# 10

# Non-Conventional Power Generation and Direct Energy Conversion

10.1. Introduction to energy and energy sources—Energy—Non-conventional energy sources. 10.2. Wind power plants—Introduction—Characteristics of wind—Advantages and disadvantages of wind energy—Sources/origins of wind—Wind availability and measurement—Wind power—Terms and definitions—Types of wind mills—Wind-electric generating power plant—Types of wind machines—Utilisation aspects of wind energy—Generating systems—Wind-powered battery chargers—Wind electricity in small independent grids—Wind electricity economics—Problems in operating large wind power generators—Considerations for selection of site for wind energy conversion systems. 10.3. Tidal power plants—Ocean energy conversion—Ocean energy sources—General aspects—Tidal power plants—Wave energy—Ocean thermal energy conversion (OTEC) plant. 10.4. Solar power plants—Solar energy—General terms of introduction—Collectors in various ranges and applications—Flat plate collectors—Focusing (or concentrating) collectors—Solar pond technology—Low temperature thermal power generation—Medium temperature systems using focusing collectors—High temperature systems—Solar farm and solar power plant. 10.5. Geothermal power plants—Geothermal energy—Geothermal sources—Geothermal power estimates—Environmental problems—Applications of geothermal energy—Advantages and disadvantages of geothermal energy over other energy forms—Geothermal energy in India and abroad. 10.6. Biogas plants—Biomass—Introduction to biomass—Biomass conversion processes—Biogas plants. 10.7. Direct energy conversion systems—Thermoelectric conversion system—Thermionic conversion system—Photovoltaic power system—Magnetohydrodynamics (MHD) system—Electrostatic mechanical generators—Electro gas-dynamic generators (EGD)—Fuel cells—Nuclear Batteries—Highlights—Theoretical Questions—Competitive Examinations Questions.

## 10.1. INTRODUCTION TO ENERGY AND ENERGY SOURCES

### 10.1.1. Energy

**Energy** *is the capability to produce motion ; force ; work ; change in shape ; change in form etc.*

Energy exists in several forms such as :

—Chemical energy

—Nuclear energy

—Mechanical energy

—Electrical energy

—Internal energy

—Bio-energy in vegetables and animal bodies

—Thermal energy etc.

*Energy* may be *classified* as follows :

**Energy :**

1. *Stored in earth :*
   - (*i*) Chemically bonded :
     - (*a*) Oil
     - (*b*) Gas
     - (*c*) Coal
   - (*ii*) Geotherm
   - (*iii*) Atomic :
     - (*a*) Fission
     - (*b*) Fusion (futuristic)
2. *Continually received by earth :*
   - Solar insolation
     - (*a*) Ocean temp. difference
     - (*b*) Tidal
     - (*c*) Hydro
       - —Irrigation
       - —Other benefits (flood control etc.)
       - —Hydroelectric (no thermal limits)
     - (*d*) Wind
       - —Wind mill generator
     - (*e*) Direct
       - —*PVC*
       - —Concentrator—Steam turbine

Water input → Thermocycle

Thermocycle
—Steam turbo-generator
—Gas turbo-generator-combined cycle
—M.H.D combined cycle

Conservation
—Cogeneration
—High thermal generation
—low trans. loss
—High efficiency motors
—Curb wasteful use

- **Energy science** focusses attention on the *'energy'* and *'energy transformations'* involved in the various other branches of science, to National economy and civilization.
- **Energy technology** *is the applied part of energy sciences for work and processes, useful to human society, nations and individuals.*

— Energy technologies deal with plants and processes involved in the energy transformation and *analysis* of the *useful energy* ***(exergy)*** and *worthless energy* ***(anergy)***

— Energy technology co-relates various sciences and technologies

***Characteristics of energy.*** Energy has the following *characteristics* :

(*i*) It can be stored.

(*ii*) It can neither be created nor destroyed.

