Unit II

RENEWABLE POWER GENERATION

2.1 INTRODUCTION

- Before the time of industrial revolution and the discovery of coal deposits, most of the energy that we were using was renewable energy for lightning and heating. Our ancients were using the wood, grass which is known as biomass for lightning. The general definitions of renewable energy sources are those sources which are radially available in nature, such as solar and wind. It also includes the resources that can be renewed in short period of time.
- Fossil fuels are the main energy sources for thermal power plants. These energy resources will get exhausted in the next few years. Therefore it becomes need of the hour to look for the other non-conventional or renewable energy sources.
- Energy is the basis of human life. With increasing population and energy demand along with challenges posed by climate change, also increasing import dependency with rise in fossil fuel prices is putting huge pressure in finding the clean energy source to fulfill the demand.
- The use of fossil fuels has produced large amounts of air pollution due to the release of harmful gases as combustion by-products. Also, increasing levels of carbon dioxide in the atmosphere from fossil fuel combustion is to be the main source of global warming over the past 150 years. Additionally, power plants often release large amounts of waste heat to the environment. This can lead to thermal pollution in rivers and lakes causing harm to many forms of plant and animal life.
- According to world report 80% of energy demand is fulfilled by fossil fuel resources such as oil, gas and coal. It is well known fact that these resources will be exhausted one day. It is a need of today's world to focus on renewable energy resources such as wind, solar, tidal etc.
- Ever since the demand for fossil fuels has begun to rise, Industries have been turning towards new, clean solutions to their energy needs.
- These renewable energy sources are direct and indirect sources of energy derived from solar energy. The direct solar radiation intercepted by solar collectors and indirect solar energy such as wind energy, tidal energy, biomass and biogas, ocean thermal energy etc.

2.2 SOLAR ENERGY [Dec. 17]

- Sun is the source of all form of energy available on the earth. Solar energy is the energy force that sustains life on the earth for all plants, animals, and people. The earth receives this radiant energy from the sun in the form of electromagnetic waves, which the sun continually emits into space.
- The earth is essentially a huge solar energy collector receiving large quantities of this energy which manifests itself in various forms, such as direct sunlight used through photosynthesis by plants, heated air masses causing wind, and evaporation of the oceans resulting as rain which can form rivers.
- This solar energy can be tapped directly as solar energy (thermal and photovoltaic), and indirectly as wind, biomass, waterpower, wave energy, and ocean temperature difference. It is the most resourceful energy which can be termed as future energy.
- The Earth receives 1.8×10^{11} MW of incoming solar radiation (insulation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses.
- It is very difficult to utilize this source commercially due to the following reasons :
  - ➢ The energy is dilute and spread out.
  - ➢ The intensity of radiation is weather-dependent. On cloudy day, the intensity is very low. Dust, fog and smog in the atmosphere also affect the intensity of radiation.
  - ➢ The day and night cycle interrupts the continuous availability of this energy.

Utilization of solar energy requires a good collector. Mainly there are two types of collectors : (i) Flat plate collector, (ii) Parabolic collector.

2.2.1 Solar Collectors

A solar collector is a device for collecting solar radiation and transferring the energy to a fluid passing in contact with it. Utilisation of solar energy requires solar collectors. These are grouped into two types :

1. Non-concentrating or flat plate type solar collector.
2. Concentrating (focusing) type solar collector.

The solar energy collector, with its associated absorber, is the essential component of any system for the conversion of solar radiation energy into more usable form (e.g. heat or electricity).

In the non-concentration type, the collector area (i.e. the area that intercepts the solar radiation) is the same as the absorber area (i.e. the area absorbing the radiation).

On the other hand, in concentrating collectors, the area intercepting the solar radiation is greater, sometimes hundred of times greater than the absorber area.

2.2.2 Flat Plate Collector

Flat-plate collectors are useful where temperature requirement applications are below about 90°C. For example, in water heating and space heating systems, flat-plate collectors are particularly convenient. They are made in rectangular panels, from about 1.7 to 2.9 m², in area, and are relatively simple to construct and erect. Flat plate can collect and absorb both direct and diffuse solar radiation, they are consequently partially effective even on cloudy days when there is no direct radiation.

Flat-plate solar collectors may be divided into two main classifications based on the type of heat transfer fluid used. Liquid heating collectors are used for heating water and non-freezing aqueous solutions and occasionally for non-aqueous heat transfer fluids. Air or gas heating collectors are employed as solar air heaters.

The majority of flat-plate collectors have five main components as follows :

- Tubes, fins, passages or channels are integral with the collector absorber plate or connected to it, which carry the water, air or other fluid.
- A transparent cover which may be one or more sheets of glass or radiation transmitting plastic film or sheet.
- The absorber plate, normally metallic or with a black surface, although a wide variety of other materials can be used with air heaters.
- Insulation, which should be provided at the back and sides to minimise the heat losses. Standard insulating materials such as fiberglass or styro-foam are used for this purpose.

Typical Flat Plate Collector

There are many flat plate collector design, but the most are based on the principle shown in Fig. 2.1 and 2.2. It is the plate and tube type collector, called absorbing surface. Typically a metal plate, usually of copper, steel or aluminium material with tubing of copper in thermal contact with the plates, are most commonly used materials. The absorber plate is usually made from a metal sheet 1 to 2 mm in thickness, while the tubes, which are also of metal, range in diameter from 1 to 1.5 cm. They are soldered, brazed or clamped to the bottom (in the same cases, to the top) of the absorber plate with the pitch ranging from 5 to 15 cm. In some designs, the tubes are also in line and integral with the absorber plate. For the absorber plate, corrugated galvanized sheet is a material widely available throughout the world in which it has been used.

