractive indices of the two media



Transmissivity based on Absorption

The Transmissivity based on absorption can be obtained by assuming that the attenuation due to absorption is proportional to the local intensity (Bouger's law). Consider a beam of intensity 'Ibn' incident normally on a transparent cover of thickness 'δc' and emerging with an intensity 'I*l*' as shown in the figure.



Where, K is a constant of proportionality and is called the extinction coefficient. It will be assumed to have a value independent of wavelength. Integrating over the length traversed by the beam, we have

$$\tau_a = \frac{I_l}{I_{bn}} = e^{-K\delta_c}$$

In case the beam is incident at an angle q1, the path traversed through the cover would be (δc/cosq2), where q2 is the angle of refraction. Then Equation gets modified to the form,

$$\tau_a = e^{-K\delta_c / \cos\theta_2}$$

The extinction coefficient K is a property of the cover material. Its value varies from about 4 to 25cm-1 for different qualities of glass. A low value is obviously desirable.

Equations are derived for one cover. If there are 'M' covers the exponent in these equations would be multiplied by 'M'.

Energy Balance in Flat-Plate Collectors

A fundamental concept for thermal analysis of any thermal system is the conservation of energy, which can be analyzed through energy balance calculation under steady state conditions. In steady state, the useful energy output of the collector is the difference between the absorbed solar radiation and the total thermal losses from the collector

Useful energy = Absorbed solar energy - Thermal losses

Obviously, the higher the useful energy output from a particular design, the higher the expected efficiency. Thermal efficiency of the collector is an important parameter to consider in this kind of analysis as it creates the basis for comparison of different materials and modifications of collector systems. So many theoretical calculations presented in the books (as well as in this Lesson), are eventually aimed at evaluating efficiency.

Let us define the thermal efficiency (η) first, as it will be the focus and final destination of this chapter.

η=QuAcGTη=QuAcGT

where Q_u is the useful energy output from a collector, G_T is the incident solar radiation flux (irradience), and A_c is the collector area. So the denominator here is the total energy input for the collector. In this formula the G_T is the parameter characterizing the external conditions, and it is usually known from practical measurements (with a pyranometer) or assumptions for a specific location. The collector area is a set technical characteristic. So the main question here is how to estimate the Q_u - the useful energy.

As was mentioned above, to find how much energy remains available for useful thermal work, we need to understand the energy balance within the collector: *absorbed energy - losses.*

The energy balance can also be expressed via the following key equation:

Qu=Ac[S−UL(Tplate−Tambient)]Qu=Ac[S−UL(Tplate−Tambient)]

where S is the absorbed solar radiation, U_L is the total losses, T_{plate} is the temperature of the absorbing plate, and $T_{ambient}$ is the temperature of the air, and A_c again is the area of the collector surface.

In a general case, when measurements of incident solar radiation (I_T) are available, the convenient approximation for the absorbed energy is given by:

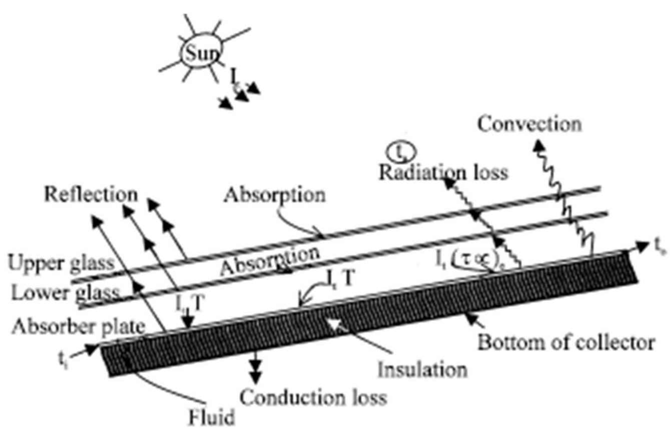
S=(τα)avITS=(τα)avIT

where $(\tau\alpha)_{av}$ is the product of transmittance of the collector cover and absorptance of the plate averaged over different types of radiation.

Thermal analysis of Flat-plate Collector

Heat losses from any solar water heating system take the three modes of heat transfer: radiation, convection and conduction. The conduction heat losses occur from sides and the back of the collector plate. The convection heat losses take place from the absorber plate to the glazing cover and can be reduced by evacuating the space between the absorber plate and the glazing cover and by optimizing the gap between them. The radiation losses occur from the absorber plate due to the plate temperature. Figure shows the heat loss pattern in a typical flat-plate collector.

The heat losses from the transparent cover to the ambient air are due to radiative and convective exchanges which are affected by the wind velocity, ground, surrounding condition and by long wave radiation from the sky.



Energy balance of a Flat-plate collector (Adapted from Garg, 1987)

They can be considerably reduced by selective black coatings which have high solar absorptivity and low long wave emmissivity (Garg, 1987). These coatings prepare surfaces such that their absorption characteristics remain high for wavelength below 2 μm and their emission characteristics low for wavelengths above 2 μm. The overall effect is the reduction of the global emissivity coefficient, ε_g which relates the absorber plate emissivity, ε_a and the transparent cover emissivity, ε_t as follows:

$$\varepsilon_g = \frac{1}{\frac{1}{\varepsilon_a} + \frac{1}{\varepsilon_t} - 1}$$

Collector overall -heat loss coefficient, U_l: The collector overall heat loss coefficient is the sum of the top, edge and bottom loss coefficients.

$$U_L = U_T + U_B + U_E$$

For a well-designed collector having a very small collector perimeter to area ratio, the edge losses are almost negligible (Garg, 1987). The bottom loss coefficient, U_B derives from the thermal conductivity, K_S and the thickness, L_s of the bottom insulator as:

$$U_B = \frac{K_s}{L_s}$$

Thus,

$$U_L = U_T + U_B$$

Following the basic procedure of Hottel and Woertz, Klein developed an empirical equation for the top loss coefficient, U_T as (Yeh *et al.*, 2003):

$$U_T = \left[\frac{N}{\frac{Ca_{ir}}{T_p}\left[\frac{T_p - T_a}{N+f}\right]^e} + \frac{1}{h_w} \right]^{-1} + \frac{\sigma (T_p + T_a)(T_p^2 + T_a^2)}{\left[(\varepsilon_p + 0.00591 N h_w)^{-1} + \frac{\left[2N + f - 1 + 0.133\varepsilon_p\right]}{\varepsilon_g} - N \right]}$$

where f = (1 + 0.089h_w-0.1166h_w ε_p) (1 + 0.07866N), C_{air} = 520 (1-0.00005β^2),

$$e = 0.43 \ (1 - \frac{100}{T_p})$$

β is the collector tilt and σ is the Stephan Boltzmann constant.

The convective heat-transfer coefficient h_w, for air flowing over the outside surface of the glass cover depends primarily on the wind velocity, v and can be determined from (Duffie and Beckman, 1974):

$$h_w = 5.7 + 3.8v$$

A more recent analysis carried out by (Malhotra *et al*., 1981) gives the overall loss coefficient in terms of gap spacing, L and reflects the effect of the collect tilt angle in a much simpler way.

$$U_L = \left[\frac{N}{\left\{\frac{204.429}{T_p}\right\} \frac{\left\{L^3 \cos\beta[T_p - T_a]\right\}^{0.252}}{N+f} / L} + \frac{1}{h_w} \right]^{-1} + \frac{\sigma(T_p^2 + T_a^2)(T_p + T_a)}{\left[\left\{\varepsilon_p + 0.0425N(1-\varepsilon_p)\right\}\right]^{-1} + \frac{2N+f-1}{\varepsilon_g} - N}$$

where

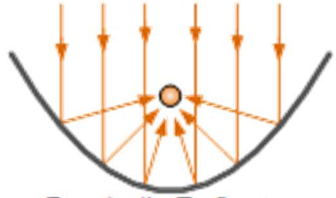
$$f = \left(\frac{9}{h_w} - \frac{30}{h_w^2}\right)\left(\frac{T_a}{316.9}\right)(1 + 0.091N)$$

FOCUSSING COLLECTORS

INTRODUCTION

One of the solar thermal energy collectors that collects solar energy over a large surface area and concentrated on a minimum area i.e., focal point. The concentration of the solar radiation on the focal point increased by a factor of two which in turn results in the increase of overall heat energy per square meter.

The concentrator is designed in such a way that solar energy intercepted by the aperture of the trough is reflected towards the focal point of the concentrator. Moreover U-shaped concentrating solar collectors i.e., parabolic trough reflects the solar energy towards the receiver tube fixed on the focal line of the trough. The concentration of the solar energy towards the receiver heats the heat transfer fluid flowing through the receiver tube after absorbing the heat energy from the receiver pipe.

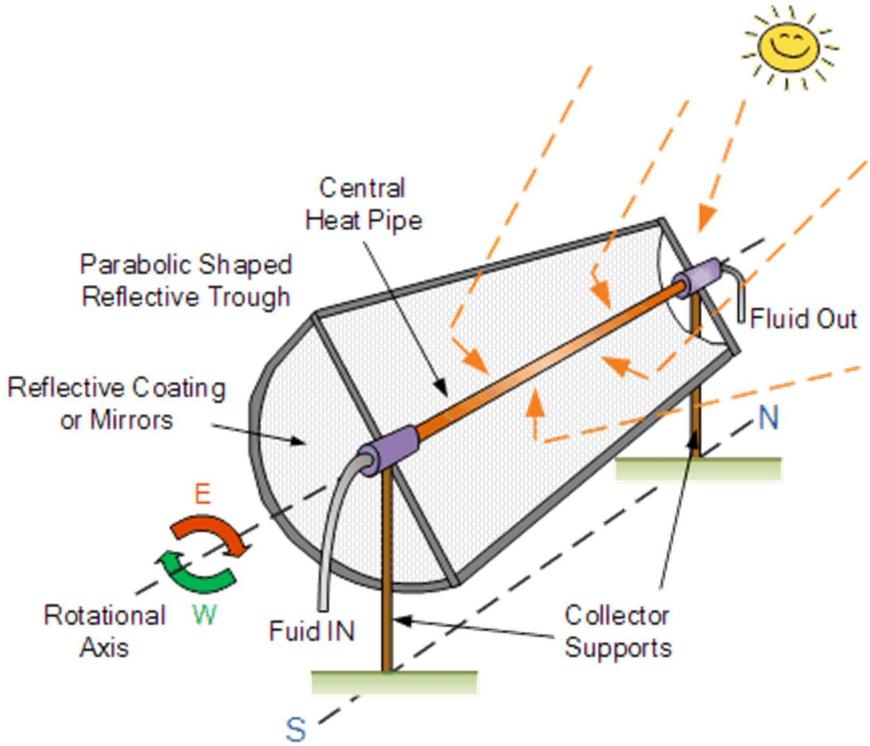


The trough can be made by bending the polished reflective metal sheet with desired angle resulting in the shape of the parabola. These type of reflectors should be oriented towards the motion of the sun throughout the day to receive the maximum amount of solar radiation.

The trough collectors are termed as solar thermal energy collector which is constructed as a long parabolic reflecting mirror which is extended linearly into the trough shape. The receiver tube is made of copper and the lengthy tube is painted black and evacuated by a glass tube to reduce the heat losses to the surroundings. Inside the evacuated receiver tube, heat transfer fluid is allowed to flow and the flow rate is minimum to absorb maximum amount of the energy from the receiver tube.

It is possible to generate higher temperature than the flat-plate collector, since the concentration ratio is higher. Also, thermal oil can be mixed with heat transfer fluid and the temperature of about 200°C is produced. The hot water output is allowed to a heat exchanger and water in the storage tank absorbs the heat energy from the exchanger tube which can be used for household applications. The closed-loop active system is used for solar heating applications and it is less effective in winter days as the trough only receive the direct solar radiation not the diffuse solar radiation.

Parabolic Trough Reflector



To receive the maximum amount of solar radiation, tracking of the trough collector towards the motion of the sun throughout the day. Therefore, a separate tracking mechanism is is indispensable such that the receiver tube can receive the solar radiation reflected during the sunny day.

The collector generally has a single rotation axis along the length of the trough which can be orientated in an east-to-west direction, tracking the sun from north to south, or orientated in a north-to-south direction and tracking the sun from east to west.

Hence parabolic troughs will be always aligned on north-to-south axis and tracking will be done towards the motion of the sun i.e., east to west. At noon, the trough will be straight as the sun is exactly above our head and during morning time, the collector performance is good when it is tracked towards the sun. In the afternoon hours, the trough should be slowly moved towards west-wise to receive maximum solar radiation. Number of single troughs can be aligned parallel to get a collector field and the outputs of all the troughs can be integrated to get steam.

Instead of water, low boiling point thermal oil can be used to get steam in no time. Care must be taken to maintain a optimum flow rate of heat transfer fluid to produce steam.

If oil of higher boiling point is circulated around the closed loop of the collector, it is possible to produce a higher temperature of about 400 ^{o}C which can be used to produce electricity. As numbers of parabolic troughs are used to get effective collective collector field, the electricity can be produced to meet the demand for larger community. Parabolic troughs can also be used to generate electricity to overcome energy savings and environmental benefits and for large scale installations, the system can be optimized.

Solar concentrators have less heat losses and increase of efficiency about 12% compared to the conventional flat-plate collector. The main disadvantage of the concentrator is it has smaller angle of incidence so that it should be tracked towards the motion of the sun manually or automatically to keep the receiver tube exactly at the focal point of the concentrator.

ADVANTAGES AND DISADVANTAGES OF FOCUSSING COLLECTORS

ADVANTAGES

(1) No Fuel Cost: Solar thermal concentrator does not require any fuel like most other sources of renewable energy. This is a huge advantages over other fossil fuels whose cost are increasing at drastic rate every year. Electricity prices are increasing by rapidly in more parts of the world much faster than general inflation. Price shocks due to high fuel costs are a big risk with fossil fuel energy these days.

(2) Predictable 24/7 Power: Solar thermal energy can generate power 24hours a day. This is made possible as solar thermal power plants store the energy in the form of molten salt etc. Other forms of Renewable energy like solar PV and wind energy are intermittent in nature.

(3) No Polution and Global Warning Effects: Solar thermal energy does not cause pollution which is one of the biggest advantages. Note there are costs associate with equipment used to build transport solar thermal energy equipment.

(4) Using existing industrial base: Solar thermal energy uses equipment like solar thermal mirror and turbines which is made in large scale at low cost by existing industrial base and require no major changes in equipment and materials unlike new technologies such as GIGs panels.

(5) Concentrated solar power production have been shown to create more permanent job and stimulate the economy as compared to its natural gas counterparts.

(6) The heat delivered by concentrating solar collectors is available at much higher temperature. Higher temperatures allow the use of power generation equipment to produce both electricity and heat.

(7) Large economy of scale effects are observed when moving towards large concentrating systems, rendering such technology very cost effective (compared with PV for example)

DISADVANTAGES

(1) High Costs: Solar thermal energy cost atleat 3.5Euro/watt and has not declined sola much in the last 3-4 years. However these costs are too high as solar PV already costs 2.5Euro/watt and even on a conservative basis will have it costs reduced by 5% in the next 10 years making it attain half the cost of thermal technology by 2020.