(*iii*) It is available in several forms

(*iv*) It does not have absolute value.

(*v*) It is associated with a potential. Free flow of energy takes place only from a higher potential to a lower potential.

(*vi*) It can be transported from one system to other system or from one place to another.

(*vii*) The energy is measured in Nm or in joules.

(*viii*) The forms of energy are graded as per their availability or exergy content.

- The total mass and energy in the closed system remains unchanged (as per law of conservation of energy).

**Energy and thermodynamics :**

*"Thermodynamics" is a branch of energy which deals with conversion of heat into work or vice versa :*

— More than 30 per cent energy conversion processes involve *thermodynamics*, while more than 30 per cent energy conversion processes involve *electromagnetic energy* and more than 30 per cent involve *chemical energy*.

In most of the energy conversion processes, First law and Second law of thermodynamics are applicable :

- *First law* of thermodynamics relates to *conservation of energy* and throws light on concept of internal energy.
- *Second law* of thermodynamics indicates the limit of *converting heat into work* and introduces the principle of increase of entropy. Following statements are based on this law :
  — Spontaneous processes are irreversible.
  — The internal energy of the environment is worthless for obtaining useful work.
  — All forms of energy are not identical with reference to useful work.
  — Every energy conversion process has certain 'losses'.

**Energy resources :**

The various sources of energy can be *classified* as follows :

1. *Commercial primary energy resources :*
   (*i*) Coal
   (*ii*) Lignite
   (*iii*) Oil and natural gas
   (*iv*) Hydroelectric
   (*v*) Nuclear fuels.
2. *Renewable energy sources :*
   (*i*) Solar photo-voltaic
   (*ii*) Wind
   (*iii*) Hydrogen fuel-cell.
3. *New sources of energy :*

Most prominent *new sources of energy* as identified by UN are :

(*i*) Tidal energy
(*ii*) Ocean waves
(*iii*) OTEC (Ocean Thermal Energy Conversion)
(*iv*) Geothermal energy
(*v*) Peat
(*vi*) Tar sand
(*vii*) Oil shales
(*viii*) Coal tar
(*ix*) Draught animals
(*x*) Agricultural residues etc.

— *Coal, oil, gas, uranium and hydro* are commonly known as ***commercial or conventional energy sources.*** These represent about 92% of the total energy used in the world.

— *Firewood, animal dung and agricultural waste* etc. are called as ***non-commercial energy sources.***

These represent about 8% of the total energy used in the world.

- Renewable energy sources include both *'direct'* solar radiation intercepted by collectors (*e.g.* solar and flat-plate thermal cells) and *'indirect'* solar energy such as *wind, hydropower, ocean energy* and *biomass resources* that can be managed in a sustainable manner. *Geothermal* is considered renewable because the resource is unlimited.

**Advantages of renewable energy sources :**

1. These energy sources recur in nature and are inexhaustible.
2. The power plants using renewable sources of energy do not have any fuel cost and hence their running cost is negligible.
3. As renewables have low energy density, there is more or less no pollution or ecological balance problem.
4. These energy sources can help to save foreign exchange and generate local employment (since most of the devices and plants used with these sources of energy are simple in design and construction, having being made from local materials, local skills and by local people).
5. These are more site specific and are employed for local processing and application, their economic and technological losses of transmission and distribution being nil.
6. Since conversion technology tends to be flexible and modular, renewable energy can usually be rapidly deployed.

**Limitations/Demerits :**

1. Owing to the low energy density of renewable energy sources large size plants are required, and as such the cost of delivered energy is increased.
2. These energy sources are intermittent and also lack dependability.
3. The user of these sources of energy has to make huge additional investment before deriving any benefit from it (whereas in case of conventional energy sources, the processing cost has traditionally been borne by large industries which borrow money from a bank and then charge the customer for each unit of energy used).
4. These energy sources, due to their low energy density, have low operating temperatures leading to low efficiencies.
5. Since the renewable energy plants have low operational efficiency, the heat rejections are large which cause thermal pollution.
6. These energy sources are energy intensive.