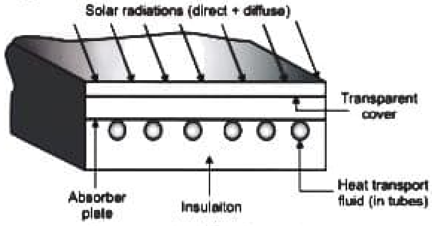


Fig. 2.1 : Typical flat plate collector

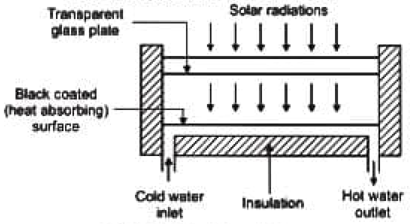


Fig. 2.2 : Flat plate collector

2.2.3 Concentrating Collector

Concentrating collectors are broadly divided into two groups (1) Focusing, (2) Non-focusing.

Focusing collectors may be considered in two general categories : line focusing and point focusing.

In practice, line is a collector pipe on which the solar radiations are focused.

Point is a small volume through which the heat transport fluid flows.

Because the sun has a finite size, focusing does in fact occur over a small area or volume rather than a line or point.

As per the number of concentrating collector geometries, the main types of concentrating collectors are :

(i) Parabolic or cylindrical collector
(ii) Mirror strip reflector
(iii) Fresnel lens collector
(iv) Flat-plate collector with adjustable mirrors
(v) Compound parabolic concentric concentrator (C.P.C.)

Parabolic or Cylindrical Collector : The principle of the parabolic trough collector studied with the help of concentrating collectors is shown in Fig. 2.3 and 2.4.

Solar radiation coming from the particular direction is collected over the area of the reflecting surface and is concentrated at the focus of the parabola.

If the reflector is in the form of a trough with parabolic *cross section*; the solar radiation is focused along a line.

Mostly cylindrical parabolic concentrators are used, in which absorber is placed along focus axis.

The collector pipe, preferably with selective absorber coating, is used as an absorber.

The dimension of parabolic trough may be roughly 3 to 5 m, and the width about 1.5 to 2.4 m.

Ten or more such units often connected end to end in row, several rows may also be connected in parallel.

Parabolic trough reflectors have been made of highly polished aluminium, of silvered glass or of a thin film of aluminized plastic on a firm base.

Instead of having a continuous form, the reflector may be constructed from a number of long flat strips on a parabolic base.

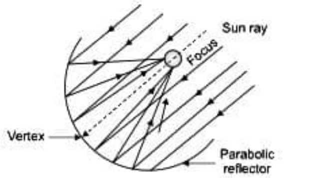


Fig. 2.3 : Cross-section of parabolic trough collector

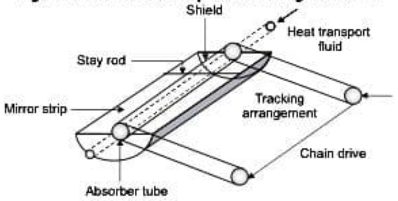


Fig. 2.4 : A typical cylindrical parabolic system

For the solar radiation to be brought to focus by parabolic trough reflector, the sun must be in such a direction that it lies on the plane passing through the focal line and vertex of the parabola.

Since the elevation of the sun is always changing, either the reflector trough or the collector pipe must turn continuously about its long axis to maintain the required orientation.

Both schemes are used in different designs. Either the trough reflector or the pipe is turned by partial rotation around the single axis parallel to the trough length.

Trough type collectors are generally oriented in the east west or north south directions.

For the E/W orientation, the collectors are led flat on the ground.

For the north-south orientation the north end trough is raised so that the collectors are sloped facing south just like flat-plate collectors.

Ideally, the slope angle should be changed periodically. It is simpler but, less efficient however to use the fixed angle design.

2.2.4 Solar Photovoltaic Cell

A *solar cell* is a solid - state semiconductor device that converts a fraction of the incident sunlight (photon) energy into dc electrical energy.

Certain configurations containing liquids also exhibit photovoltaic properties, and are known as photo-electrochemical cells.

The conversion of solar energy to electricity continues as long as photons are incident on the active surface of a solar cell.

Conversion efficiency depends on the properties of the semiconductor material of which the solar cell is made.

Energy conversion occurs due to the existence of a barrier layer at the metallurgical junction between two dissimilar semiconducting materials forming the cell.

The barrier layer can be formed in semi-conducting material, say silicon, by making a metallurgical junction between two dissimilar materials.

There are following possible structures containing a barrier layer, which may produce a solar cell :

1. p-n homojunction;
2. p-n heterojunction;
3. Tandem of two junctions having a p-i-n structure.

A p-n homojunction results when a metallurgical junction is formed between two oppositely doped (i.e., n-type and p-type) layers of the same semiconductor material, such as silicon. The p-n homojunction is the most prevalent configuration in commercial solar cells made of crystalline silicon.

The p-n heterojunction structure is normally used with two dissimilar semiconductor materials, such common solar cell structures include Gallium Arsenide (GaAs)- Gallium Aluminium-Arsenide (GaAs-GaAlAs), Cadmium-sulphide-Copper-sulphide ($CdS-Cu_2S$), Cadmium-sulphide Copper-Indium-Diselenide ($CdS-DuInSe_2$) or Cadmium Telluride (CdTe) materials.

A tandem junction is used in an amorphous silicon (a-Si) material, where a simple p-n homojunction does not produce an efficient solar cell. To achieve an efficient a-Si solar cell, a p-I-n configuration is used.

There are a number of *semi-conducting materials*, which can be used to make efficient solar cells. In fact, silicon is technically not a very suitable semiconductor to fabricate efficient solar cells. However, silicon continues to be commercially the most widely used semiconductor used for solar cells.

Virtually, all international production of terrestrial solar cells is currently based on silicon. For space applications, both silicon and GaAlAs solar cells are in use.

Incident photons with energy less than the semiconductor band gap cannot produce changed carriers, and hence, do not contribute to the energy conversion process.

On the other hand, incident photons with energy higher than the band gap would have to shed their excess energy through the creation or annihilation of photons, thus producing unwanted thermal energy.

Therefore, the excess energy is also not available for useful energy conversion. The spectrum of incident sunlight is known. Therefore, there should be an optimum energy band gap that should yield the most efficient semiconductor for solar photovoltaic energy conversion.

Detailed calculations show that a semiconductor having a band gap energy of around 1.5 eV at room temperature should convert sunlight to electrical energy most efficiently.