(2) Future Technology has a probability of marking CSP obsolete: Solar energy has become a hot bed of innovation with daily news of some new breakthrough in material and process in PV technology. "**Oerlikon**" has come out with a radial new a-si technology while GIGs players are touting increased efficiencies. Chinese solar companies have captured large chunks of the solar market through low cost leadership while number of Global Heavyweight like POSCO, Samsung, Hyundai, Sharp, GE, TSMC, promise to further decrease these costs.

(3) Water Issue: Solar thermal plant use lot of water which is major problem in desert areas. Using non-water cooling raises the cost of CSP projects too much. While using sea water has been proposed it remains to be seen If it possible to implement this solution as this would imply building plants very near the coastline.

(4) Ecological and Cultural Issue: This usage of massive arrays of Mirrors is noted to heavily impact the Desert wildlife endangering the endangered species. California has already seen massive fight on this issue with project Developers Curtailing the size of their plants and spending money to move wildlife (applicable only to CSP)

(5) Since concentrators can focus only direct solar radiation, this performance is poor on cloudy days.

(6) Tracking mechanisms must be used to move the collectors during the day to keep then focused on the sun.

(7) Maintaince and construction costs of the system is high.

(8) Concentrators are only practical in areas of high direct insolation, such as arid and desert areas.

Solar water heating systems

Active Solar Domestic Water Heating

The active water systems that can be used to heat domestic hot water are the same as the ones that provide space heat. A space heat application will require a larger system and additional connecting hardware to a space heat distribution system.

There are five major components in active solar water heating systems:

- Collector(s) to capture solar energy.
- Circulation system to move a fluid between the collectors to a storage tank
- Storage tank
- Backup heating system
- Control system to regulate the overall system operation

There are two basic categories of active solar water heating systems – direct or open loop systems and indirect or closed loop systems.

Direct Systems

The water that will be used as domestic hot water is circulated directly into the collectors from the storage tank (typically a hot water heater which will back up the solar heating).

There are two types of direct systems – draindown and recirculating. In both systems, a controller will activate a pump when the temperature in the collectors is higher than the temperature in the storage tank.

The draindown system includes a valve that will purge the water in the collectors when the outdoor temperature reaches 38 degrees. When the temperature is higher than 38 degrees and the collectors are hotter than the storage tank, the valve allows the system collectors to refill and the heating operation resumes.

The recirculating system will pump heated water from the storage tank through the collectors when the temperature drops to 38 degrees.

These two systems have serious drawbacks. The draindown valves can fail in a draindown system and the result can be the expensive breakage of the solar collectors. The draindown valve will typically sit unused for a very long time and then will need to work the first time without failing. The cycling of air and water in a draindown system collectors as a result of periodically draining down (thereby emptying the collectors) can cause a buildup of mineral deposits in the collectors and reduce their efficiency. The recirculating system circulates buildup from potable water heated from the storage tank through collectors during potential freeze conditions and effectively cools the water (wasting energy).

Indirect Systems

Systems that use antifreeze fluids need regular inspection (at least every 2 years) of the antifreeze solution to verify its viability. Oil or refrigerant circulating fluids are sealed into the system and will not require maintenance. A refrigerant system is generally more costly and must be handled with care to prevent leaking any refrigerant.

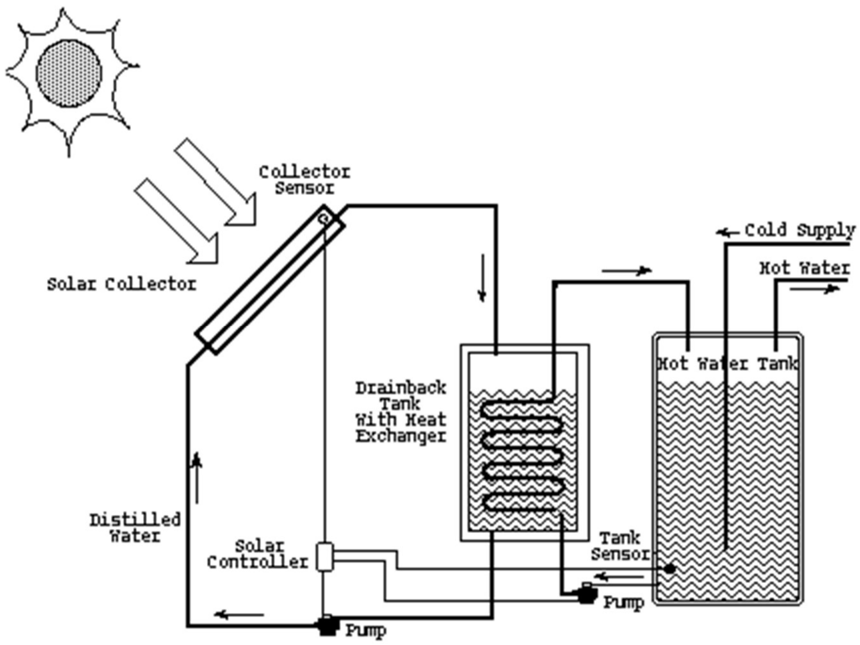
An indirect system that exhibits effectiveness, reliability, and low maintenance is the drainback system (see Figure 1 on next page).

The drainback system typically uses distilled water as the collector circulating fluid.

The collectors in this system will only have water in them when the pump is operating. This means that in case of power failure as well as each night, there will be no fluids in the collector that could possibly freeze or cool down and delay the startup of the system when the sun is shining.

This system is very reliable and widely used. It requires that the collectors are mounted higher than the drainback tank/heat exchanger. This may be impossible to do in a situation where the collectors must be mounted on the ground.

An indirect or direct system can be used for heating swimming pools and spas. Lower cost unglazed (no glass cover) collectors are available for this purpose.



The fluids that are circulated into the collectors are separated from the heated water that will be used in the home by a double-walled heat exchanger.

A heat exchanger is used to transfer the heat from the fluids circulating through the collectors to the water used in the home. The fluids that are used in the collectors can be water, oil, an antifreeze solution, or refrigerant.

The heat exchangers should be double-walled to prevent contamination of the household water.

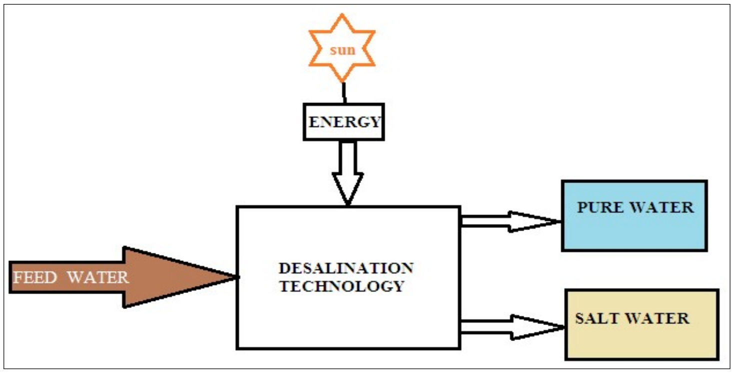
The controller in these systems will activate the pumps to the collectors and heat exchanger when design temperature differences are reached.

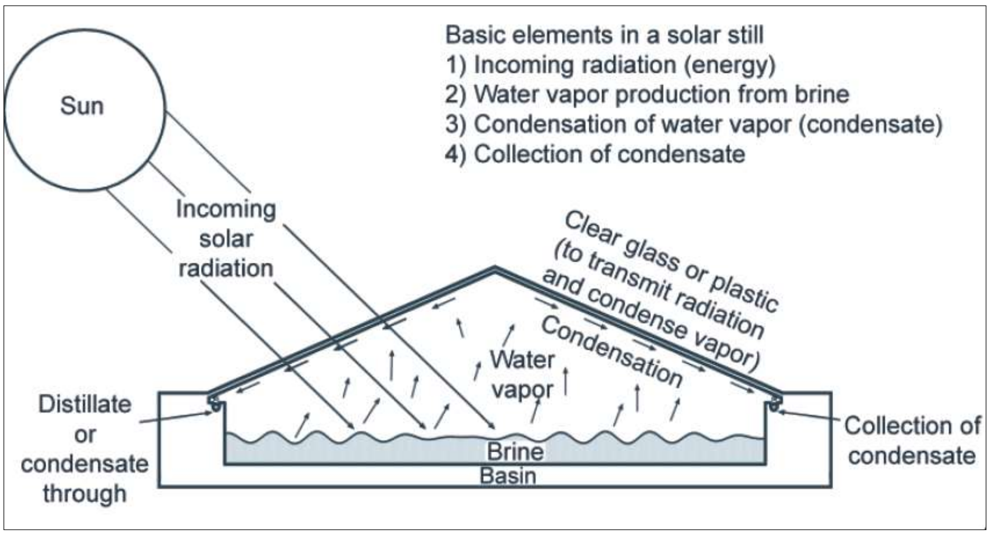
The heat exchanger may be separate from the storage tank or built into it.

Solar distillation

The solar still has a shallow black basin to hold the salt water and absorb solar radiation; water vaporizes from the brine is condensed on the underside of a sloped transparent cover and runs into the trough and is collected in tanks at the end of the still. The working principle of the distiller unit is described below.

"Solar radiation is transmitted inside the enclosure of the distiller unit after reflection and absorption by the glass cover. The transmitted radiation is partially absorbed by the water mass and partially reflected by the water mass. The transmitted radiation further reaches the blackened surface where it is mostly absorbed. The thermal energy absorbed by the basin liner (i.e., the blackened surface) is then convected to the water mass in the basin and the rest of the energy is lost in atmosphere by conduction through the insulated bottom and sides of the distiller unit. Due to convection of energy by the basin liner, the water mass in the basin gets heated and the temperature of the water mass is higher than the glass cover temperature, there occurs internal heat transfer from the water surface to the glass cover. The heat is transferred by radiation, convection and evaporation. After releasing the latent heat of vaporization, the evaporated water is condensed on inner surface of glass cover. Due to cover's small inclination, condensate flows by gravity into the collection troughs at the lower edge of the glass cover. The cover is at sufficient slope such that surface tension of the condensate water causes to flow only into the collection trough and not to drop back into the basin. Finally the condensed water is trickled into the container. The collected water is taken out of the system for an appropriate use. Externally the thermal energy received by the glass cover is lost to ambient by convection and radiation".





Solar Cooking

A solar cooker is basically a large insulated box with a glass lid that acts as a solar energy trap by exploiting the green house effect. The heat losses over a larger surface area will partially offset the additional gain through having a greater heat collecting surface. What is usually done to compensate for this is that a glazed surface cover and reflectors are used to increase the apparent collector area. Solar radiation penetrates through the window and absorbs into the walls, the bottom of the cooker and the cooking utensils. The window is not transparent to heat radiation. So, the heat radiation from the walls and pots will be trapped inside the cooker. Double window is better than a single window because it reduces heat conduct. To minimize the heating effect, the walls and the pots should be black. The bottom should be covered with black metal plate to carry heat to the pots. To increase the incoming solar radiation, reflective plates can be used and are required in less than optical solar condition. They should be directed to reflect radiation from a wider area into the box. The insulating material allows cooking temperature to reach similar level on cold and windy days as on hot days, as well as having an added benefit of blocking any leakages that could potentially seep through the cooker.

Thermal figures of merit

Figures of merit are used to provide simple reference numbers that are assumed to be determined for all cookers in a consistent manner. The data collected from the measurements will be reduced to four thermal figures of merit, or standards of performance. The comparison of different types of solar cooker can be done with the help of these figures which are based on Funk (2000) and Ashok Kundapur and Sudhir (2009). In addition to these primary figures of merit, there will be several other factors such as safety, ease of use, and, if available, cost as points of comparison. Due to inaccuracies in temperature measurements near the boiling point of water, all tests involving water will be conducted up to a maximum of 95°C. The test should be concluded when the temperature reaches 95°C and any data above 95°C will be disregarded.

Standard Cooking Power

Based on the temperature change of the test load under known insolation conditions, this figure is taken and its values are corrected to a standard horizontal insolation of 700 W/m^2. The process for calculating this figure is nearly identical to that developed by Funk *et al.* in ASAE S580, and is given below. The temperature change of the water shall be measured over 10-minute intervals, and cooking power shall be computed by

$$P = \frac{M_w C_w (T_2 - T_1)}{600}$$

where T_2 is the water temperature at the end of the interval and T_1 is the water temperature at the beginning of the interval. The equation is divided by 600 because there are 600 seconds in each ten minutes interval.

Cooking power for each interval shall be corrected to a standard insolation of 700 W/m^2 by multiplying the interval observed cooking power by 700 W/m^2 and dividing by the interval average insolation recorded during the corresponding interval.

The standardized cooking power $P_s = P\left[\frac{700W / m^2}{I_{measured}}\right]$

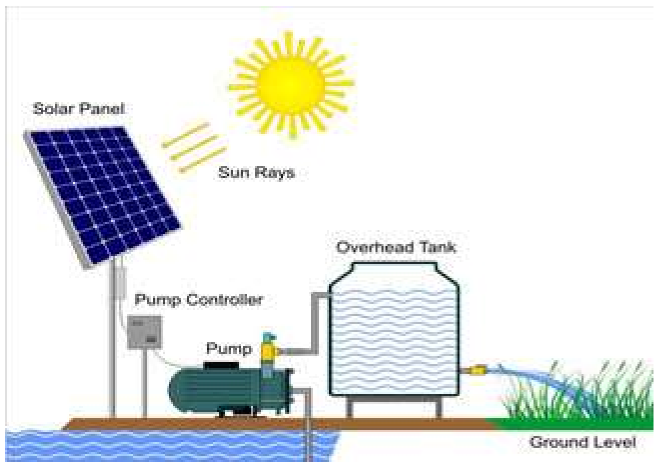
where $I_{measured}$ = Horizontal insolation averaged over the 10-minute interval.

Finally, these equations must be reduced to a single measure of performance. This is done by plotting P_s against ΔT and performing a linear regression, where ΔT refers to T_{water} -$T_{ambient}$ (recorded for each interval). The Standard Cooking Power is taken from this regression for a ΔT value of 50°C. The regression coefficient of determination (R^2) value for this regression fit should be reported and the data must be taken until a fit can be made with an R^2 of at least 0.75. The length of time taken for this test should be either 4 hours, beginning in the morning or the length of time taken for the pot contents to reach 95°C, whichever occurs first. If R^2 results are below the required 0.75, testing can be continued on a second day and these values added to the regression until the required fit can be achieved.

The Standard Cooking Power figure of merit is particularly useful to potential users of solar cookers. This figure provides an opportunity to study the cooker's ability to cook food. It also allows for a comparison of devices tested under the proposed standard and devices tested under ASAE S580. The latter lacks some of the other figures of merit that are included in the proposed standard.