**Note.** Energy cannot be economically stored in electrical form in large quantities. Energy in large quantities is stored in conventional forms (Hydro-reservoirs, coal stocks, fuel stocks, nuclear fuel stocks). Electrical energy is generated, transmitted and utilised almost simultaneously without intermediate storage in electrical form. Hence a large *electrical network* is formed *to pool up electrical energy* available from various generating stations and to distribute to various consumers over the large geographical area. Consumers draw power as per their load requirement (*e.g.* lighting, heating, mechanical drives etc.)

### 10.1.2. Non-conventional energy sources

A plenty of energy is needed to sustain industrial growth and agricultural production. The existing sources of energy such as coal, oil, uranium etc. may not be adequate to meet the ever increasing energy demands. These conventional sources of energy are also depleting and may be exhausted at the end of the century or beginning of the next century. Consequently sincere and untiring efforts shall have to be made by the scientists and engineers in exploring the possibilities of harnessing energy from several non-conventional energy sources. The various non-conventional energy sources are as follows :

(*i*) Solar energy (*ii*) Wind energy

(*iii*) Energy from biomass and biogas
(*iv*) Ocean thermal energy conversion
(*v*) Tidal energy
(*vi*) Geothermal energy
(*vii*) Hydrogen energy
(*viii*) Fuel cells
(*ix*) Magneto-hydrodynamics generator
(*x*) Thermionic converter
(*xi*) Thermo-electric power.

**Advantages of non-conventional energy sources :**

The leading advantages of non-conventional energy sources are :

1. They do not pollute the atmosphere.
2. They are available in large quantities.
3. They are well suited for decentralised use.

According to energy experts the non-conventional energy sources can be used with advantage for *power generation* as well as other applications in a large number of locations and situations in our country.

## 10.2. WIND POWER PLANTS

### 10.2.1. Introduction

- **Wind** *is air set in motion by small amount of insolation reaching the upper atmosphere of earth.*
  — Nature generates about $1.67 \times 10^5$ kWh of wind energy annually over land area of earth and 10 times this figure over the entire globe.
  — Wind contains *kinetic energy* which can easily be *converted to electrical energy.*
- The wind energy, which is an indirect source of energy, can be used to run a wind will which in turn drives a generator to produce electricity. Although wind mills have been used for more than a dozen centuries for grinding grain and pumping water, interest in large scale power generation has developed over the past 50 years. A largest wind generator built in the past was 800 kW unit operated in France from 1958-60. The flexible 3 blades propeller was about 35 m in diameter and produced the rated power in a 60 km/hour wind with a rotation speed of 47 r.p.m. The maximum power developed was 12 MW. In India the interest in the wind mills was shown in the last fifties and early sixties. Apart from importing a few from outside, new designs were also developed, but these were not sustained. It is only in last 15—20 years that development work is going on in many institutions. An important reason for this lack of interest in wind energy must be that wind, in India is *relatively low and vary appreciably with seasons. These low and seasonal winds imply a high cost of exploitation of wind energy. In our country high wind speeds are however available in coastal areas of Sourashtra, Western Rajsthan and some parts of central India. In these areas there could be a possibility of using medium and large sized wind mills for generation of electricity.*

**Applications of wind plants :**

Following are the main *applications* of wind plants :

1. Electrical generation.
2. Pumping.
3. Drainage.
4. Grinding grains.
5. Saw milling.

### 10.2.2. Characteristics of Wind

The main characteristics of wind are :

- *Wind speed increases roughly as* $\frac{1}{7}$ *th power of height. Typical* tower heights are about 20–30 m.
- *Energy-pattern factor.* It is the ratio of the actual energy in varying wind to energy calculated from the cube of mean wind speed. This factor is always *greater than unity* which means that energy estimates based on mean (hourly) speed are pessimistic.