On this criterion too, CdTe having a band gap of about 1.5 eV at room temperature should be the efficient semiconductor for sunlight conversion. Silicon, with a room temperature band gap of about 1.1 eV, is clearly not the most efficient material.

In fact, GaAs with a band gap of about 1.4 eV at room temperature and having a direct band gap is a better material than silicon for solar cell fabrication.

2.2.5 Operating Principle

- The physical cross-sectional structure of a typical state-of-the-art commercial n-on-p silicon solar cell is schematically shown in Fig. 2.5. The bulk base material is p-type single crystalline silicon having thickness between 100 and 350 micron. A thin layer of an n-type dopant-usually phosphorus is diffused on the top surface to form a thin n-p junction.
- The top active surface of the n-layer has a metallic grid structure, which forms the ohmic contact to silicon and whose total area covers less than 10% of the total top surface area.
- Similarly, the bottom inactive surface has an ohmic metallic covering the complete area. These two metallic contacts on the p and n-layers respectively form the positive and negative terminals of the solar cell.
- The n-on-p is the most widely used configuration for silicon solar cells.

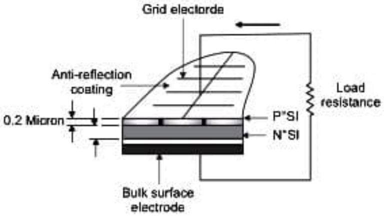


Fig. 2.5 : N-P type solar cell

- Consider such a solar cell placed in sunlight with no load connected across the positive and negative terminals. Incident photons, having energy greater than the band gap energy for crystalline silicon, approximately 1.1 eV at room temperature, get absorbed-some on the surface and some inside the bulk material during their travel.
- Photon absorption increases exponentially with distance depending on the wavelength-dependent absorption coefficient.
- Charged carriers consisting of equal number of electrons and holes are generated as a result. Longer wavelength photons, with energy less than the band gap energy travel through the bulk to get absorbed at the opaque back metallic contact.

- These photons do not contribute to the generation of electron-hole pairs. Also, photons incident on the top metallic grid contact do not generate electron-hole pairs.
- After generation, electrons in the p-layer and holes in the n-layer, i.e., the minority carriers, diffuse towards the metallurgical junction. As soon as the electrons and holes reach the junction from the two opposite directions, they are swept away to the other sides due to the existence of the junction potential at the barrier.
- In the process, the electrons collecting on the n-side and the holes collecting on the p-side charge these two sides oppositely. Thus, an open-circuit voltage develops across the two external terminals, with the p-region becoming positive and the n-region negative.
- If a load is now connected across these external terminals, an electric current flows due to the generated potential.
- This is the basic physical process of conversion of sunlight into electrical energy. The energy conversion process continues as long as light is incident on the active top surface of the solar cell.

Conversion Efficiency

The conversion efficiency of a solar cell is the ratio of the electrical power output to the incident solar power.

The ideal and maximum conversion efficiency of a crystalline silicon solar cell can be as high as 30%.

In laboratory studies, the highest conversion efficiency achieved is about 23% using a crystalline silicon solar cells of about 1 cm^2 area.

Crystalline silicon solar cells of 4 to 8 cm^2 area, designed for space applications, have conversion efficiencies of 16% to 18%.

Conversion efficiencies of commercially produced solar cells, having 75-120 cm^2 areas, are in the range of 13% to 15%.

In general, it is more difficult to achieve high conversion efficiencies with larger-area solar cells, particularly on a routine production basis.

Various loss mechanisms in a silicon solar cell tend to limit the cell conversion efficiency. These losses can be grouped in two broad categories :

1. Loss due to Photon Energy

Incident photons having energy higher than the band gap would lose its excess energy (over and above 1.1 eV) in the form of heat loss.

This loss may be as high as 30% to 45% of the combined energy of all photons having energy larger than the silicon band gap, or which is equal to between 5% and 20% of the total incident photon energy.

Thus, the net effect of the spectral characteristics of the input solar radiation is that as much as 30 to 40% of the incident photon energy may not be utilized for the generation of electron-hole pairs in silicon solar cells.

2. Loss due to Material Characteristics

The second most significant loss mechanism in a silicon solar cell occurs due to its inherent material properties and the underlying physical principles on which the PV operation is based.

The open-circuit voltage can be increased, within limits, by increasing the doping on the two sides of the junction.

The magnitude of this loss is a function of the barrier height. The net result of all such inherent physical processes is an energy loss, which can be as high as 30% to 40% of the energy-contained in the photo-generated carriers.

Cell Parameters

Two important parameters of a solar cell are the Open-circuit voltage (V_{OC}) and the Short-circuit current (I_{SC}). These parameters are explained in Fig. 2.6, which schematically shows a typical illuminated current-voltage characteristic of a solar cell.

The intercept of the curve with the x-axis is called open-circuit voltage and its intercept with y-axis as short-circuit current. The maximum power obtainable from a cell corresponds to the point on the curve resulting a rectangular area below it.

The current and voltage corresponding to this point are I_m and V_m respectively.

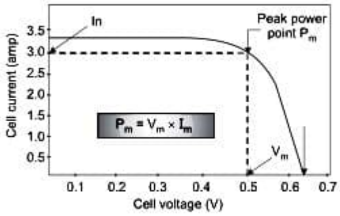


Fig. 2.6 : Current-voltage characteristics of a silicon solar cell

2.2.6 Application of Solar Cells

- The major application of photovoltaic systems lies in water pumping for drinking water supply and irrigation in rural area. The photovoltaic water pumping system essentially consists of : (a) A photovoltaic array, (b) Storage battery, (c) Power control equipment, (d) Motor pump set, (e) Water storage tank.

- These are used for electrification for remote villages providing street lighting.
- To provide electricity needed for telecommunication for post and telegraph.
- To provide electricity needed for railway signaling and traffic signaling in cities.
- To provide electricity needed for battery charging.
- To provide electricity for weather monitoring.
- To provide electricity for cathodic protection of oil pipe lines.