Solar pumping

A solar water pump has a mini power house at its heart and consists of a calibrated and matching solar array of modules – tuned with the equivalent power of pump for that particular application. The solar water pumping system is capable of running all types of electrical water pumps with applications varying from irrigation to household demands. Irrigation pumps such as submersible, surface or deep well can also be coupled with drip irrigation systems to enhance the returns from this configuration. Components of solar water pumping system: Solar PV Moduleϖ Electronics/Controllerϖ Pumpϖ The "Motor Pump Set" capacity in the range of 1 hp to 10 hp with the following features: The mono block DC/ AC centrifugal motor pump set with the impeller mounted directly on the motor shaft and with appropriate mechanical seals which ensures zero leakage. Submersible pumps will be used according to the dynamic head of the site at which the pump is to be used. The suction and delivery head will depend on the site specific condition of the field. Maximum Power Point Tracker (MPPT) will be included to optimally use the Solar panel and maximize the water discharge. The motor of the capacity ranging from 1 hp to 10 hp will be AC, PMDC or BLDC type.



Solar PV cells

Pure silicon crystal is doped with phosphorous which has valency of five. The four electron of the silicon form covalent bond with the four electrons of phosphorous making the fifth electron free to move in the crystal lattice. Therefore the silicon will become an extrinsic semiconductor and it has free electrons moving around the lattice.

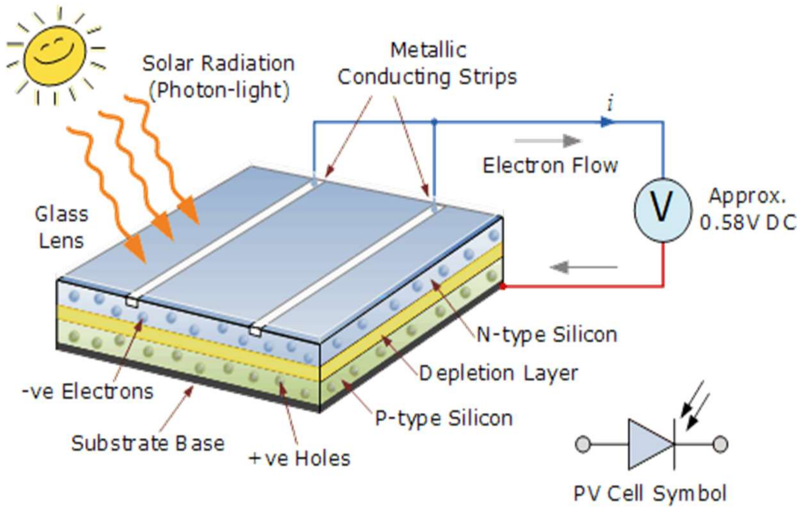
When the extrinsic silicon is illuminated by solar energy, the free electron in the crystal lattice move towards the p-type semiconductor producing a conventional current in the opposite direction. Therefore the pentavalent phosphorous atom is called as the donor atom as it donates one electron to the crystal lattice.

Photovoltaic Solar Cell P-Type Semiconductors

When pure silicon is doped with Boron of valency three, the three electrons form covalent bond with the three electrons of silicon and a hole is created in excess. Therefore, the crystal lattice has abundance of positive charges called holes and these holes are responsible for conduction in semiconductor device. As the sun shines, the holes moved in the crystal lattice creating conventional current and can be called as P-type semiconductor device. Therefore the trivalent atom is called as acceptor atom. Both P-type and N-type semiconductor are joined together to form PN junction. Near to the junction on P-side immovable negative ions are produced and in the N-side, immovable positive ions are produced. This process is known as diffusion. Therefore a potential is developed across the junction and it is called as potential barrier. When this PN semiconductor device is illuminated by solar energy, the immovable negative and positive ions are converted into electrons and holes. The abundant electrons and holes move towards the opposite electrode and produce a conventional current flowing through the external circuit.

The DC current produced is stored in the battery and the output of the battery is connected to the inverted to convert into AC current. The AC current in turn will fulfill the demand for electricity in industrial and domestic applications

Photovoltaic Solar Cell Construction



POSSIBLE QUESTION

Part – B

1. What are the advantages of flat-plate collector?
2. Distinguish between liquid flat-plate collectors and air collectors.
3. Explain the basic design of flat-plate collectors.
4. How do you write energy balance equations for flat-plate collector?
5. What are the applications of air-heater.
6. What is the difference between porous and non-porous absorber type air heater.
7. Discuss the design and construction of flat-plate collectors.
8. Briefly write about the selective absorber coating
9. With a diagram explain the working of a sunshine recorder
10. What are the significances of solar radiation data

Part - B

1. Write a note on heat transport system in flat-plate collector

Wind Energy: Principle of energy conversion, Power generation, Forces on blades, energy estimation, Wind data, Components of WECS, Classification of WECS, Advantages and Disadvantages, Types of Wind machines, Performance of Wind machines, Applications of wind energy.Problems

Energy from Biomass: Conversion technology, Factors affecting gas generation, classification of biogas plants, Advantages and disadvantages of different types of plants.

Wind energy:

Wind is basically caused by the solar energy irradiating the earth. Energy of wind can be economically used for the generation of electrical energy. Wind is caused due to two main factors:

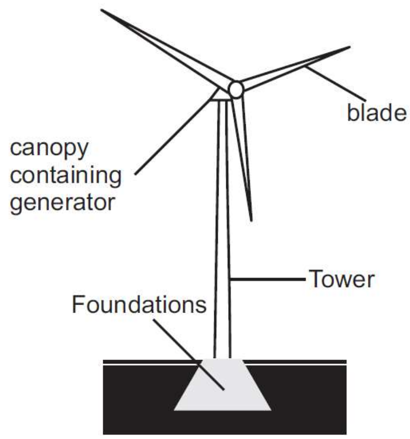
(a) Due to air in motion. Air motion arises from a pressure gradient. The surface winds flow from the poles toward the equator. Solar radiation heats the air near the equator, and this low density heated air buoyed up. At the surface, it is displaced by cooler, more dense higher pressure air flowing from the poles. In the upper atmosphere near the equator the air tend to flow towards the poles and away from the equator. The net result is a flow of surface winds from north to south in the northern hemisphere. Similarly the flow of surface winds is from south to north in the southern hemisphere of the earth.

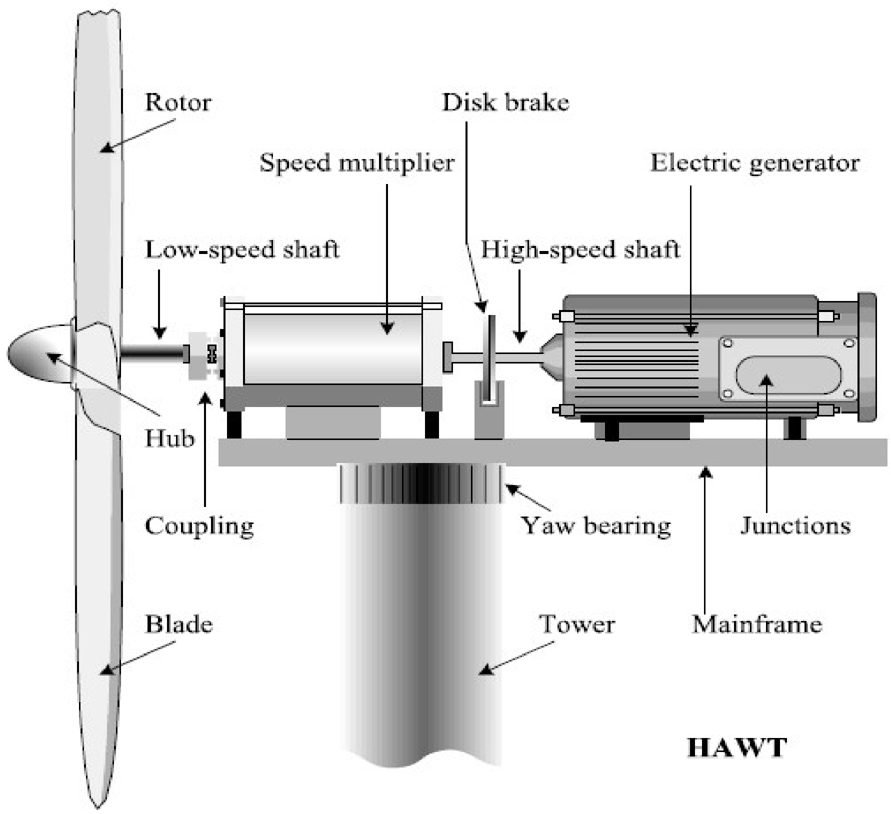
(b) Due to the rotation of the earth with respect to atmosphere, and its motion around the sun.

Wind energy which is an indirect source of solar energy conversion can be utilized to run windmill, which in turn drives a generator to produce electricity. Wind can also be used to provide mechanical power, such as for water pumping.

Some characteristics of wind energy are stated below:

- It is a renewable source of energy.
- Wind-power systems are non-polluting, so it does not affect the environment.
- Wind energy systems avoid fuel provision and transport.
- Large areas are needed to install wind forms for electrical power generation and wind energy needs storage means because of its irregularity in the speed of flow.
- Manufacture and implementation of wind farms can be costly. As our country has lot of wind throughout the year, the energy in the wind can be used to generate power that can be used for domestic and industrial uses. The wind mill is the form in which we can convert the wind energy to electricity. The potential of wind energy is of the order of 1.6x107MW. The wind mill generally consists of a turbine (a dynamo which can produce electricity when rotated) connected to large rotating blades. The blades rotate by using the wind.





PERFORMANCE OF WIND MACHINES

WECS efficiency is of interest to both aerogenerator designers and system engineers. As WECS is a capital intensive technology, it is desirable for the overall wind electric plant to have the highest efficiency possible, thus optimally utilizing capital resources and minimizing the busbar electric energy cost.

The overall conversion efficiency, $\mu_o$of an aerogenerator of the general type is

$$\eta_0 = \frac{\text{Useful Output Power}}{\text{Wind Power Input}} = \eta_A \cdot \eta_G \cdot \eta_C \cdot \eta_{Gen}$$

Where,

η_A → Efficiency of the aeroturbine,

η_G → Efficiency of gearing,

η_C → Efficiency of the mechanical coupling, and

η_{Gen} → Efficiency of the generator.

Above equation shows an application of cascaded energy conversion, from which overall efficiency will be strongly determined by the lowest efficiency converter in the cascade. For the aerogenerator this is the aeroturbine; the efficiency of the remaining three elements can be made quite high but less than 100 percent. It is now evident why so much emphasis is placed on the efficiency of the aeroturbine in wind literature.

Consider an arbitrary aeroturbine (Here Aero turbine is not equal to aerogenerator) of cross-sectional area ‘A’ driven by the wind. Its efficiency would be:

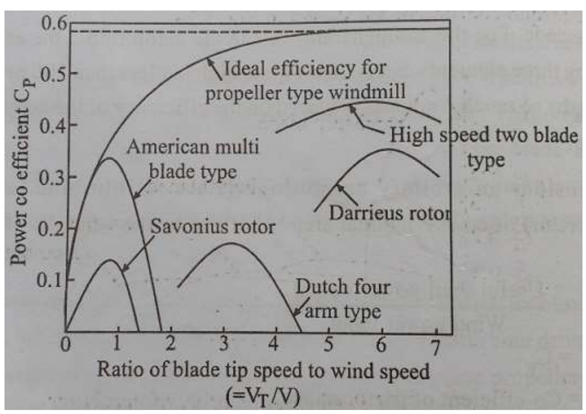
$$\eta_A = \frac{\text{Useful shaft power output}}{\text{Wind power input}}$$
$$= C_P$$
$$= \text{Co-efficient of performance.}$$

Thus the coefficient of performance of an aeroturbine is the fraction of power in the wind through the swept area which is converted into useful mechanical shaft power. The coefficient of performance is widely utilized throughout the recent wind research. We have seen that C_p for horizontal axis wind machine has theoretical maximum value = 0.593.

This theoretical efficiency limitation on a wind energy conversion system is loosely analogical similar to the thermodynamic carnot efficiency limitation on a conventional thermal power plant.

We know that the convertible power of energy is proportional to the cube of the wind speed. Thus if the wind speed decreases by 20%, the power output is reduced by almost 50%. The wind speed may very considerable from day to day and from season to season. The efficiency of a wind generator depends on the design of an wind rotor and rotational speed, expressed as the ratio of blade tip speed to wind speed i.e., V_T/V (is called as TSR – Tip Speed Ratio), if n is the rotation frequency, ie., rotation per second, if a rotor diameter D meters, the tip speed is πnD m/sec.

The dependence of the power coefficient on the tip speed ratio (TSR) for some common rotor types is indicated in Fig. 5.13. It is seen that the two-bladed propeller type of rotor can attain a much higher power coefficient (i.e., it is more efficient) than the American multi-blade wind mill and the classical Dutch four-bladed windmill. In practice two-bladed propeller (horizontal axis) rotor are ound to attain a maximum power coefficient of 0.40 to 0.45 at a tip speed ratio in the range a roughly 6 to 10



Typical performance of wind machine

Golding has derived the expression for aeroturbine efficiency as,

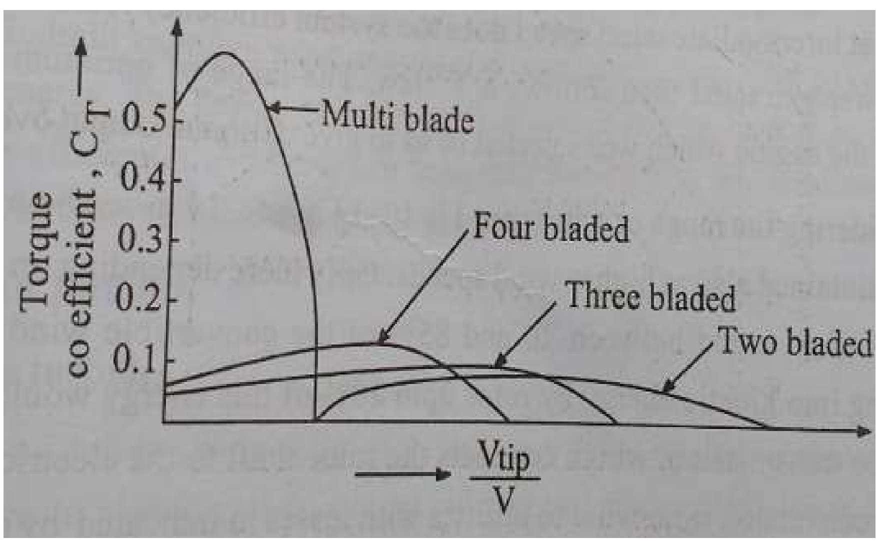
$$\eta_A = \frac{1 - K\dfrac{V_T}{V}}{1 + K\dfrac{V}{V_T}} = CP$$

$$K = \frac{F_D}{F_L} = \frac{\text{Drag}}{\text{Lift}} \text{ ratio}$$

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

If one assembles models of various types of aeroturbine blades and puts them in a wind tunnel and runs carefully controlled experiments of their efficiencies as function of their TSR'S, then one obtains a family of curves similar to that shown in Fig.5.14.