### 10.2.3. Advantages and Disadvantages of Wind Energy

Following are the *advantages* and *disadvantages* of wind energy :

***Advantages :***

1. It is a renewable energy source.
2. Wind power systems being non-polluting have no adverse effect on the environment.
3. Fuel provision and transport are not required in wind energy conversion systems.
4. Economically competitive.
5. Ideal choice for rural and remote areas and areas which lack other energy sources.

***Disadvantages :***

1. Owing to its irregularity, the wind energy needs storage.
2. Availability of energy is fluctuating in nature.
3. The overall weight of a wind power system is relatively high.
4. Wind energy conversion systems are noisy in operation.
5. Large areas are required for instàllation/operation of wind energy systems.
6. Present systems are neither maintenance free, nor practically reliable.
7. Low energy density.
8. Favourable winds are available only in a few geographical locations, away from cities, forests.
9. Wind turbine design, manufacture and installation have proved to be most complex due to several variables and extreme stresses.
10. Requires energy storage batteries and/or stand by diesel generators for supply of continuous power to load.
11. Wind farms require flat, vacant land free from forests.
12. Only in kW and a few MW range ; it does not meet the energy needs of large cities and industry.

### 10.2.4. Sources /Origins of Wind

Following are the two sources/origins of wind (a natural phenomenon) :

1. Local winds.
2. Planetary winds.

1. **Local winds.** These winds are caused by *unequal heating and cooling of ground surfaces and ocean / lake surfaces during day and night.* During the day warmer air over land rises upwards and colder air from lakes, ocean, forest areas, shadow areas flows towards warmer zones.

2. **Planetary winds.** These winds are caused by *daily rotation of earth around its polar axis and unequal temperature between polar regions and equatorial regions.* The strength and direction of these planetary winds change with the seasons as the solar input varies.

- Despite the wind's intermittent nature, *wind patterns at any particular site remain remarkably constant year by year.*
- Average wind speeds are greater in hilly and coastal areas than they are well in land. The winds also tend to blow more consistently and with greater strength over the surface of the water where there is a less surface drag.
- *Wind speeds increase with height.* They have traditionally been measured at a standard height of 10 metres where they are found to be 20–25 percent greater than close to the surface. At a height of 60 m they may be 30–60 percent higher because of the reduction in the drag effect of the surface of the earth.

### 10.2.5. Wind Availability and Measurement

Wind energy can only be economical in areas of good wind availability. Wind energy differs with region and season and also, possibly to an even greater degree with local terrain and vegetation. Although wind speeds generally increase with height, varying speeds are found over different kinds of terrain. Observations of wind speed are carried out at meteorological stations, airports and lighthouses and are recorded regularly with ten minute mean values being taken every three hours at a height of 10 m. But airports, sometimes are in valleys and many wind speed meters are situated low and combinations of various, other factors mean that reading can be misleading. It is difficult, therefore, to determine the real wind speed of a certain place without actual in-situ measurements.

The World Meteorological Organization (WMO) has accepted four methods of wind recording :

(*i*) Human observation and log book.

(*ii*) Mechanical cup-counter anemometers.

(*iii*) Data logger.

(*iv*) Continuous record of velocity and direction.

1. **Human observation and log book.** This involves using the Beaufort Scale of wind strengths which defines visible "symptoms" attributable to different wind speeds. The method is *cheap* and *easily implemented* but is *often unreliable*. The best that can be said of such records is that they are better than nothing.

2. **Mechanical cup-counter anemometers.** The majority of meteorological stations use mechanical cup-counter anemometers. By taking the readings twice or three times a day, it is possible to estimate the mean wind speed. This is a *low cost method*, but is *only relatively reliable*. The instrument has to be in good working order, it has to be correctly sited and should be reliably read at least daily.