2.2.7 Advantages of Photovoltaic System

- Direct conversion of solar radiations at room temperature to dc electricity using a solid solar cell.
- Since there is direct conversion of solar radiations at room temperature to electricity moving parts are absent.
- Solar cell is able to function for a long time without attended.
- Free from maintenance problems.
- Since no fuel is burnt to generate electrical power, hence pollution free.
- System is highly reliable.
- The systems give rapid response to inputs. The output varies with the intensity of solar radiations falling on it.
- These work without sun tracking arrangement.
- These have high power to weight ratio. This parameter is more important in space applications.
- These are easy to manufacture.

2.2.8 Disadvantages of Photovoltaic System

- Solar energy panels require additional equipment (solar inverters) to convert direct electricity (DC) to alternating electricity (AC) in order to be used on the power network.
- For a continuous supply of electric power, especially for on-grid connections, Photovoltaic panels require not only Inverters but also storage batteries; thus increasing the investment cost for PV panels considerably
- Solar panels efficiency levels are relatively low (between 14%-25%) compared to the efficiency levels of other renewable energy systems.
- Another disadvantage is solar radiations are not available in the night. So for every application of solar must accompany a storage facility so that it can be used in the night. Power available through solar cell per unit area is very small. Therefore, these require large area to obtain a sizable power.

2.3 WIND ENERGY

Wind is nothing but motion of air. The winds are created due to :

(i) Uneven heating of land and water because of which a pressure difference occurs. Therefore, air flows from higher pressure to lower pressure and winds are created.

(ii) Global heating, i.e. equatorial belt of earth gets heated at a large extent compared with that of poles. Hence heavy winds will be created due to this uneven heating. Many projects on wind mills have been taken up by various organizers such as National Aeronautical Laboratory, Bangalore, Central Salt and Marine Chemicals Research Institute, Bhavanagar. A public company Suzalon has erected many wind mills all over India.

Power from Wind Energy

Wind possesses energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller, can extract part of the wind energy and convert it into useful work.

The following factors determine the output of wind mills :

(i) Wind speed.

(ii) Cross-sectional area of wind swept by the rotor.

(iii) The overall efficiency of rotor, transmission system and generator of a wind mill.

No device can extract all the wind energy.

$$\text{The K. E. of a particle} = \frac{1}{2}\, mv^2 \text{ N-m}$$

The amount of air flowing in unit time through an area A (m^2), with velocity v (m/s), is $m = \rho \cdot A{\cdot}v$, kg/s where ρ = density of air (kg/m^3).

$$\therefore \quad \text{The power of wind} = \frac{1}{2}\,(\rho\, A\, v) \cdot v^2$$

$$= \frac{1}{2} \cdot \rho \cdot A \cdot v^3 \text{ watts}$$

$$\text{If} \quad A = \text{swept area of rotor} = \frac{\pi}{4} \cdot D^2,$$

$$\text{Available wind power} = \frac{1}{8} \cdot \rho \cdot \pi\, D^2 \cdot v^3 \text{ watts}$$

2.3.1 Basic Components of Wind Power Generation

The basic components of wind power generation system are as indicated in Fig. 2.7.

It consists of (i) Wind turbine, (ii) Transmission system, (iii) Generator, (iv) Structure.

The wind turbine includes blades, hub, pitch changer and mounting.

As wind flows over the blades, the turbine rotates. The speed of the turbine depends on the velocity of wind. The turbine shaft is coupled to transmission system, where the speed of the shaft can be changed to the required one; further this shaft work is converted into electrical energy by the generator. The whole unit is supported on a rigid structure.

The speed of rotation can also be controlled by varying the pitch (i.e. the distance between two successive blades).

The commercially available wind mill has a rated capacity from 0.5 MW to 3 MW.

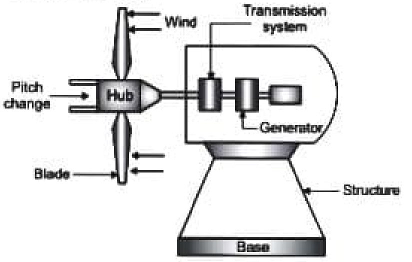


Fig. 2.7: Wind power plant

2.3.2 Advantages of Wind Energy

- Power generation is pollution-free, as there is no combustion of fuel.
- Wind is at free of cost and abundantly available.
- Small wind mill can be easily installed on bore-wells for pumping water.

2.3.3 Disadvantages of Wind Energy

- The velocity of wind varies from zero to infinity (very high velocity). Therefore, it is very difficult to design a wind mill for its successful operation.
- If the velocity of wind is insufficient, then power will not be generated. So the reliability is less.
- If bearings of the wind mills fail earlier, so the maintenance is a problem.
- Installation cost is more.
- Usually located in the coastal areas, the electrical energy is to be transmitted through transmission to the consumers.

2.4 BIOGAS AND BIOMASS

2.4.1 Biogas

It is a gaseous fuel. It is produced in a gobar gas plant. Gobar gas plant is a device to convert fermentable organic matter into a combustible gas.

A fermentable matter may be such as cattle dung, wood leaves, farm residues, night soil, etc. This matter is converted into combustible gas due to two chemical processes; 'Anaerobic' and 'Aerobic' fermentation.

(A) Anaerobic Process : **[Oct. 17]**

Cattle dung, night soil, poultry droppings, etc. when confined in a place out of contact with oxygen, give rise to a large number of bacteria. These bacteria can be broadly classified as

(a) Acid-forming bacteria

(b) Gasifying bacteria.

The acid-forming bacteria convert hydrocarbonates, proteins, fats into volatile acids and produce carbon dioxide. This phase is known as liquidification phase.

Now, gasifying bacteria work upon the material with the help of intracellular enzymes and convert it into methane (CH_4) and carbon dioxide (CO_2). Hence these bacteria are also known as methane bacteria.

(B) Aerobic Process :

It consists of three phases, namely Hydrolysis, Acid-formation and Methane fermentation.

Hydrolysis : In this, sludge and large particles of matter are reduced to smaller particles which are soluble in water. The extracellular enzyme will accelerate this process.