The various types of windmills performance characteristics with respect to TSR and torque coefficient are shown in Fig. 5.14.



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

Considering the range of wind speed is 10-14m/sec, 14m/sec being the rated velocity maintained also at higher wind speeds. Only there depending on the degree of sophistication, could between 70 and 85% of the convertible wind energy by the gear type transmission, which connects the rotor shaft to the electric generator. The energy conversion from wind to utilities with losses in indicated by energy flow diagram shown in Fig.

Types of Wind Turbines

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.

Vertical Axis Wind Turbine **Horizontal Axis Wind Turbine**

Parts of a Wind Turbine

- The nacelle contains the key components of the wind turbine, including the gearbox, and the electrical generator.
- The tower of the wind turbine carries the nacelle and the rotor. Generally, it is an advantage to have a high tower, since wind speeds increase farther away from the ground.
- The rotor blades capture wind energy and transfer its power to the rotor hub.
- The generator converts the mechanical energy of the rotating shaft to electrical energy
- The gearbox increases the rotational speed of the shaft for the generator.

Vertical Axis Wind Turbines

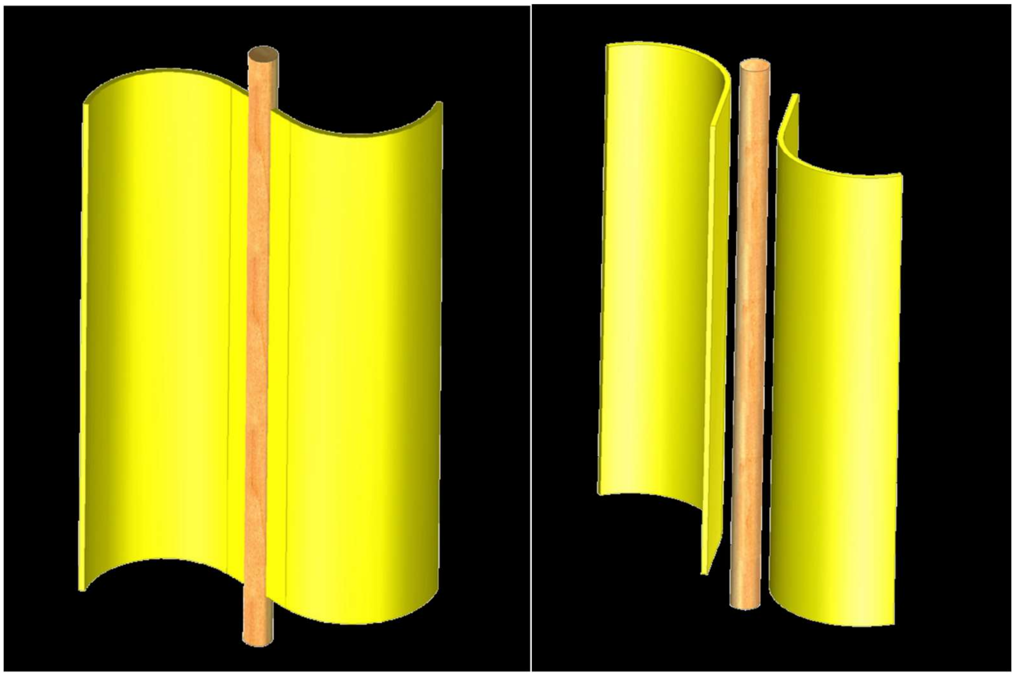
Although vertical axis wind turbines have existed for centuries, they are not as common as their horizontal counterparts. The main reason for this is that they do not take advantage of the higher wind speeds at higher elevations above the ground as well as horizontal axis turbines.

An Early Wind Turbine

The Persian windmill was used around 1000 b.c. to turn a grindstone. It is the oldest known windmill design. The machine works by blocking the wind blowing on ½ of its sails. The sails exposed to the wind are pushed downwind due to drag, causing the windmill to rotate.

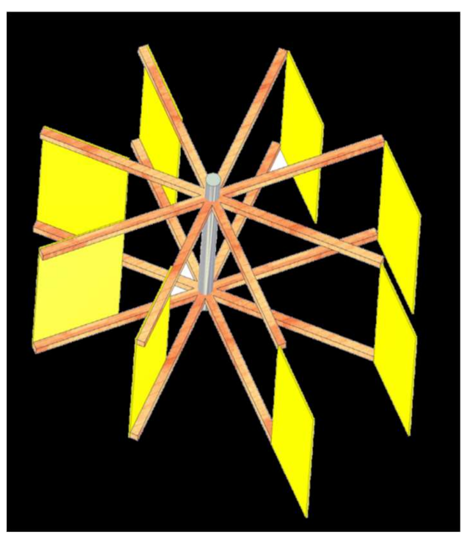
Savonius Wind Turbine

The Savonius turbine is S-shaped if viewed from above. This drag-type VAWT turns relatively slowly, but yields a high torque. It is useful for grinding grain, pumping water, and many other tasks, but its slow rotational speeds make it unsuitable for generating electricity on a large-scale.



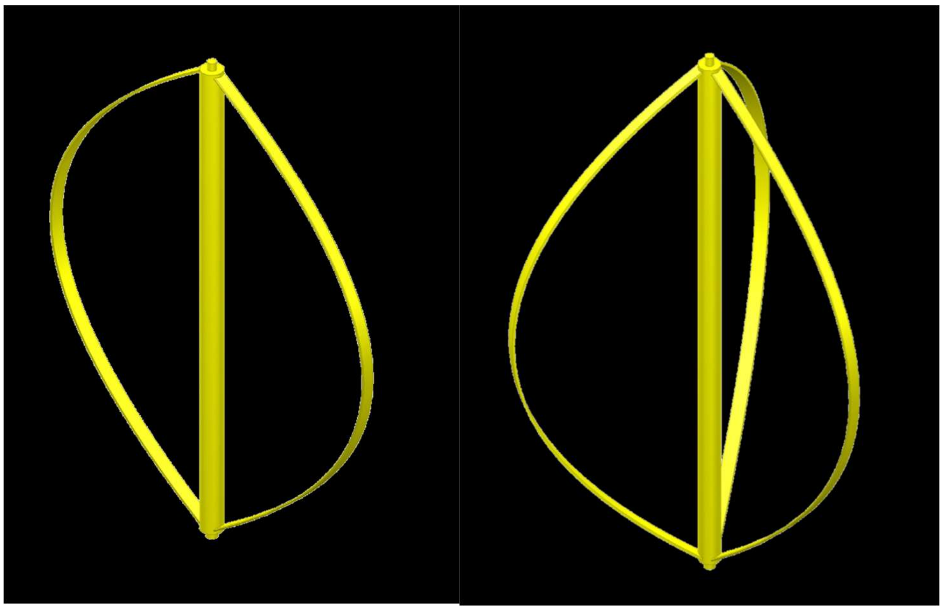
Flapping Panel Wind Turbine

This illustration shows the wind coming from one direction, but the wind can actually come from any direction and the wind turbine will work the same way.



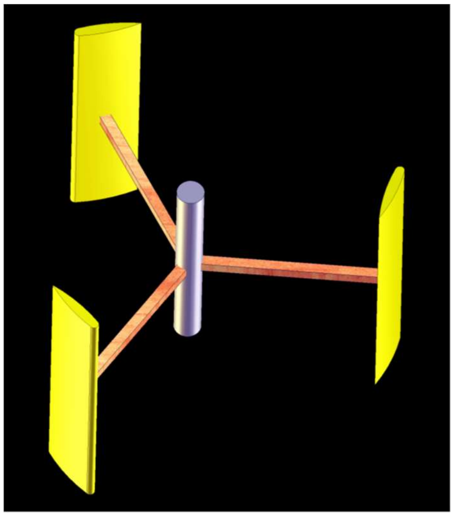
Darrieus Wind Turbine

The Darrieus turbine is the most famous vertical axis wind turbone. It is characterised by its C-shaped rotor blades which give it its eggbeater appearance. It is normally built with two or three blades**.**



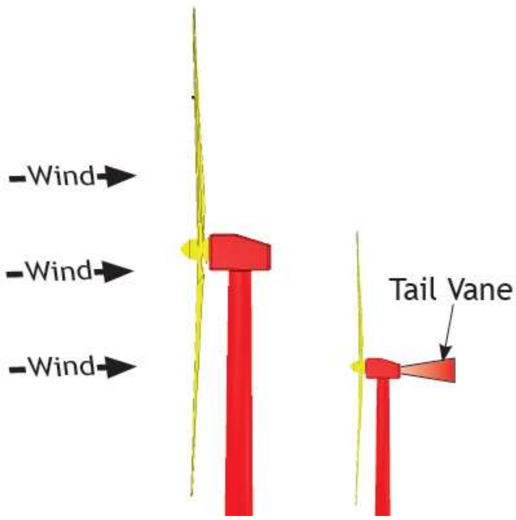
Giromill Wind Turbine

The giromill is typically powered by two or three vertical aerofoils attached to the central mast by horizontal supports. Giromill turbines work well in turbulent wind conditions and are an affordable option where a standard horizontal axis windmill type turbine is unsuitable.



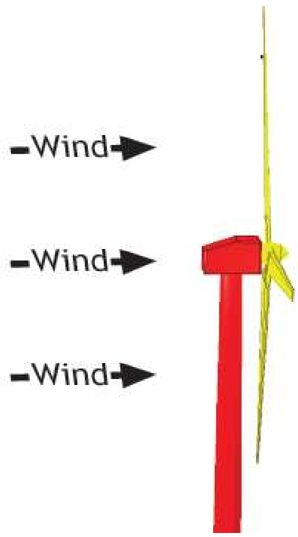
Up-Wind Turbines

Some wind turbines are designed to operate in an upwind mode (with the blades upwind of the tower). Large wind turbines use a motor-driven mechanism that turns the machine in response to a wind direction. Smaller wind turbines use a tail vane to keep the blades facing into the wind.



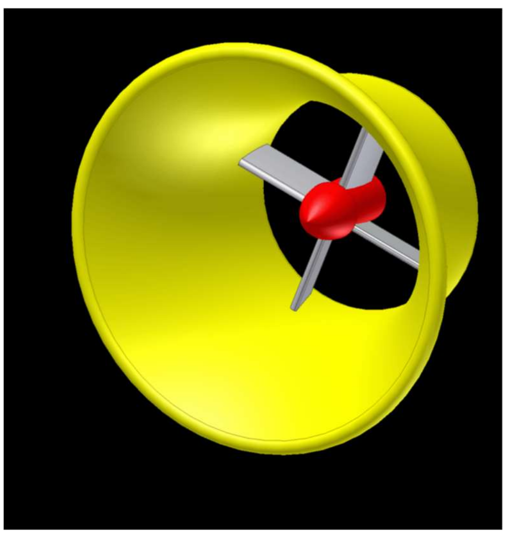
Down-Wind Turbines

Other wind turbines operate in a downwind mode so that the wind passes the tower before striking the blades. Without a tail vane, the machine rotor naturally tracks the wind in a downwind mode.



Shrouded Wind Turbines

Some turbines have an added structural design feature called an augmentor. The augmentor is intended to increase the amount of wind passing through the blades.



CLASSIFICATION OF WECS

(1) Based on axis

(a) Horizontal axis machines

(b) Vertical axis machines

(2) According to size

(a) Small size machines (upto 2k W)

(b) Medium size machines (2 to 100k W)

(c) Large size machines (100k W and above)

(a) Single generator at single site

(b) Multiple generators

(3) Types of output

(a) DC output

i. DC generator

ii. Alternator rectifier

(b) AC output

i. Variable frequency, variable or constant voltage AC.

ii. Constant frequency, variable or constant voltage AC

(4) According to the rotational speed of the area turbines

(1) Constant speed and variable pitch blades

(2) Nearly constant speed with fixed pitch blades

(3) Variable speed with fixed pitch blades

(a) Field modulated system

(b) Double output indication generator

(c) AC-DC-AC link

(d) AC commentator generator

Variable speed constant frequency generating system.

(5) As per utilization of output

(a) Battery storage

(b) Direct conversion to an electromagnetic energy converter

(c) Thermal potential

(d) Inter convention with conventional electric utility guides

Energy from Biomass

We have used biomass energy, or "bioenergy"—the energy from plants and plant-derived materials—since people began burning wood to cook food and keep warm. Wood is still the largest biomass energy resource today, but other sources of biomass can also be used. These include food crops, grassy and woody plants, residues from agriculture or forestry, oil-rich algae, and the organic component of municipal and industrial wastes. Even the fumes from landfills (which are methane, the main component in natural gas) can be used as a biomass energy source.

Benefits of Using Biomass

- Biomass can be used for fuels, power production, and products that would otherwise be made from fossil fuels. In such scenarios, biomass can provide an array of benefits. For example:
- The use of biomass energy has the potential to greatly reduce greenhouse gas emissions. Burning biomass releases about the same amount of carbon dioxide as burning fossil fuels. However, fossil fuels release carbon dioxide captured by photosynthesis millions of years ago—an essentially "new" greenhouse gas. Biomass, on the other hand, releases carbon dioxide that is largely balanced by the carbon dioxide captured in its own growth (depending how much energy was used to grow, harvest, and process the fuel). However, recent studies have found that clearing forests to grow biomass results in a carbon penalty that takes decades to recoup, so it is best if biomass is grown on previously cleared land, such as under-utilized farm land.
- The use of biomass can reduce dependence on foreign oil because biofuels are the only renewable liquid transportation fuels available.

Biomass energy supports U.S. agricultural and forest-product industries. The main biomass feedstocks for power are paper mill residue, lumber mill scrap, and municipal waste. For biomass fuels, the most common feedstocks used today are corn grain (for ethanol) and soybeans (for biodiesel). In the near future—and with NREL-developed technology—agricultural residues such as corn stover (the stalks, leaves, and husks of the plant) and wheat straw will also be used. Long-term plans include growing and using dedicated energy crops, such as fast-growing trees and grasses, and algae. These feedstocks can grow sustainably on land that will not support intensive food crops.

NREL's vision is to develop technology for biorefineries that will convert biomass into a range of valuable fuels, chemicals, materials, and products—much like oil refineries and petrochemical plants do.

Research to develop and advance technologies for the following biomass energy applications:

- Biofuels—Converting biomass into liquid fuels for transportation
- Biopower—Burning biomass directly, or converting it into gaseous or liquid fuels that burn more efficiently, to generate electricity
- Bioproducts—Converting biomass into chemicals for making plastics and other products that typically are made from petroleum.

Biofuels

Liquid biofuels include pure plant oil, biodiesel, and bioethanol. Biodiesel is based on esterification of plant oils. Ethanol is primarily derived from sugar, maize, and other starchy crops. Global production of biofuels consists primarily of ethanol, followed by biodiesel production. These are described below.