3. **Data logger.** The equipment summarizes velocity frequency and direction. It is *more expensive and prone to technical failures but gives accurate data*. The method is tailored to the production of readily interpretable data of relevance to wind energy assessment. It does not keep a time series record but *presents the data in processed form*.

4. **Continuous record of velocity and direction.** This is how data is recorded at major airports of permanently manned meteorological stations. The *equipment is expensive and technically complex*, but it retains a detailed times-series record (second-by-second) of wind direction and wind speed. Results are given in copious quantities of data which require lengthy and expensive analysis.

### 10.2.6. Wind Power

The wind power can be computed by using the concept of kinetics. The mind mill works on the principle of *converting kinetic energy of the wind to mechanical energy.*

*"Power density" in moving air* is given by

$$P_w = KU_w^3 \; W/m^2 \qquad ...(10.1)$$

where, $U_w$ = Wind speed in km/h, and

$K = 1.3687 \times 10^{-2}$

Theoretically a fraction $\frac{16}{27} = 0.5926$ of the power in the wind is recoverable. This is called *Gilbert's limit* or *Betz coefficient.* Aerodynamically efficiency for converting wind energy to mechanical energy can be reasonably assumed to be 70 percent. So the mechanical energy available at the rotating shaft is limited to 40 per cent or at the most 45 percent of wind energy.

- Available wind power ($P_a$) may be given as :

$$P_a = \frac{1}{2} mU_w^2 = \frac{1}{2} \cdot \rho.A.U_w U_w^2 = \frac{1}{2} \rho. \frac{\pi}{4} D^2.U_w^3$$

$$= \frac{1}{8} \rho\pi D^2 U_w^3 \text{ watts} \qquad ...(10.2)$$

where, $\rho$ = Density of air (1.225 kg/m$^3$ at sea level), and

$D$ = Diameter ( in meters), in *horizontal axis* aeroturbines.

Eqn. (10.2) indicates that maximum power available from the wind *varies according to square of the diameter* of the intercept area (or square of the root diameter) normally taken to be swept area of the aeroturbine. The combined effects of wind speed and rotor diameter variations is shown in Fig. 10.1. Thus, *wind machines intended for generating substantial amounts of power should have large rotors and be located in areas of high wind speeds.*

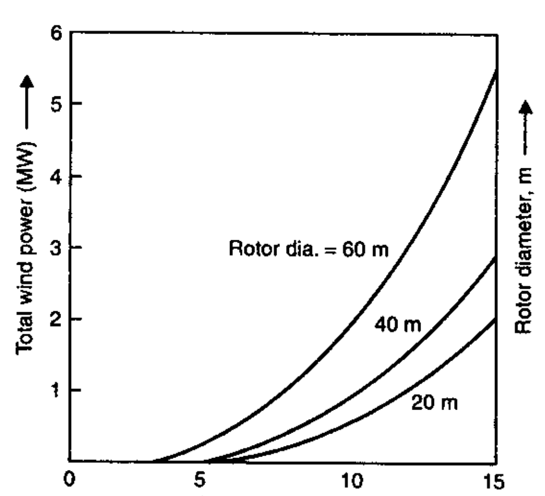


Fig. 10.1. The combined effects of variations of wind speed and diameter.

- State-wise wind power potential and wind power addition capacity (as on 31-12-2004) are given in table 10.1 and table 10.2 respectively.

**Table 10.1. Wind Power Potential**

| *State* | *Gross potential(MW)* *(a)* | *Technical potential (MW)* *(b)* |
|---|---|---|
| AndhraPradesh | 8275 | 1750 |
| Gujarat | 9675 | 1780 |
| Karnataka | 6620 | 1120 |
| Kerala | 875 | 605 |
| Medhya Pradesh | 5500 | 825 |
| Maharashtra | 3650 | 3020 |
| Orissa | 1700 | 680 |
| Rajasthan | 5400 | 895 |
| Tamil Nadu | 3050 | 1750 |
| West Bengal | 450 | 450 |
| **Total** | **45195** | **12875** |