Acid Formation : Acid-forming bacteria convert hydrocarbonates, proteins and fats etc. into volatile acids.

Methane Fermentation : Certain bacteria convert the volatile acids produced in the previous phase into methane and carbon dioxide (CO_2).

Bio-Gas Plant :

There are two types of bio-gas plants : (i) Daily fed system, (ii) Batch fed system.

The layout of a daily fed (continuously fed) system is as shown in Fig. 2.8.

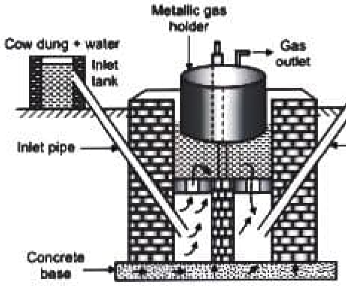


Fig. 2.8 : Biogas plant floating type

2.4.2 Construction

- It consists of a digester (fermentation well) usually built in bricks along with inlet pipe and outlet pipe. Many times, the digester is underground.
- A gas-holder (made from metallic sheet) floats over the organic matter in the digester. An outlet pipe is placed in this gas-holder to carry away the gas produced to the consumer point.
- It is also provided with inlet tank and outlet tank.

  The unit is located where sunlight falls for the maximum time of the day and shielding should be provided against wind.

2.4.3 Working

- At the beginning, the digester is filled with a homogeneous mixture of dung and water (1 : 1 ratio) and gas-holder is kept in position. Also all the trapped air is removed from the gas-holder.
- The digester is supplied with organic matter (dung) as required (daily or weekly) or till the digester is full.
- The first two or three installments of gas will not burn as it contains excessive CO_2.
- It takes 4 to 8 weeks, depending on temperature; for generation of bacteria and further to start methane production.
- It is not advisable to start fresh addition of dung till the digestion is established. The methane gas is tested for its combustion qualities initially. If it burns satisfactorily, it can be used continuously.
- The feeding of dung and water mixture will be again started as per the requirement of production of gas.

2.4.4 Advantages of Biogas

- The bio-gas is generated continuously at cheaper rate, useful for domestic use.
- It is pollution-free.
- It is useful to meet the heat requirement of rural people, therefore, leads to save the forest.
- The waste from the gobar-gas plant is a good fertilizer.
- With small investment, fuel is made locally available.
- It provides better life for rural people.
- Generation of gas is at the door of consumer, hence no problem of gas-transportation.

2.4.5 Disadvantages of Biogas

- Gas cannot be generated without fermentable organic matter. Therefore, gas production and its use is limited to rural areas.
- As the plant is located near the consumer house, the area becomes dirty and smell may spread.

2.4.6 Biomass

The organic matter produced by plants, both grown on land and grown in water and their derivatives in water are called Biomass. This includes forest crops. The Biomasses can be considered as a renewable energy sources because plant life renews and adds to itself every year. This can also be considered as a form of solar energy as the plants are grown by photosynthesis.

Solar energy is stored in the form of chemical energy. Hence

Solar Energy → Photosynthesis → Biomass → Energy generation

Biomass are divided in three categories.

(i) Biomass in its traditional solid mass, example wood and agriculture residue.

This kind of biomass are used to burn directly to get energy,

(ii) Biomass in non-traditional form. This kind of biomass is converted into ethanol (ethyl alcohol) and methanol (methyl alcohol) to be used as liquid fuel.

(iii) The third category is to ferment the biomass anaerobically to obtain a gaseous fuel called bio-gas.

Wood waste and bagasse are generally, used as the biomass, which have potential of generating substantial electric power.

These biomass are bulky and contains large amount of water (50 to 90%).

Biomass can be converted to liquid or gaseous fuels.

2.4.7 Biomass Conversion Efficiency

The fuels from the biomass can be derived by wide variety of conversion technologies :

1. Direct combustion
2. Thermochemical conversion
3. Biochemical conversion

1. **Direct Combustion :** The process of burning the biomass in presence of oxygen to produce heat, light and by products is called direct combustion. Wood, dung, vegetable wastes are dried initially and then burnt to provide heat. These wastes can be converted into low calorific value gas by "pyrolysis". Pyrolysis is the process in which the organic material is converted to gases, solids and liquid by heating to elevated temperature in the absence of oxygen.

   Methanol, charcoal and acetic acid are the products of wood pyrolysis. The quality of biomass can be increased by lowering moisture, ash and sulphur content.

2. **Thermochemical Conversions :** Gasification and liquification are two thermochemical conversion technologies of biomass. In gasification the biomass is heated with limited oxygen to produce low heating value gas. The medium heating value gas can be produce by reacting if with the steam and oxygen at high pressure. In liquification the biomass can be converted to methanol or ethanol.

3. **Biochemical Conversion :** Biochemical conversion takes into two forms anaerobic digestion and fermentation. The microbial digestion of biomass involves the anaerobic digestion. This process takes place at low temperature upto 65° and requires a moisture content of at least 80 per cent. This process produces the gas consisting mostly of CO_2 and methane (CH_4) with minimum impurities such as hydrogen sulphide. The gas is burned directly.

   Fermentation is the process of breaking complex molecules in organic compound by bacteria, yeasts, enzymes etc. It is the well known and widely used technology for the conversion of grains and sugar crops into ethanol.

2.5 OCEAN THERMAL ENERGY CONVERSION (OTEC)

This is the indirect form of solar energy. In this the collection and storage are free. The surface of the water of sea acts as the collector for solar heat while the upper layer constitutes heat storage reservoir.

This heat contained in the upper layer of sea, which is solar in origin could be converted into electricity. It is observed that there is a temperature difference of 20-25°C between the warm surface water of the tropical oceans and the colder water in the depths.

This temperature difference could be utilities to produce electricity. Some low boiling point organic fluid could be heated by warm surface water to convert the organic fluid into vapour. These vapour is used to run the heat engine. The exit vapour from the heat engine would be condensed by pumping the cold water from the deeper region of the ocean.

This kind of energy available from ocean thermal power generation is enormous and is replenished continuously.

2.5.1 Methods of Ocean Thermal Electric Power Generation

There are two methods for harnessing ocean thermal energy.