Straight Vegetable Oil (SVO)/Pure Plant Oil (PPO):

SVP/PPO can be used in most modern diesel vehicle engines only after some technical modifications. Principally, the viscosity of the SVO/PPO must be reduced by preheating it. However, some diesel engines can run on SVO/PPO without modifications. PPO is obtained from edible oil-producing plants such as the African palm, groundnuts, cotton seeds, sunflower, canola, or non-edible oils such as jatropha, neem, or even balanites. These raw oils, unused or used, can be employed in certain diesel engines, for cooking, or in diesel generators for the production of electricity.

Biodiesel:

Biodiesel can be used in pure form or may be blended with petroleum diesel at any concentration for use in most modern diesel engines. Biodiesel is raw vegetable oil transformed, treated, and standardized through chemical processes. The standardization of this product, and its industrial production, renders its use much more diverse than PPO. Biodiesel is used in diesel engines and diesel vehicles. Biodiesel can be produced from different feedstocks, such as oil feedstock (e.g., rapeseed, soybean oils, jatropha, palm oil, hemp, algae, canola, flax, and mustard), animal fats, and/or waste vegetable oil.

Alcohols:

Ethanol, butanol, and methanol are produced principally from such energy crops as sugarcane, maize, beets, yam, or sweet sorghum. Ethanol is the most widely used alcohol, primarily as a fuel for transportation or as a fuel additive. Bioethanol can be produced from a variety of feedstocks, including sugarcane, corn, sugar beet, cassava, sweet sorghum, sunflower, potatoes, hemp, or cotton seeds, or derived from cellulose waste.

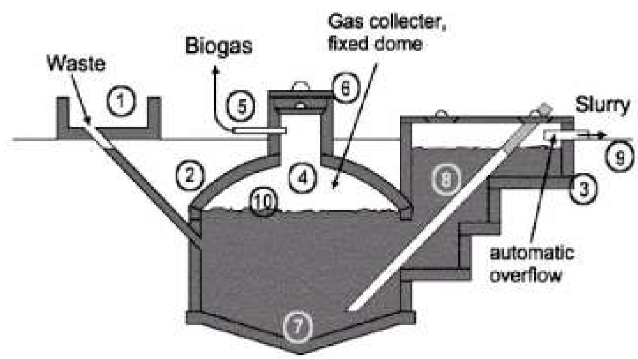
Types of Biogas Plants

A total of seven different types of biogas plant have been officially recognised by the MNES.

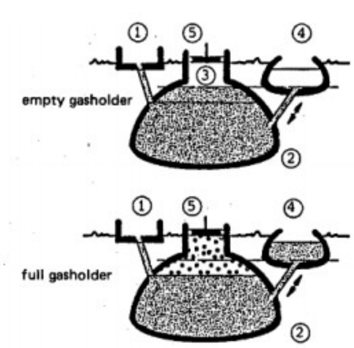
1. the floating-drum plant with a cylindrical digester (KVIC model),
2. the fixed-dome plant with a brick reinforced, moulded dome (Janata model)
3. the floating-drum plant with a hemisphere digester (Pragati model)
4. the fixed-dome plant with a hemisphere digester (Deenbandhu model)
5. the floating-drum plant made of angular steel and plastic foil (Ganesh model)
6. the floating-drum plant made of pre-fabricated reinforced concrete compound units
7. the floating-drum plant made of fibre-glass reinforced polyester.

1. Fixed-dome Plants

A fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank. The costs of a fixed-dome biogas plant are relatively low. It is simple as no moving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected. The plant is constructed underground, protecting it from physical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons, sunshine and warm seasons take longer to heat up the digester. No day/night fluctuations of temperature in the digester positively influence the bacteriological processes. The construction of fixed dome plants is labor-intensive, thus creating local employment. Fixed-dome plants are not easy to build. They should only be built where construction can be supervised by experienced biogas technicians. Otherwise plants may not be gas-tight (porosity and cracks). The basic elements of a fixed dome plant (here the Nicarao Design) are shown in the figure below.



Fixed dome plant Nicarao design:
1. Mixing tank with inlet pipe and sand trap. 2. Digester. 3. Compensation and removal tank. 4. Gasholder. 5. Gaspipe. 6. Entry hatch, with gastight seal. 7. Accumulation of thick sludge. 8. Outlet pipe. 9. Reference level. 10. Supernatant scum, broken up by varying level.



Dr. A.NAGAMANI PRABU
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Basic function of a fixed-dome biogas plant,

1 Mixing pit, 2 Digester, 3 Gasholder, 4 Displacement pit, 5 Gas pipe

Function

A fixed-dome plant comprises of a closed, dome-shaped digester with an immovable, rigid gas-holder and a displacement pit, also named 'compensation tank'. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gas-holder, the gas pressure is low.

Digester

The digesters of fixed-dome plants are usually masonry structures, structures of cement and ferro-cementexist. Main parameters for the choice of material are:

Technical suitability (stability, gas- and liquid tightness);

- cost-effectiveness;
- availability in the region and transport costs;
- availability of local skills for working with the particular building material.

Fixed dome plants produce just as much gas as floating-drum plants, if they are gas-tight. However, utilization of the gas is less effective as the gas pressure fluctuates substantially. Burners and other simple appliances cannot be set in an optimal way. If the gas is required at constant pressure (e.g., for engines), a gas pressure regulator or a floating gas-holder is necessary.

Gas Holder - The top part of a fixed-dome plant (the gas space) must be gas-tight. Concrete, masonry and cement rendering are not gas-tight. The gas space must therefore be painted with a gas-tight layer (e.g. 'Water-proofer', Latex or synthetic paints). A possibility to reduce the risk of cracking of the gas-holder consists in the construction of a weak-ring in the masonry of the digester. This "ring" is a flexible joint between the lower (water-proof) and the upper (gas-proof) part of the hemispherical structure. It prevents cracks that develop due to the hydrostatic pressure in the lower parts to move into the upper parts of the gas-holder.

Types of Fixed Dome Plants

Chinese fixed-dome plant Chinese fixed-dome plant is the archetype of all fixed dome plants. Several million have been constructed in China. The digester consists of a cylinder with round bottom and top.

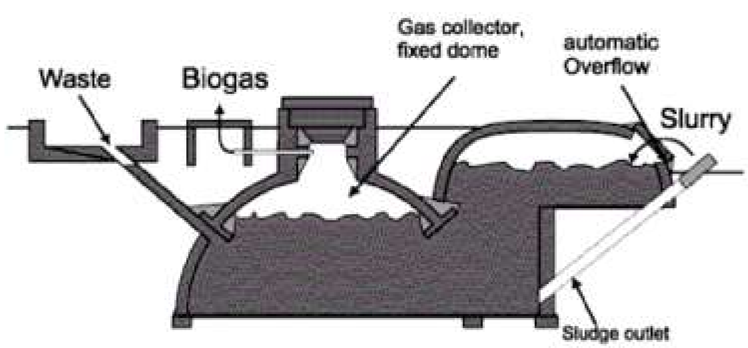
Janata model

Janata model was the first fixed-dome design in India, as a response to the Chinese fixed domeplant. It is not constructed anymore. The mode of construction lead to cracks in the gasholder - very few of these plant had been gas-tight.

Deenbandhu, the successor of the Janata plant in India, with improved design, was more crack proof and consumed less building material than the Janata plant. with a hemisphere digester

CAMARTEC model

CAMARTEC model has a simplified structure of a hemispherical dome shell based on a rigid♣ foundation ring only and a calculated joint of fraction, the so-called weak / strong ring. It was developed in the late 80s in Tanzania



Climate and Size - Fixed-dome plants must be covered with earth up to the top of the gas-filled space to counteract the internal pressure (up to 0,15 bar). The earth cover insulation and the option for internal heating makes them suitable for colder climates. Due to economic parameters, the recommended minimum size of a fixed-dome plant is 5 m3 . Digester volumes up to 200 m3 are known and possible.

Advantages: Low initial costs and long useful life-span; no moving or rusting parts involved; basic design is compact, saves space and is well insulated; construction creates local employment. Advantages are the relatively low construction costs, the absence of moving parts and rusting steel parts. If well constructed, fixed dome plants have a long life span. The underground construction saves space and protects the digester from temperature changes. The construction provides opportunities for skilled local employment.

Disadvantages: Masonry gas-holders require special sealants and high technical skills for gas-tight construction; gas leaks occur quite frequently; fluctuating gas pressure complicates gas utilization; amount of gas produced is not immediately visible, plant operation not readily understandable; fixed dome plants need exact planning of levels; excavation can be difficult and expensive in bedrock. Disadvantages are mainly the frequent problems with the gas-tightness of the brickwork gas holder (a small crack in the upper brickwork can cause heavy losses of biogas). Fixed-dome plants are, therefore, recommended only where construction can be supervised by experienced biogas technicians. The gas pressure fluctuates substantially depending on the volume of the stored gas. Even though the underground construction buffers temperature extremes, digester temperatures are generally low. Fixed dome plants can be recommended only where construction can be supervised by experienced biogas technicians.

Variations: Some companies are now looking into small pre-fab fixed dome plants made of fibreglass which appears to be a low cost alternative to construction intensive masoned plants. A custom made plant can be produced in 2 days and -after transport- installed in less than 1 day

2. Floating Drum Plants Floating-drum plants consist of an underground digester and a moving gas-holder. The gas-holder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guiding frame. If the drum floats in a water jacket, it cannot get stuck, even in substrate with high solid content.

Drum - In the past, floating-drum plants were mainly built in India. A floating-drum plant consists of a cylindrical or dome-shaped digester and a moving, floating gas-holder, or drum. The gas-holder floats either directly in the fermenting slurry or in a separate water jacket. The drum in which the biogascollects has an internal and/or external guide frame that provides stability and keeps the drum upright. If biogas is produced, the drum moves up, if gas is consumed, the gas-holder sinks back.

Size - Floating-drum plants are used chiefly for digesting animal and human feces on a continuousfeed mode of operation, i.e. with daily input. They are used most frequently by small- to middle-sized farms (digester size: 5-15m3) or in institutions and larger agro-industrial estates (digester size: 20- 100m3).

Disadvantages: The steel drum is relatively expensive and maintenance-intensive. Removing rust and painting has to be carried out regularly. The life-time of the drum is short (up to 15 years; in tropical coastal regions about five years). If fibrous substrates are used, the gas-holder shows a tendency to get "stuck" in the resultant floating scum.

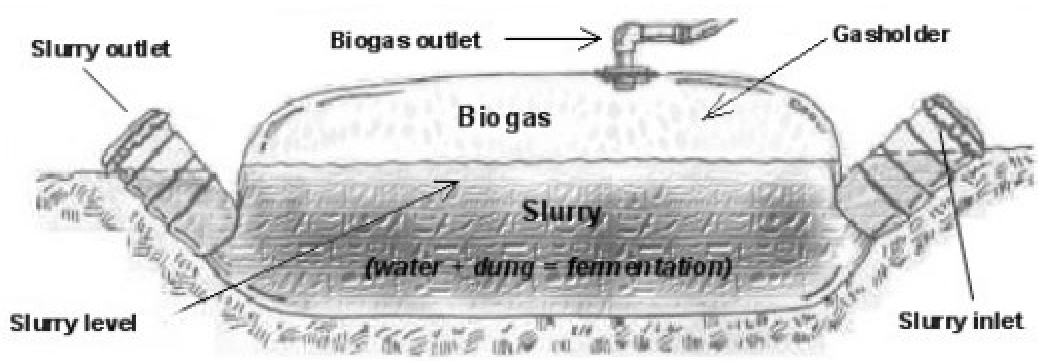
Water Jacket Floating Drum Plant Water-jacket plants are universally applicable and easy to maintain. The drum cannot get stuck in a scum layer, even if the substrate has a high solids content. Water-jacket plants are characterized by a long useful life and a more aesthetic appearance (no dirty gas-holder). Due to their superior sealing of the substrate (hygiene!), they are recommended for use in the fermentation of night soil. The extra cost of the masonry water jacket is relatively modest.

Material of Digester and Drum The digester is usually made of brick, concrete or quarry-stone masonry with plaster. The gas drum normally consists of 2.5 mm steel sheets for the sides and 2 mm sheets for the top. It has welded-in braces which break up surface scum when the drum rotates. The drum must be protected against corrosion. Suitable coating products are oil paints, synthetic paints and bitumen paints. Correct priming is important. There must be at least two preliminary coats and one topcoat. Coatings of used oil are cheap. They must be renewed monthly. Plastic sheeting stuck to bitumen sealant has not given good results. In coastal regions, repainting is necessary at least once a year, and in dry uplands at least every other year. Gas production will be higher if the drum is painted black or red rather than blue or white, because the digester temperature is increased by solar radiation. Gas drums made of 2 cm wiremesh-reinforced concrete or fiber-cement must receive a gas-tight internal coating. The gas drum should have a slightly sloping roof, otherwise rainwater will be trapped on it, leading to rust damage. An excessively steep-pitched roof is unnecessarily expensive and the gas in the tip cannot be used because when the drum is resting on the bottom, the gas is no longer under pressure. Floating-drums made of glass-fiber reinforced plastic and high-density polyethylene have been used successfully, but the construction costs are higher compared to using steel. Floating-drums made of wire-mesh-reinforced concrete are liable to hairline cracking and are intrinsically porous. They require a gas-tight, elastic internal coating. PVC drums are unsuitable because they are not resistant to UV

Guide Frame The side wall of the gas drum should be just as high as the wall above the support ledge. The floatingdrum must not touch the outer walls. It must not tilt, otherwise the coating will be damaged or it will get stuck. For this reason, a floating-drum always requires a guide. This guide frame must be designed in a way that allows the gas drum to be removed for repair. The drum can only be removed if air can flow into it, either by opening the gas outlet or by emptying the water jacket. The floating gas drum can be replaced by a balloon above the digester. This reduces construction costs but in practice problems always arise with the attachment of the balloon to the digester and with the high susceptibility to physical damage.

2. **Low Cost Polyethylene Tube Digester**

Digester - In the case of the Low-Cost Polyethylene Tube Digester model which is applied in Bolivia (Peru, Ecuador, Colombia, Centro America and Mexico), the tubular polyethylene film (two coats of 300 microns) is bended at each end around a 6 inch PVC drainpipe and is wound with rubber strap of recycled tire-tubes. With this system a hermetic isolated tank is obtained.



One of the 6" PVC drainpipes serves as inlet and the other one as the outlet of the slurry. In the tube digester finally, a hydraulic level is set up by itself, so that as much quantity of added prime matter (the mix of dung and water) as quantity of fertilizer leave by the outlet. Because the tubular polyethylene is flexible, it is necessary to construct a "cradle" which will accommodate the reaction tank, so that a trench is excavated.

Gas Holder and Gas Storage Reservoir - The capacity of the gasholder corresponds to 1/4 of the total capacity of the reaction tube. To overcome the problem of low gas flow rates, two 200 microns tubular polyethylene reservoirs are installed close to the kitchen, which gives a 1,3 m^3 additional gas storage.