**Table 10.2. State-Wise Wind Power Capacity Addition(As on 31.12.2004)**

| *State* | *Demonstration projects (MW) (a)* | *Private sector projects (MW) (b)* | *MW (Total) capacity (MW) (a) + (b)* |
|---|---|---|---|
| Andhra Pradesh | 5.4 | 95.9 | 101.3 |
| Gujarat | 17.3 | 202.6 | 219.9 |
| Karnataka | 7.1 | 268.9 | 276.0 |
| Kerala | 2.0 | 0.0 | 2.0 |
| Madhya Pradesh | 0.6 | 27.0 | 27.6 |
| Maharashtra | 8.4 | 402.8 | 411.2 |
| Rajasthan | 6.4 | 256.8 | 263.2 |
| Tamil Nadu | 19.4 | 1658.0 | 1677.4 |
| West Bengal | 1.1 | 0.0 | 1.1 |
| Others | 0.5 | 0.0 | 0.5 |
| **Total** | **68.2** | **2912.0** | **2980.2** |

**Characteristics of a good wind power site :**

A good wind power site should have the following *characteristics :*

1. High annual wind speed.
2. An open plain or an open shore line.
3. A mountain gap.
4. The top of a smooth, well rounded hill with gentle slopes lying on a flat plain or located on an island in a lake or sea.
5. There should be no full obstructions within a radius of 3 km.

### 10.2.7. Terms and Definitions

1. **Aerodynamics.** It is the branch of science which deals with air and gases in motion and their mechanical effects.

2. **Wind .** Air in motion.
3. **Windmill.** It is the machinery driven by the wind acting upon sails used chiefly in flat districts for grinding of corn, pumping of water etc.
4. **Wind turbine (Aeroturbine, wind machine).** It is a machine which converts wind power into rotary mechanical power. A wind turbine has aerofoil blades mounted on the rotor. The wind drives the rotor and produces rotary mechanical energy.
5. **Wind turbine generator unit.** It is an assemblage of a wind turbine, gear chain, electrical generator, associated civil works and auxiliaries.
6. **Wind farm (wind energy park).** It is a zone comprising several turbine-generator units, electrical and mechanical auxiliaries, substation, control room etc.
   Wind farms are located in areas having continuous favourable wind. Such locations are on-shore or off-shore away from cities and forests.
7. **Nacelle.** It is an assemblage comprising of the wind turbine, gears, generator, bearings, control gear etc. mounted in a housing.
8. **Propeller (wheel).** It is a revolving shaft with blades. The blades are set at an angle and twisted (like thread of a screw).
9. **Hub.** It is control solid part of the wheel (propeller).
10. **Pitch angle.** It is the angle between the direction of wind and the direction perpendicular to the planes of blades.
11. **Pitch control.** It is the control of pitch angle by turning the blades or blade tips [Fig. 10.2 (*a*)].
12. **Yaw control.** It is the control for orienting (steering) the axis of wind turbine in the direction of wind [Fig. 10.2 (*b*)].
13. **Teethering.** It is see-saw like swinging motion with hesitation between two alternatives. The plane of wind turbine wheel is swung in inclined position at higher wind speeds by teethering control [Fig. 10.2 (*b*)].