1. Open cycle also known as Claude cycle
2. Closed Cycle also known as Anderson cycle

1. **Open Cycle also known as Claude Cycle :** In the open cycle turbine system water of the sea itself is the working fluid. The warm surface water placed in the low pressure container where it boils at low pressure without supplying additional heat. The steam produced in the low pressure container drives the turbine. The exhaust steam from the turbine is condensed by the deeper cooler water and is discharged. A heat exchange is not required in the evaporator. Because of the low energy content of low pressure vapour, very large turbines would be required.

   Fig. 2.9 shows the schematic diagram of the open cycle OTEC system.

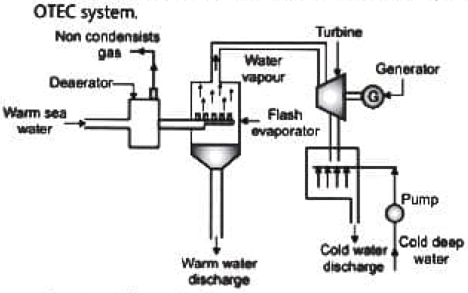


Fig. 2.9 : Schematic of the open cycle OTEC system

2. **Closed Cycle System :** This system used working fluid with a low boiling point such as amonia or propane, which is vaporized in an evaporator (or boiler).

   The heat from the warm surface water of sea is transferred to the working fluid for vaporization by means of a heat exchanger.

The high pressure vapour turns the expansion turbine after leaving the evaporator, similar to stream turbine.

This turbines are design to operate at lower inlet pressure. The generator connected to the turbine generates the electricity in the usual manner.

The cold deep water is used to cool the exhaust steam from the turbine in the another heat exchanger. The liquid working fluid is the pumped back to the evaporator, thus closing the cycle.

Fig. 2.10 shows the schematic diagram of the closed cycle OTEC system.

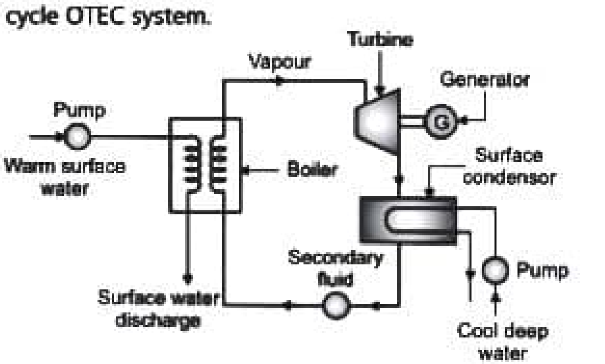


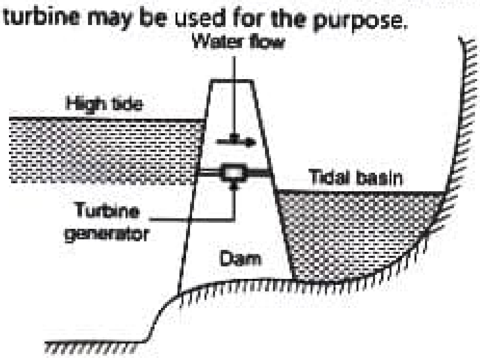
Fig. 2.10 : Schematic of the closed cycle OTEC system

2.6 TIDAL ENERGY

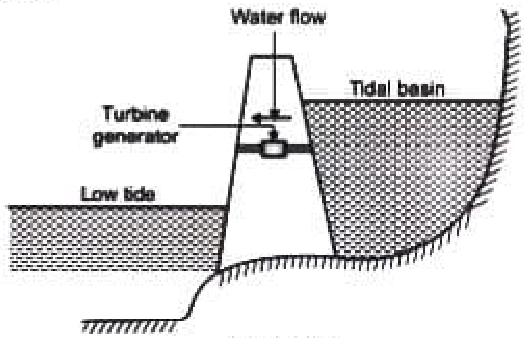
Tide is a periodic rise and fall of the water-level of the sea. Tides occur due to the attraction of sea-water by the moon. These tides can be used to generate electrical power which is known as **Tidal Power**.

When the level of water is above sea-level, then it is called as **flood tide** and when the level is below sea-level, it is called as **ebb tide**.

The water is stored during the flood tide and is used to generate power allowing this water to flow through a turbine. But the available head is very small. Therefore, Kaplan turbine may be used for the purpose.



further converted into electrical power with the help of a generator.



(b) Ebb tide

Fig. 2.11 : Tidal power

At the time of low tide (ebb tide), level of water on tidal basin is higher. Therefore, water is allowed to flow through turbine, towards the low tide, again generating the power.

For sometime, when there is no level difference, then turbine does not generate any power.

2.6.1 Advantages of Tidal Power

- Free from pollution as it does not use fuel.
- Power generation is independent of the rainfall, hence superior to hydro-power plants.
- It does not require valuable land as it is located on the bays.
- It has a unique capacity to meet the peak power demand effectively when it works in combination with thermal power plant.
- It does not require a large catchment area as required by hydro-power plant.

2.6.2 Disadvantages of Tidal Power

- The power generation is not continuous as it depends upon the timing of tides.
- These power plants can be developed only if natural sites are available.
- The suitable sites may be far away from the load centres. Therefore, power generated has to be transmitted through a longer distance.
- Sedimentation of the basins may be an added problem.
- It may become a problem for the navigation.

2.7 FUEL CELL [Oct. Dec. 17]

- A fuel cell system requires continuous supply of fuel and an oxidant and generates Direct Current (DC) electric power continuously. Battery stores electric charge.
- A battery has stored electro-chemical energy within its container. After discharge it needs recharging or replacement. Fuel cells do not need such recharging and replacement.
- Fuel cells convert chemical energy directly to electrical energy, without intermediate less efficient thermal / turbine stage. Fuel cell efficiency is not limited by Carnot limitation imposed on thermal cycle.
- Fuel cell can have almost 90% efficiency. Fuel cells do not have moving parts. Fuel cells are simple and safe.

These are electrochemical devices in which the chemical energy of fuel is converted into electrical energy.