4.Baloon Plants - A balloon plant consists of a heat-sealed plastic or rubber bag (balloon), combining digester and gas-holder. The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the skin of the balloon. Gas pressure can be increased by placing weights on the balloon. If the gas pressure exceeds a limit that the balloon can withstand, it may damage the skin. Therefore, safety valves are required. If higher gas pressures are needed, a gas pump is required. Since the material has to be weather- and UV resistant, specially stabilized, reinforced plastic or synthetic caoutchouc is given preference. Other materials which have been used successfully include RMP (red mud plastic), Trevira and butyl. The useful life-span does usually not exceed 2-5 years.

Advantages: Standardized prefabrication at low cost, low construction sophistication, ease of transportation, shallow installation suitable for use in areas with a high groundwater table; high digester temperatures in warm climates; uncomplicated cleaning, emptying and maintenance;

difficult substrates like water hyacinths can be used. Balloon biogas plants are recommended, if local repair is or can be made possible and the cost advantage is substantial.

Disadvantages: Low gas pressure may require gas pumps; scum cannot be removed during operation; the plastic balloon has a relatively short useful life-span and is susceptible to mechanical damage and usually not available locally. In addition, local craftsmen are rarely in a position to repair a damaged balloon. There is only little scope for the creation of local employment and, therefore, limited selfhelp potential.

Variations: A variation of the balloon plant is the channel-type digester, which is usually covered with plastic sheeting and a sunshade. Balloon plants can be recommended wherever the balloon skin is not likely to be damaged and where the temperature is even and high.

5. Horizontal Plants - Horizontal biogas plants are usually chosen when shallow installation is called for (groundwater, rock). They are made of masonry or concrete.

Advantages: Shallow construction despite large slurry space.

Disadvantages: Problems with gas-space leakage, difficult elimination of scum.

6. Earth Pit Plants - Masonry digesters are not necessary in stable soil (e.g. laterite). It is sufficient to line the pit with a thin layer of cement (wire-mesh fixed to the pit wall and plastered) in order to prevent seepage. The edge of the pit is reinforced with a ring of masonry that also serves as anchorage for the gas-holder. The gas-holder can be made of metal or plastic sheeting. If plastic sheeting is used, it must be attached to a quadratic wooden frame that extends down into the slurry and is anchored in place to counter its buoyancy. The requisite gas pressure is achieved by placing weights on the gasholder. An overflow point in the peripheral wall serves as the slurry outlet. Advantages: Low cost of installation (as little as 20% of a floating-drum plant); high potential for self help approaches. Disadvantages: Short useful life; serviceable only in suitable, impermeable types of soil. Earth-pit plants can only be recommended for installation in impermeable soil located above the groundwater table. Their construction is particularly inexpensive in connection with plastic sheet gasholders.

7. Ferrocement Plants - The ferro-cement type of construction can be applied either as a selfsupporting shell or an earth-pit lining. The vessel is usually cylindrical. Very small plants can be prefabricated. As in the case of a fixed-dome plant, the ferrocement gasholder requires special sealing measures (proven reliability with cemented-on aluminium foil). Advantages: Low cost of construction, especially in comparison with potentially high cost of masonry for alternative plants; mass production possible; low material input. Disadvantages: Substantial consumption of essentially good-quality cement; workmanship must meet high quality standards; uses substantial amounts of expensive wire mesh; construction technique not yet adequately time-tested; special sealing measures for the gas-holder are necessary. Ferrocement biogas plants are only recommended in cases where special ferro-cement know-how is available.

Possible questions

Part – B

1. Write down the advantages of horizontal axis wind machines.
2. Write down the advantages of vertical axis wind machines.
3. What are the different types of horizontal axis wind machine?
4. What are the different types of vertical axis wind machine?
5. What are the applications of wind energy data?
6. What is the basis of wind energy conversion?
7. With neat diagram explain the working of different types of vertical axis wind machine.
8. Derive an expression for power in wind.
9. Write down the difference between horizontal and vertical axis machine.
10. What is the basic principle of wind energy conversion?

Part - C

1. Describe about the nature of the wind.

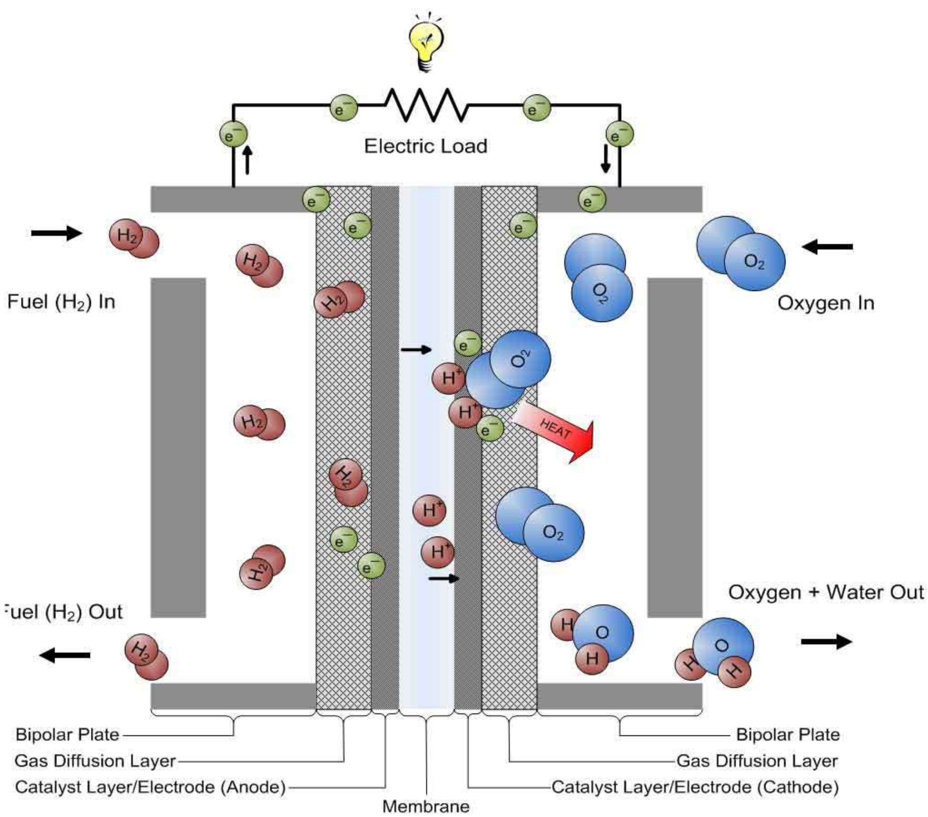
Fuel Cells: Design and Principle of operation, Classification, Types, Advantages and disadvantages, Conversion efficiency, Types of electrodes, Work output and EMF of Fuel Cells, Applications of Fuel Cells.

Thermo Nuclear Fusion Energy: Fusion Reactions, Requirements, Plasma, Magnetic and Inertial Confinement fusion, Muon Catalyzed Fusion, Characteristics of D-T Reaction, Advantages of Nuclear Fusion, Fusion Hybrid, Cold Fusion.

Explain the construction and working of green fuel cell.

Working Principle A fuel cell is a device that uses hydrogen (or hydrogen-rich fuel) and oxygen to create electricity by an electrochemical process.

A single fuel cell consists of an electrolyte sandwiched between two thin electrodes (a porous anode and cathode) Hydrogen, or a hydrogen-rich fuel, is fed to the anode where a catalyst separates hydrogen's negatively charged electrons from positively charged ions (protons) At the cathode, oxygen combines with electrons and, in some cases, with species such as protons or water, resulting in water or hydroxide ions, respectively



- **Fuel cell** converts the chemical energy of the fuels directly to electric energy.
- **Fuel + Oxygen Oxidation products + Electricity**
- It consists of two porous carbon electrode as anode and cathode.
- They are coated with Pt or Pd

- Aqueous KOH or H_2SO_4 is electrolyte.
- Anode and cathode are connected through voltmeter
- Fuel is pumped at the anode and oxidation at the cathode

Working:

i) Anode Reaction : $2H_2 + 4OH^- \quad 4H_2O + 4e^-$

ii) Cathode Reaction : $O_2 + 4H_2O + 4e^- \quad 4OH^-$

iii) Overall cell Reaction : $2H_2 + O_2 \quad 4H_2O$

- Used in cars, buses, electric boats, space crafts, submarines, military vehicles.
- Used in producing drinking water for astronauts in the space.

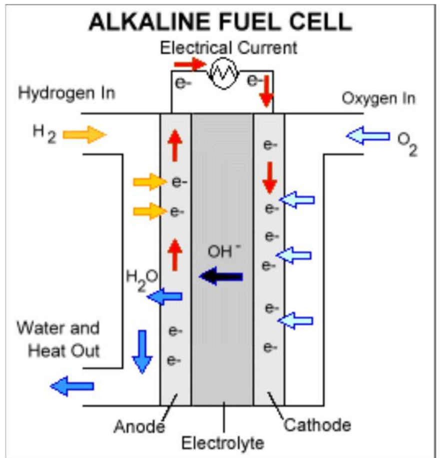
Classification of Fuel Cells

Based on the type of Electrolyte	**Based on Types of Fuel and oxidant**
1. Alkaline Fuel cell (AFC) **2.** Phosphoric Acid Fuel cell (PAFC) **3.** Polymer Electrolytic Membrane Fuel Cell (PEMFC) Solid Polymer Fuel Cell (SPFC) and Proton Exchange Membrane Fuel cell (PEMFC) **4.** Molten Carbonate Fuel Cell (MCFC) **5.** Solid Oxide Fuel Cell (SOFC)	**1**. Hydrogen (pure)-Oxygen (pure) fuel cell **2**. Hydrogen rich gas-air fuel cell **3**. Ammonia –air fuel cell **4**. Synthesis gas- air fuel cell **5.** Hydro carbon (gas)- air fuel cell Based on operating temperature

Different types of fuel cells.

Alkaline Fuel

Alkali fuel cells operate on compressed hydrogen and oxygen. They generally use a solution of potassium hydroxide (chemically, KOH) in water as their electrolyte. Efficiency is about 70 percent, and operating temperature is 150 to 200 degrees C, (about 300 to 400 degrees F). Cell output ranges from 300 watts (W) to 5 kilowatts (kW). Alkali cells were used in Apollo spacecraft to provide both electricity and drinking water. They require pure hydrogen fuel, however, and their platinum electrode catalysts are expensive. And like any container filled with liquid, they can leak.



Anode Reaction: 2H2 + 4OH- »» 4H2O + 4e-

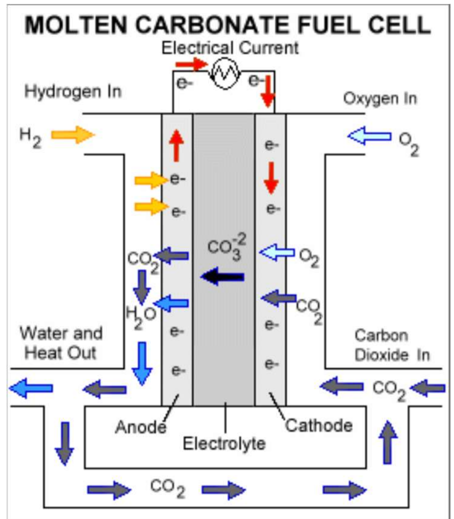
Cathode Reaction: O2 + 2H2O + 4e- »» 4OH-

Molten Carbonate fuel cells (MCFC) use high-temperature compounds of salt (like sodium or magnesium) carbonates (chemically, CO_3) as the electrolyte. Efficiency ranges from 60 to 80 percent, and operating temperature is about 650 degrees C (1,200 degrees F). Units with output up to 2 megawatts (MW) have been constructed, and designs exist for units up to 100 MW. The high temperature limits damage from carbon monoxide "poisoning" of the cell and waste heat can be recycled to make additional electricity. Their nickel electrode-catalysts are inexpensive compared to the platinum used in other cells. But the high temperature also limits the materials and safe uses of MCFCs–they would probably be too hot for home use. Also, carbonate ions from the electrolyte are used up in the reactions, making it necessary to inject carbon dioxide to compensate.

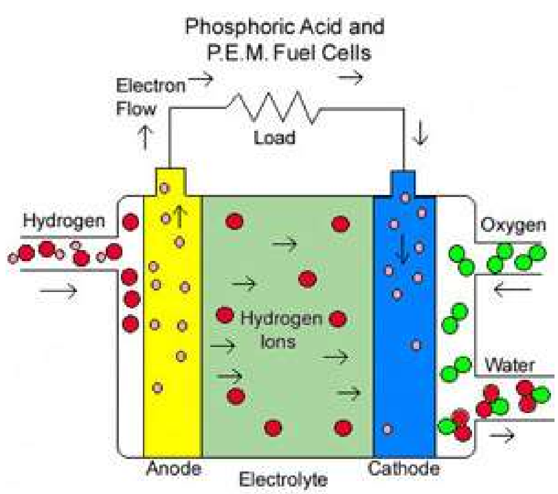
Anode Reaction: CO3-2 + H2 → H2O + CO2 + 2e-

Cathode Reaction: CO2 + ½O2 + 2e- → CO3-2

Overall Cell Reaction: H2 + ½O2 → H2O

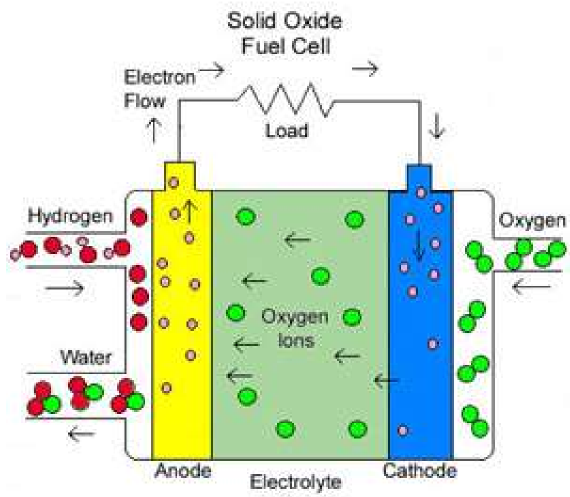


Phosphoric Acid fuel cells (PAFC) use phosphoric acid as the electrolyte. Efficiency ranges from 40 to 80 percent, and operating temperature is between 150 to 200 degrees C (about 300 to 400 degrees F). Existing phosphoric acid cells have outputs up to 200 kW, and 11 MW units have been tested. PAFCs tolerate a carbon monoxide concentration of about 1.5 percent, which broadens the choice of fuels they can use. If gasoline is used, the sulfur must be removed. Platinum electrode-catalysts are needed, and internal parts must be able to withstand the corrosive acid.



Proton Exchange Membrane (PEM) fuel cells work with a polymer electrolyte in the form of a thin, permeable sheet. Efficiency is about 40 to 50 percent, and operating temperature is about 80 degrees C (about 175 degrees F). Cell outputs generally range from 50 to 250 kW.