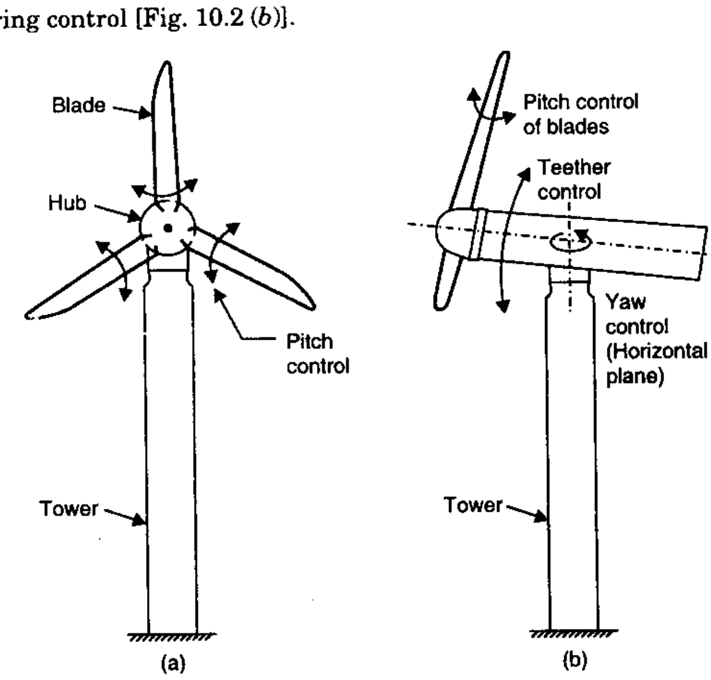


Fig. 10.2. Controls in wind-turbines: Pitch control; Yaw control ; Teether control.

14. **Wind speeds for turbines :**

(*i*) ***Cut-in-speed.*** It is the wind speed at which wind-turbine starts delivering shaft power. For a typical horizontal shaft propeller turbine it may be around 7m/s.

(*ii*) ***Mean wind speed.*** $U_{wm} = \frac{U_{w_1} + U_{w_2} + \ldots\ldots U_{w_n}}{n}$

(*iii*) ***Rated wind speed.*** It is the velocity at which the wind-turbine generator delivers rated power.

(*iv*) ***Cut-out wind velocity (furling wind velocity).*** It is the speed at which power conversion is cut out.

### 10.2.8. Types of Wind Mills

The various types of wind mills (See Fig. 10.3) are :

1. Multiple blade type.
2. Savonius type.
3. Darrieus type.

1. **Multiple blade type.** It is the *most widely used* wind mill.

- It has 15 to 20 blades made from metal sheets. The *sail type* has three blades made by stitching out triangular pieces of convass cloth. Both these types run at low speeds of 60 to 80 r.p.m.

2. **Savonius type.** This type of windmill has hollow circular cylinder sliced in half and the halves are mounted on vertical shaft with a gap in between.

- Torque is produced by the pressure difference between the two sides of the half facing the wind.
- This is quite efficient but needs a large surface area.

*Characteristics of savonius rotor :*

(*i*) Self starting.
(*ii*) Low speed.
(*iii*) Low efficiency.

3. **Darrieus type.** This wind mill needs *much less surface area.*

- It is shaped like an egg beater and has two or three blades shaped like aerofoils.

*Characteristics of Darrieus rotor :*

(*i*) Not self starting.
(*ii*) High speed.
(*iii*) High efficiency.
(*iv*) Potentially low capital cost.

It may be noted that :

- Both the Savonius and Darrieus types are mounted on a *vertical axis* and hence they *can run independently of the direction of wind.*
- The horizontal axis mills *have to face the direction of the wind* in order to generate power.