The chemical energy is free energy (energy of formation) of reactants.

These conversions take place at constant pressure and temperature. The basic feature of the fuel cell is that the fuel and its oxidant are combined in the form of ions rather than neutral molecules.

The research and development in fuel cell technology has continued over last hundred years. During 1962-1980's particle fuel cells have been developed and used successfully.

The fuel cell technology has been ignored until recently due to success of internal combustion engines and storage batteries. Secondly, earlier proto type fuel cells were costly and were not competitive economically.

However, the interest in fuel cells has been revived after nineteen sixty's due to :

(a) Chemical energy of the fuel is converted directly to electrical energy. In case of I. C. engines, power is generated by burning the fuel and hence, energy conversion efficiency is limited by Carnot efficiency. However, the direct conversion efficiency of fuel cell is higher than 90%.

(b) No fuel is required to be burnt and hence no pollution.

(c) No moving parts, therefore free from noise pollution.

2.7.1 Principle and Operation of Fuel Cell

Conversion of chemical energy of fuel directly to electrical energy takes place at constant temperature and pressure. The fuel and oxidants are combined in the form of ions rather than neutral molecules.

As per the fuel used, the main types of fuel cells are :

(1) Hydrogen fuel cell,

(2) Hydrazine (N_2H_4) fuel cell,

(3) Hydrocarbon fuel cell and

(4) Alcohol (Methanol) fuel cell.

The operation of fuel cell can be described with reference to a specific device. Fuel cell can be adapted to a variety of fuels by changing the catalyst. Here hydrogen-oxygen (hydrox) cell is described for example.

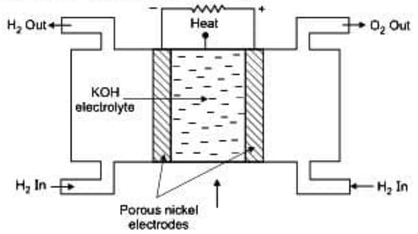


Fig. 2.12 : Alkaline hydrox fuel cell (H_2, O_2 cell)

The main components of a fuel cell are shown in Fig. 2.12 and are given below :

(1) A fuel electrode (anode),

(2) An oxidant or air electrode (cathode), and

(3) An electrolyte.

An electrolyte may either may acidic or alkaline one.

There are two porous electrodes, namely anode and cathode. Between the electrodes is layer of electrolyte.

Hydrogen is the active material at negative electrode and oxygen is active at positive electrode.

Fuel gas hydrogen and an oxidant O_2 gas are supplied from separate sources.

The porous electrode has large number of sites where gas, electrode and electrolyte are in contact. The electro-chemical reaction occurs at these sites.

The reactions are normally slow and catalyst is included in to expedite them. Platinum metals, nickel (for hydrogen) and silver (for oxygen) are used as catalyst.

Most existing fuel cells operate at temperature below about 200°C. The electrolyte is then usually retained in a porous membrane.

The electrochemical reactions occurring at the electrodes of a hydrogen-oxygen cell may vary with the nature of electrolyte.

They are as follows :

At negative electrode/ cathode :

$$H_2 \rightarrow 2H^+ + 2e^-$$

These electrons flow from cathode to anode through the external load R_L and generate DC current. At this electrode, hydrogen is diffused through the permeable nickel, in which a catalyst is embedded. The catalyst enables the hydrogen molecules to be absorbed on the electrode surface. On electrode surface, hydrogen atoms react with the hydroxyl ions (OH^-) in the electrolyte to form water.

At the positive electrode/ anode :

$$\frac{1}{2} O_2 + H_2O + 2e^- \rightarrow 2OH^-$$

Overall reaction : $H^+ + OH^- \rightarrow H_2O + \Delta H$

The net reaction in the fuel cell is hydrogen and oxygen supplied to the fuel cell produce electrical energy, water and heat (ΔH).

The above equations show that hydroxyl ions produced at one electrode are involved in the reaction at the other. Also electrons are absorbed from oxygen electrode and released to the hydrogen electrode. Thus overall reaction when the cell is operating is $H_2 + \frac{1}{2} O_2 \longrightarrow H_2O$

For the electrodes in open circuit shown in Fig. 2.13, the hydrogen electrode accumulated a surface layer of negative charges. These attract potassium ions (K^+) from electrolyte and provide an electrical double layer. Similarly, the loss of electrons from the oxygen electrode results in a layer of positive charges and attracts hydroxyl ions (OH^-) from the electrolyte. The magnitude of this e.m.f. is 1.23 volt at 1 atm and 25°C.

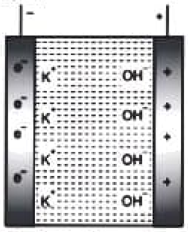


Fig. 2.13 : Electrodes on open circuit

For the closed circuit shown in Fig. 2.14, the electrons can now leave the electrodes pass through the connecting circuit to the oxygen electrodes and take part in the reaction. This movement of electrons constitutes a current passing through an external load.

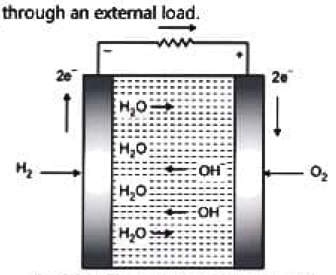


Fig. 2.14 : Electrodes on closed circuit

Acidic Electrolyte : The chemical reactions with acidic electrolyte (H_2SO_4) are as given below.

- Hydrogen dissociates on anode surface and forms positively charged hydrogen ions and negatively charged electrons.

  Anode reaction : $H_2 \rightarrow 2H^+ + 2e^-$
- Hydrogen ions migrate internally from the anode region to the catalytic surface of the cathode; through the electrolyte and the porous barrier.
- Simultaneously, electrons move from anode, through external circuit, to the cathode catalytic surface.
- Oxygen, hydrogen and electrons combine on the catalytic surface of cathode to form water.

  Cathode reaction : $\frac{1}{2} O_2 + 2H^+ + 2e \rightarrow H_2O$
- Overall chemical reaction :

  $$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$$

The net reaction in the fuel cell is hydrogen and oxygen supplied to the fuel cell produce electrical energy, water, heat (ΔH).