The solid, flexible electrolyte will not leak or crack, and these cells operate at a low enough temperature to make them suitable for homes and cars. But their fuels must be purified, and a platinum catalyst is used on both sides of the membrane, raising costs.



Solid Oxide fuel cells (SOFC) use a hard, ceramic compound of metal (like calcium or zirconium) oxides (chemically, O_2) as electrolyte. Efficiency is about 60 percent, and operating temperatures are about 1,000 degrees C (about 1,800 degrees F). Cells output is up to 100 kW. At such high temperatures a reformer is not required to extract hydrogen from the fuel, and waste heat can be recycled to make additional electricity. However, the high temperature limits applications of SOFC units and they tend to be rather large. While solid electrolytes cannot leak, they can crack.

More detailed information about each fuel cell type, including histories and current applications, can be found on their specific parts of this site. We have also provided a glossary of technical terms–a link is provided at the top of each technology page.

Alkaline Fuel Cells (AFC)

The alkaline fuel cell uses an alkaline electrolyte such as 40% aqueous potassium hydroxide. In alkaline fuel cells, negative ions travel through the electrolyte to the anode where they combine with hydrogen to generate water and electrons.It was originally used by NASA on space missions. NASA space shuttles use Alkaline Fuel Cells. Alkaline fuel cells (AFCs) were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electrical energy and water onboard spacecraft. These fuel cells use a solution of potassium hydroxide in water as the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode. High-temperature AFCs operate at temperatures between 100ºC and 250ºC (212ºF and 482ºF). However, more-recent AFC designs operate at lower temperatures of roughly 23ºC to 70ºC (74ºF to 158ºF).

AFCs are high-performance fuel cells due to the rate at which chemical reactions take place in the cell. They are also very efficient, reaching efficiencies of 60 percent in space applications. The disadvantage of this fuel cell type is that it is easily poisoned by carbon dioxide (CO2). In fact, even the small amount of CO2 in the air can affect the cell's operation, making it necessary to purify both the hydrogen and oxygen used in the cell. CO2 can combine with KOH to form potasium carbonate which will increase the resistance. This purification process is costly. Susceptibility to poisoning also affects the cell's lifetime (the amount of time before it must be replaced), further adding to cost. Cost is less of a factor for remote locations such as space or under the sea. However, to effectively compete in most mainstream commercial markets, these fuel cells will have to become more cost effective. AFC stacks have been shown to maintain sufficiently stable operation for more than 8,000 operating hours.

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Molten Carbonate Fuel Cells (MCFC):

The molten carbonate fuel cell uses a **molten carbonate salt as the electrolyte.** It has the potential to be fuelled with coal- derived fuel gases, methane or natural gas. These fuel cells can work at up to 60% efficiency In molten carbonate fuel cells, negative ions travel through the electrolyte to the anode where they combine with hydrogen to generate water and electrons. Molten carbonate fuel cells (MCFCs) are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide (LiAlO2) matrix. Since they **operate at extremely high temperatures of 650ºC** and above, nonprecious metals can be used as catalysts at the anode and cathode, reducing costs Unlike alkaline, phosphoric acid, and polymer electrolyte membrane fuel cells, MCFCs don't require an external reformer to convert more energy-dense fuels to hydrogen. Due to the high temperatures at which they operate, these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, which also reduces cost. Although they are more resistant to impurities than other fuel cell types, scientists are looking for ways to make MCFCs resistant enough to impurities from coal, such as sulfur and particulates. The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life.

Scientists are currently exploring corrosion-resistant materials for components as well as fuel cell designs that increase cell life without decreasing performance.

Advantages:

1. Most abundant element:

Hydrogen is the most abundant element in the Universe, which makes up about 3/4 of all matter. Anywhere there is water (H_2O) you have hydrogen and oxygen.

2. Hydrogen has the highest energy content:

Energy content of hydrogen is the highest per unit of weight of any fuel. Therefore it offers the most "bang for the buck". When water is broken down into HHO, otherwise known as oxyhydrogen or Brown's Gas, it becomes a very, very efficient fuel.

3. Hydrogen is non-polluting:

Along with its effectiveness as a fuel, hydrogen is non-polluting. The only byproduct of hydrogen when it burns is heat and water.

4. Hydrogen is a renewable fuel source:

Hydrogen is very plentiful. The trick is to break the water molecules down to release it.

5. Reduce dependency on foreign oil:

It will greatly reduce the import of highly expensive oil demands of our country.

Disadvantages:

1. Hydrogen is currently very expensive, not because it is rare (it's the most common element in the universe!) but because it's difficult to generate, handle, and store, requiring bulky and heavy tanks like those for compressed natural gas (CNG) or complex insulating bottles if stored as a cryogenic (super-cold) liquid like liquefied natural gas (LNG).

2. It can also be stored at moderate temperatures and pressures in a tank containing a metal-hydride absorber or carbon absorber, though these are currently very expensive

Fuel cell efficiencies

There seems to be no commitment how to define or name the different efficiencies for fuel cells. Therefore the only thing I can do here is to clarify the differences; well knowing that in literature other definitions and wordings are used. Don't talk about efficiency if you don't know what you are talking about! All efficiencies can be based on either LHV or HHV of the fuel. There is also no commitment to use LHV or HHV. Therefore be careful and keep in mind that the efficiency is higher if it refers to LHV! In general the energy conversion efficiency ŋ is defined as:

$$\eta = \frac{\text{(useful) energy output}}{\text{energy input}} = \frac{\text{(useful) power output}}{\text{power input}}$$

Thermodynamic efficiency The thermodynamic or maximum or ideal efficiency is the ratio between enthalpy (or heating value)ΔH and Gibbs free enthalpy ΔG (reflecting the maximum extractible work) of any electrochemical device:

$$\eta_{\text{el, max}} = \frac{\Delta G}{\Delta H}$$

For the hydrogen fuel cell it is:

$$\eta_{\text{el, TD, LHV}} = \frac{-\Delta_f G_{H_2O_{(g)}}}{\text{LHV}} = \frac{E_g^0}{E_{\text{LHV}}^0} = \frac{1.184\ \text{V}}{1.253\ \text{V}} = 94.5\%$$

$$\eta_{\text{el, TD, HHV}} = \frac{-\Delta_f G_{H_2O_{(l)}}}{\text{HHV}} = \frac{E_l^0}{E_{\text{HHV}}^0} = \frac{1.229\ \text{V}}{1.481\ \text{V}} = 83.1\%$$

APPLICATIONS The three main markets for fuel cell technology are:

4.1 Stationary Power

- Fuel cells can be used for load leveling. When the generation exceeds the demand, excess generated energy can be converted and stored as hydrogen by electrolysis of water. During peak load time, when demand exceeds the generation, the stored hydrogen would be used in fuel cells to meet demand.
- Fuel cells are also suitable for dispersed generation. By locating the fuel cells near the load centre, transmission and distribution cost would be avoided or reduced.
- To meet the demand of isolated sites such as construction sites, military camps and small village, fuel cells are more suited than DG sets.
- Emergency or auxiliary supply to critical loads such as hospitals, educational institutions etc can be met using fuel cells.
- Combined Heat and Power: energy produced during the conversion of chemical energy to electrical energy can be extracted from the Fuels cells operating at high temperature, like Solid Oxide fuel cells and Molten carbonate fuel cells. This heat can be used to provide industrial process heat or to generate additional power employing waste heat boilers and steam turbines. It is a significant opportunity to increase the efficiency of the power plant.

Transportation Power

- Fuel cells can also be used as a mobile power source in vehicles, submarines and spacecrafts. A hydrogen-oxygen alkali fuel cell has been used successfully to provide power in shuttle spacecrafts.
- Fuel cells are also being tested now a days as a power source for propulsion of electric vehicles like car, buses etc. In India Tata Motors and Indian space research Organization (ISRO) are conducting trials on a hydrogen powered fuel cell bus with 250 HP.

Portable Power

- Fuel cells can be used to power portable electronic devices, (e.g., mobile phones, laptops and other low-power appliances, especially those used in military).
- It can be used as substitute for primary or rechargeable batteries. Instead of waiting for several hours for recharging, a small cartridge of methanol can be replaced in the way as an ink cartridge in a printer.

Possible questions

Part – B

1. Discuss about the work output, emf and applications of fuel cell.
2. Write a note on magnetic and inertial confinement fusion.
3. What are the different types of fuel cells and its advantages?
4. Determine the conversion efficiency of fuel cell.
5. Discuss about the design and principle of operation of a fuel cell.
6. Explain the characteristic of D-T reaction
7. Determine the work output and EMF of fuel cell
8. What are the different types of electrodes available for fuel cell.
9. Explain about the material selection for geothermal power plants
10. Explain the conversion technology for the generation of gas.

Part – C

1. Derive an equation for the efficiency of fuel cell.

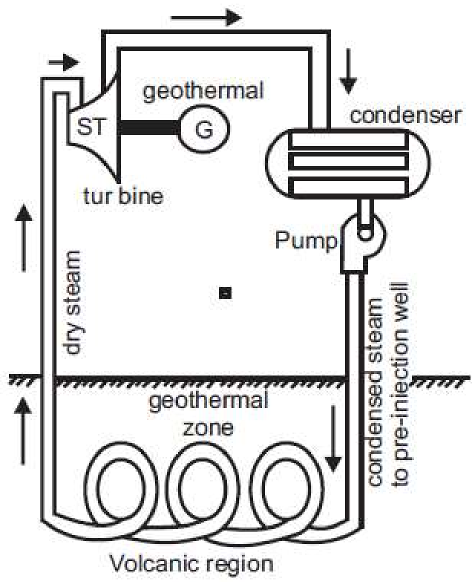
Principles of working: Geothermal, OTEC, Tidal, Waves, and Hydrogen (Generation and Application)

Geothermal energy:

Energy present as heat (i.e. thermal energy) in the earth's crust, in the upper most 10 km or so of the crust constitutes a potentially useful and almost inexhaustible source of energy. Geothermal source is defined as "all of the heat stored in the earth's crust above 15° C to a depth of 10 km". It occurs when the immense heat energy in the core of earth rises closer to the surface of the earth due to cracks or faults in the crust and heats the surrounded rock. These are tapped to use the stored heat energy, for power generation and several other uses, depending upon the temperature of occurrence and other parameters.

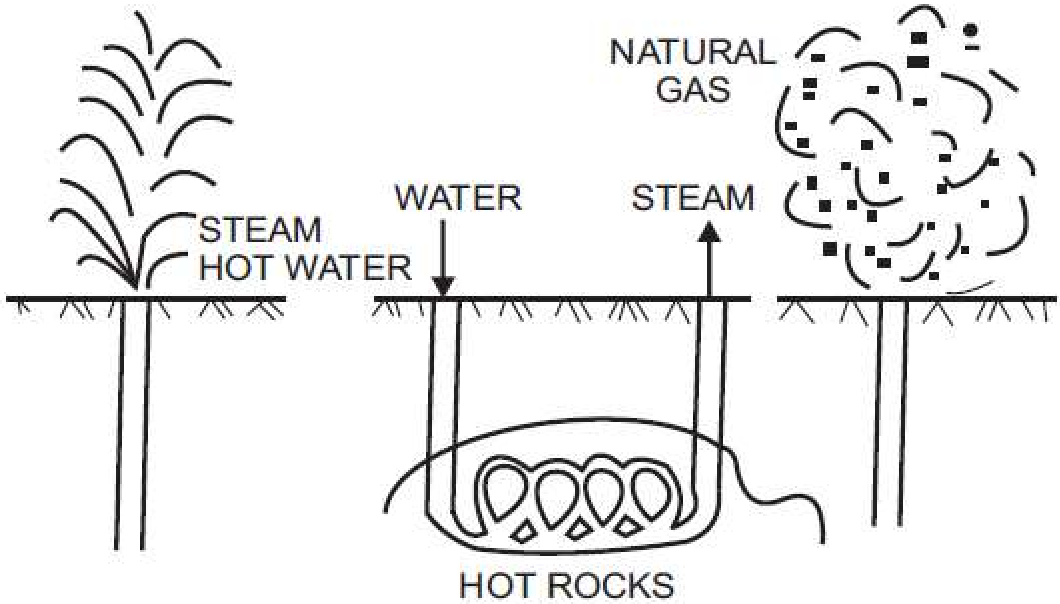
Hot molten rock, called "Magma" is commonly present at depths greater than 24 to 40 km. The hot magma near the surface solidifies into igneous rock which is formed by volcanic action. The heat of the magma is conducted upward to this igneous rock. Ground water that finds its way down to this rock through fissures (cracks) in it, will be heated by the heat of the rock or by mixing with hot gases and steam let out from the magma. The heated water will then rise convectively upward into a porous and permeable reservoir above the igneous rock. The reservoir is capped by a layer of impermeable solid rock that traps the hot water in the reservoir. The solid rock, however, has fissures that act as vents of the giant underground boiler. The vents show up at the surface as geysers or hot spring. A well taps steam from the fissures for use in a geothermal power plant. Geothermal energy has the highest energy density and it is classified as renewable because the earth's interior will continue to be hot for an indefinite future. But it is very expensive to set up, and works in areas of volcanic activity. Dangerous underground gases have to be disposed of very carefully in this source of energy.

Geothermal power stations use the naturally produced steam to drive turbines and generators. Once used, the steam turns back into water and is pumped back into the ground again to be reheated by the earth.



Hot dry rock resources (HDR):

This system is composed of hot dry rock (HDR) without underground water. They represent the largest geothermal resource available. The hot rock, occurring at moderate depths, has very low permeability and needs to be fractured to increase its heat transfer to surface. Hot dry rocks exist because they are impermeable to water or because water does not have access to them. Heat is recovered from such hot dry rocks by breaking up or cracking the rock to make it permeable and then introducing water from the surface. The water is heated up by the rock and is returned to the surface where the heat is utilized. There are two methods to tap this geothermal energy. One possible method is to detonate a high explosive at the bottom of a well drilled into the rock. This may be a nuclear explosive. Another method is to use hydraulic fracturing to produce the heat transfer surface and permeability required to extract energy at a high rate from hot dry rock. Heat can then be extracted from the hot rock by circulating water through the crack. The thermal energy of HDR is used in a power plant to produce electricity. The limitation of HDR is, two wells are to be drilled deeper and in much harder rock. This is expected to make the exploitation very costly, unless the underground rock targeted is very hot.



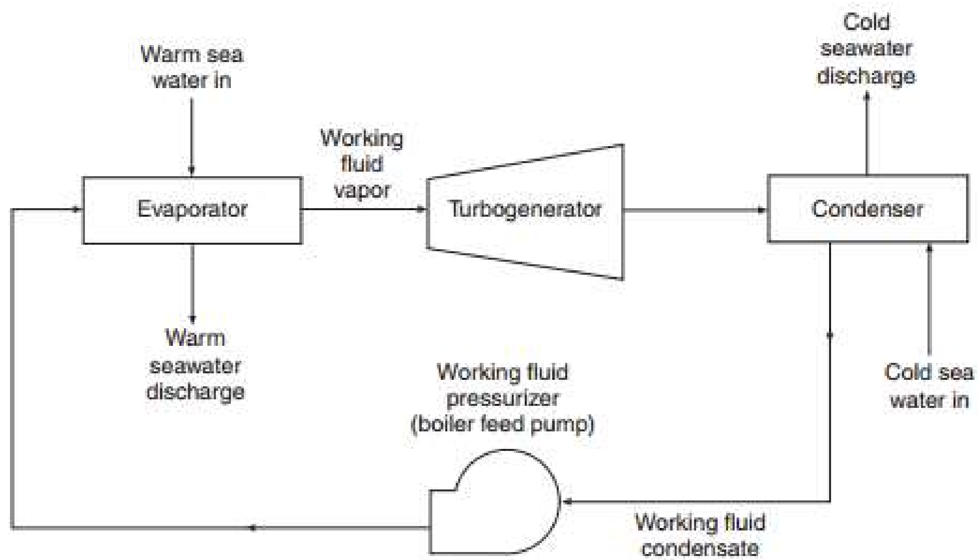
Ocean Thermal Energy Conversion

Ocean thermal energy conversion (OTEC) generates electricity indirectly from solar energy by harnessing the temperature difference between the sun-warmed surface of tropical oceans and the colder deep waters. A signiRcant fraction of solar radiation incident on the ocean is retained by seawater in tropical regions, resulting in average year-round surface temperatures of about 283C. Deep, cold water, meanwhile, forms at higher latitudes and descends to Sow along the seaSoor toward the equator. The warm surface layer, which extends to depths of about 100}200m, is separated from the deep cold water by a thermocline. The temperature difference, T, between the surface and thousand-meter depth ranges from 10 to 253C, with larger differences occurring in equatorial and tropical waters. T establishes the limits of the performance of OTEC power cycles; the rule-ofthumb is that a differential of about 203C is necessary to sustain viable operation of an OTEC facility. Since OTEC exploits renewable solar energy, recurring costs to generate electrical power are minimal. However, the Rxed or capital costs of OTEC systems per kilowatt of generating capacity. are very high because large pipelines and heat exchangers are needed to produce relatively modest amounts of electricity. These high Rxed costs dominate the economics of OTEC to the extent that it currently cannot compete with conventional power systems, except in limited niche markets. Considerable effort has been expended over the past two decades to develop OTEC by-products, such as fresh water, air conditioning, and mariculture, that could offset the cost penalty of electricity generation.

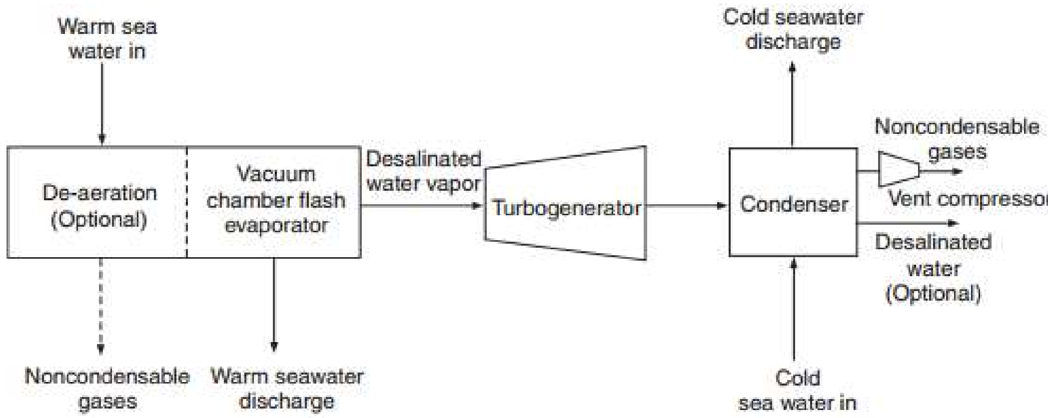
State of the Technology

State of the Technology OTEC power systems operate as cyclic heat engines. They receive thermal energy through heat transfer from surface sea water warmed by the sun, and transform a portion of this energy to electrical power. The Second Law of Thermodynamics precludes the complete conversion of thermal energy in to electricity. A portion of the heat extracted from the warm sea water must be rejected to a colder thermal sink. The thermal sink employed by OTEC systems is sea water drawn from the ocean depths by means of a submerged pipeline. A steady-state control volume energy analysis yields the result that net electrical power produced by the engine must equal the difference between the rates of heat transfer from the warm surface water and to the cold deep water. The limiting (i.e., maximum) theoretical Carnot energy conversion efRciency of a cyclic heat. engine scales with the difference between the temperatures at which these heat transfers occur. For OTEC, this difference is determined by T and is very small; hence, OTEC efRciency is low. Although viable OTEC systems are characterized by Carnot efRciencies in the range of 6}8%, state-of-the-art combustion steam power cycles, which tap much higher temperature energy sources, are theoretically capable of converting more than 60% of the extracted thermal energy into electricity. The low energy conversion efRciency of OTEC means that more than 90% of the thermal energy extracted from the ocean's surface is 'wasted' and must be rejected to the cold, deep sea water. This necessitates large heat exchangers and seawater Sow rates to produce relatively small amounts of electricity. In spite of its inherent inefRciency, OTEC, unlike conventional fossil energy systems, utilizes a renewable resource and poses minimal threat to the environment. In fact, it has been suggested that widespread adoption of OTEC could yield tangible environmental beneRts through avenues such as reduction of greenhouse gas CO2 emissions; enhanced uptake of atmospheric CO2 by marine organism populations sustained by the nutrient-rich, deep OTEC sea water; and preservation of corals and hurricane amelioration by limiting temperature rise in the surface ocean through energy extraction and artiRcial upwelling of deep water. Carnot efRciency applies only to an ideal heat engine. In real power generation systems, irreversibilities will further degrade performance. Given its low theoretical efRciency, successful implementation of OTEC power generation demands careful engineering to minimize irreversibilities. Although OTEC consumes what is essentially a free resource, poor. thermodynamic performance will reduce the quantity of electricity available for sale and, hence, negatively affect the economic feasibility of an OTEC facility. An OTEC heat engine may be configured following designs by J.A. D'Arsonval, the French engineer who Rrst proposed the OTEC concept in 1881, or G. Claude, D'Arsonval's former student. Their designs are known, respectively, as closed cycle and open cycle OTEC.

Closed Cycle OTEC



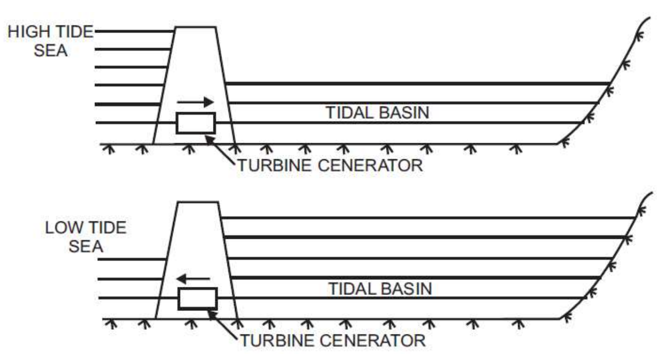
Schematic diagram of a closed-cycle OTEC system. The working fluid is vaporized by heat transfer from the warm sea water in the evaporator. The vapor expands through the turbogenerator and is condensed by heat transfer to cold sea water in the condenser. Closed-cycle OTEC power systems, which operate at elevated pressures, require smaller turbines than open-cycle systems.



Schematic diagram of an open-cycle OTEC system. In open-cycle OTEC, warm sea water is used directly as the working fluid. Warm sea water is flash evaporated in a partial vacuum in the evaporator. The vapor expands through the turbine and is condensed with cold sea water. The principal disadvantage of open-cycle OTEC is the low system operating pressures, which necessitate large components to accommodate the high volumetric flow rates of steam.

Tidal energy:

Tide is a periodic rise and fall of the water level of sea due to gravitational effect of the sun and moon on the water of the earth. Due to fluidity of water mass, there is a periodic rise and fall in levels of sea water which is in rhythms with the daily cycle of rising and setting of sun and moon. As the earth rotates, the position of a given area relative to the moon changes, and thus a periodic succession of high and low tides occur. This periodic rising and falling of the water level of sea is known as tidal power.



The large scale up and down movement of sea water due to tide represents an unlimited source of energy. If some part of the vast energy can be converted into electrical energy it would be an important source of hydro – power. Using a hydraulic turbine, the tidal energy could be converted into electrical energy by means of an attached generator. Water at the time of a high tide is at a higher level and can be let into a basin to be stored at a high level there. The same water can be let back into the sea during the low tide through the turbines, thus producing
power. The advantages of tidal power are 1) It is free from pollution, as it does not use any fuel and does not produce any unhealthy waste like gases, ash, atomic refuse, etc. 2) These power plants do no demand large area of valuable land because they are on the bays (Sea shore).
Its own limitations are
1) Sea water is corrosive and it was feared that the machinery may get corroded. But using vinyl paint exhibited good results.
2) Cost is not favourable compared to the other sources of energy and it is feared that the tidal power plant would hamper the other natural uses such as fishing or navigation.

Hydrogen generation

The potential of hydrogen gas as an energy carrier is immense, though it carries less energy than fossil fuel by volume. Its overall effect on the environment is minimal. Hydrogen is the smallest and the most abundant element in the universe [1]. It rarely exists in pure nature as hydrogen gas (H2) but in compounds such as hydrides and hydrocarbons. Hydrogen gas was first artificially produced and formally described by T. Von Hohenheim (1493 – 1541) via the mixing of metals with strong acids. In 1671, Robert Boyle rediscovered and described the reaction between iron fillings and diluted acids which results in the production of hydrogen gas. In 1766, Henry Cavendish [2] was the first to recognize hydrogen gas as a discrete substance, by identifying the gas from a metal-acid reaction as "inflammable air" and further finding that the gas produced water when burned in the air. In 1783, Antoine Lavoisier, considered widely as the "Father of Modern Chemistry", gave the element the name of hydrogen when (with Laplace) reproduced the Cavendish experiment [3]. One of the famous early uses of hydrogen gas was for lifting in balloons, and later in airships. The hydrogen was obtained by reacting sulfur acid and metallic iron. The famous "Hindenburg" air disaster was attributed to hydrogen gas [4] but investigation carried out by NASA investigator proved otherwise [5]. Hydrogen can be produced industrially by steam reforming of natural gas. Hydrogen is mostly produced close to where needed [6].

Hydrogen generator: The hydrogen generator, Fig. 4, is a device that is designed to produce hydrogen gas from electrolysis of water. It is a closed container containing six lead electrode rods and an aqueous electrolyte with the electrodes being connected to two terminals of the battery. The generator housing is made from low density plastic, with a cover made from the same material and reinforced with Perspex for rigid and support. A pair of terminals was fabricated from lead into the cover. The exit valve for the gas is situated at the middle of the cover connected to hose. The electrodes are three pairs placed on their sides on the floor of the container. They are stacked into two stands, one each on the opposite ends of the electrodes. Insulated copper wires were connected from the terminals to the electrodes to deliver necessary electric current to the electrodes. The generator is designed to use electricity to produce hydrogen and oxygen gases by electrolysis of aqueous solution of sodium hydroxide and water. Electric current is passed through the water to break down the molecules of water to produce hydrogen and oxygen gases. If there is partition in the generator chamber, the pure hydrogen and oxygen gases can be collected separately but in this case, they are collected together as a mixture of hydrogen and oxygen gases called "hydroxyl‟ gas. The hydroxyl gas is eventually passed through water to dissolve oxygen and liberate hydrogen gas.

Researchers are developing a wide range of technologies to produce hydrogen economically from a variety of resources in environmentally friendly ways.

Natural Gas Reforming

Hydrogen can be produced from natural gas using high-temperature steam. This process, called steam methane reforming, accounts for about 95% of the hydrogen used today in the U.S. Another method, called partial oxidation, produces hydrogen by burning methane in air. Both steam reforming and partial oxidation produce a "synthesis gas" or "syn gas," which is then reacted with additional steam to produce a higher hydrogen content gas stream.

Renewable Electrolysis

Electrolysis uses an electric current to split water into hydrogen and oxygen. The electricity required can be generated using any of a number of resources. However, to minimize greenhouse gas emissions, electricity generation using renewable energy technologies (such as wind, solar, geothermal, and hydroelectric power), nuclear energy, or natural gas and coal with carbon capture, utilization, and storage are preferred.

Gasification

Gasification is a process in which coal or biomass is converted into gaseous components by applying heat under pressure and in the presence of air/oxygen and steam. A subsequent series of chemical reactions produces a syn gas, which is then reacted with steam to produce a gas stream with an increased hydrogen concentration that then can be separated and purified. With carbon capture and storage, hydrogen can be produced directly from coal with near-zero greenhouse gas emissions. Since growing biomass consumes carbon dioxide from the atmosphere, producing hydrogen through biomass gasification results in near-zero net greenhouse gas emissions.

Renewable Liquid Reforming

Biomass can also be processed to make renewable liquid fuels, such as ethanol or bio-oil, which are relatively convenient to transport and can be reacted with hightemperature steam to produce hydrogen at or near the point of use. Researchers are also exploring a variation of this technology known as aqueous-phase reforming.

Nuclear High-Temperature Electrolysis

Heat from a nuclear reactor can be used to improve the efficiency of water electrolysis to produce hydrogen. By increasing the temperature of the water, less electricity is required to split it into hydrogen and oxygen, which reduces the total energy required.

High-Temperature Thermo chemical Water-Splitting

Another water-splitting method uses high temperatures generated by solar concentrators (mirrors that focus and intensify sunlight) or nuclear reactors to drive a series of chemical reactions to split water into hydrogen and oxygen. All of the intermediate process chemicals are recycled within the process.

Biological

Certain microbes, such as green algae and cyan bacteria, produce hydrogen by splitting water in the presence of sunlight as a byproduct of their natural metabolic processes. Other microbes can extract hydrogen directly from biomass. Photo electrochemical (PEC) Hydrogen can be produced directly from water using sunlight and a special class of semiconductor materials. These highly specialized semiconductors absorb sunlight and use the light energy to directly split water molecules into hydrogen and oxygen.

Possible questions

Part – B

1. Write about the principle and working of geothermal energy device in detail.
2. Explain about the hydrogen generation and its application.
3. Write a note on utilization of hydrogen gas.
4. Briefly explain about ocean thermal electric conversion principle
5. Give the principle to estimate the nature of geothermal fields.
6. Explain the basic principle of tidal power and its components
7. Write a note on hydrogen storage and transportation
8. Give the basics of nuclear fusion and its reactions.
9. Explain about the waves and energies for the production of electrical energy.
10. Give the generation and application of hydrogen

Part - C

1. Write a note on lift and drag in wind mill