At ambient temperature, the H_2O_2 fuel cell has DC potential of about 0.6 V, current density of about 100 to 200 mA/cm.

Anode Reaction : $H_2 \rightarrow 2H^+ + 2e^-$

Cathode Reaction : $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$

Overall Reaction : $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

2.7.2 Advantages of Fuel Cells

- In the conventional thermal process for generating electricity, heat energy produced by combustion of the fuel is converted partially into mechanical energy in a steam turbine and then into electricity by means of a generator.
- The performance of such conventional thermal energy conversion devices, such IC engines are restricted due to Carnot efficiency.
- The operating temperatures limit the efficiency of a heat engine. Recent advances in the IC engines show that almost 40 to 45% thermal efficiency has been achieved.
- In fuel cells, the chemical energy of fuel is directly converted into electrical energy. Therefore, it has very high conversion efficiencies as high as 70 percent have been observed. Fuel cells, on the other hand, are not heat engines and are not subjected to their temperature limitations.
- Fuel cells can be installed near the use point, thus reducing electrical transmission requirements and accompanying losses.

- Fuel cells have few mechanical components; hence, they operate fairly quietly and require little attention and less maintenance.
- There are no exhaust emissions like conventional engines. So atmospheric pollution is small. For hydrogen as a primary energy source, the only waste product is water. If the source is a hydrocarbon, carbon dioxide is also produced. Nitrogen oxides, such as accompany combustion of fossil fuels in the air, are not formed in the fuel cell. Some heat is generated by a fuel cell, but it can be dissipated to the atmosphere or possible used locally.
- There is no requirement for large volumes of cooling water such as are necessary to condense exhaust system from a turbine in conventional power plant.
- Free from noise pollution, fuel cells can be readily accepted in residential areas.
- No starting time is needed.
- The space requirement for fuel cell power plant is considerably less as compared to conventional power plants.

2.7.3 Disadvantages of Fuel Cells

- The main disadvantages of fuel cells are their high initial costs and low service life.
- Hydrogen in a H_2 - O_2 cell, which is not available in the required form.
- Hydrocarbon fuels for cells are to be prepared before being used.
- The output voltage is very small compared to its cost.

2.7.4 Applications of Fuel Cells

The applications of fuel cells may be discussed with reference to the following :

- Domestic use
- Central power station
- Automotive vehicles
- Special applications

2.8 MAGNETO HYDRO DYNAMIC (MHD)

- The electric power generated by Magneto hydro dynamic power generation is said to be of high efficiency and low pollution. As the name implies, MHD consist of flow of a conducting fluid in the presence of magnetic and electric field.
- The fluid used may be gas at high temperature or liquid metal like sodium or potassium. The heat energy supplied by fuel is directly converted into electric energy without a conventional electric generator.
- The MHD converter is a heat engine in which the heat which is taken at higher temperature, part of it is used to generate useful work and the remainder is rejected at a low temperature.
- If the heat is supplied at highest practical temperature and rejecting at the lowest possible temperature then the highest possible efficiency is achieved in MHD. As compared to the other power generator the MHD generator operates with no moving parts.

2.8.1 Principles of MHD Power Generation

[Oct. 17, May 18]

- The working principle of MHD is based on the faradays law of electromagnetic induction. This law states that an electric conductor moving through a magnetic field experiences a retarding force as well as induces an electric field and current. This is the working principle of the electric generator also, where the conductors consists of copper strips.
- In MHD generators, the solid conductors of conventional electric generator are replaced by a fluid which is electrically conducting. Generally an ionized gas or liquid metal is used as a working fluid. To generate the electrical energy through MHD, the hot, partially ionized and compressed gas is passed with a high velocity through a powerful magnetic field, which generates the electric potential in the gas.
- This current can be extracted by placing electrodes in a suitable position in the stream. Fig. 2.15 shows the schematic of the working principle

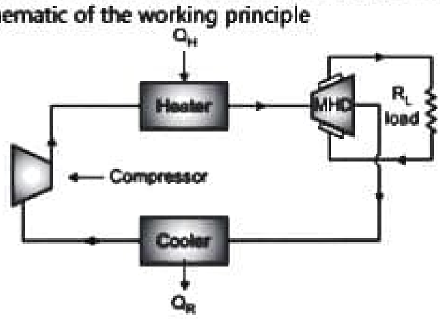


Fig. 2.15 : Schematic of the working principle

- The gas is ionized by heating it to a high temperature. When the gas is heated to high temperature the outer electrons escape from its atom or molecules.
- This gas molecules acquires an electric charge and the gas passes into the state of plasma. To produce necessary ionization of the gas very high temperature in excess of 2800°C is needed.
- The exhaust gas which is coming from MHD generator is at temperature of about 2500 K and can be used as the heating of the boilers of steam power plant, which increases the overall efficiency. This becomes the combined cycle.

- As compared to the conventional power plant, the conversion efficiency of MHD is high and can be around 50%, the conventional power plant efficiency is less than 40%.
- The MHD system is reliable as it has no moving parts.
- This system produces power free of pollution.
- After starting the system it can easily rich to full power within less time.
- The plant size is considerable small compared with the conventional power plant.

2.8.3 Disadvantages of MHD System [May 18]

- Very large magnets are required which are costly.
- Very high operating temperature, the material should sustain the temperature.
- The system is having high friction and heat transfer

October 2017

1. (a) Principle of MHD Generator [6]
   (b) Anaerobic digestion of biomass
   (c) Fuel cell
2. What is the present status of Nuclear energy in India and what are its future prospects? [6]
3. Enumerate at least five applications of solar PV cell energy. Discuss in detail any one of them with a neat sketch [6]

December 2017

1. Define solar energy? What is flat plate collector? Describe its components with suitable sketch.
2. Give classification of fuel cells using a flowchart. What are the advantages and disadvantages of a fuel cell? State any four each. [6]

May 2018

1. Describe the basic principle of operation of an MHD generator. Enumerate any three major advantages and limitations of MHD generating plant? [6]

June 2019