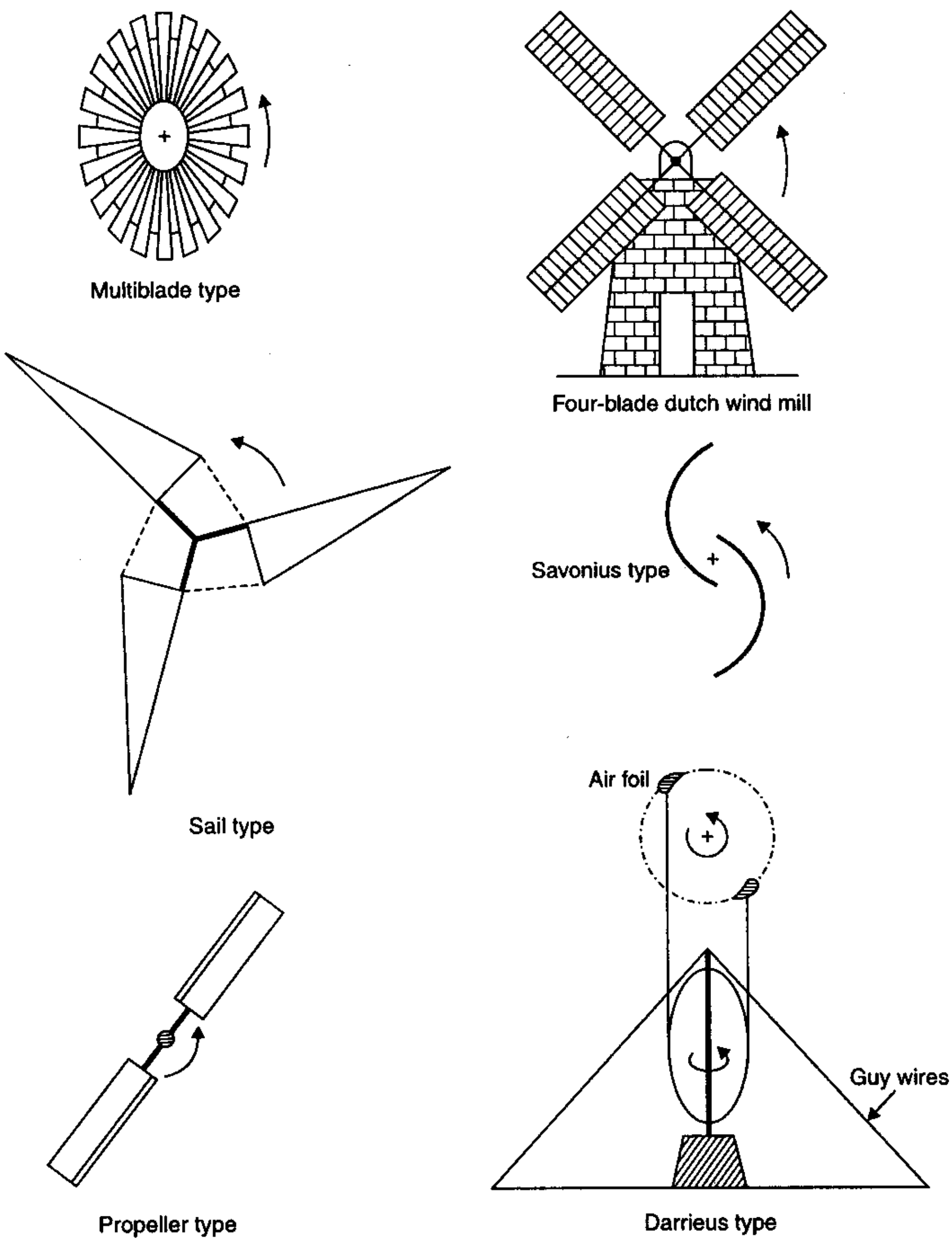


Fig. 10.3. Types of wind mills.

**Performance of Wind mills :**

The performance of a wind mill is defined as *'Co-efficient of performance'* ($K_p$).

$$K_p = \frac{\text{Power delivered by the rotor}}{\text{Maximum power available in the wind}}$$

or
$$K_p = \frac{P}{P_{max}} = \frac{P}{\frac{1}{2}\rho A U_w^3}$$

where, $\rho$ = Density of air,
$A$ = Swept area, and
$U_w$ = Velocity of wind.

Fig. 10.4 shows a plot between $K_p$ and tip speed ratio $U_{bt}/U_w$
where, $U_{bt}$ = Speed of blade tip.

It can be seen that $K_p$ is the *lowest of Savonius* and *Dutch types* whereas the *propeller types have the highest value.*

In the designing of wind mills, it is upper most to keep the *power to weight ratio at the lowest possible level.*

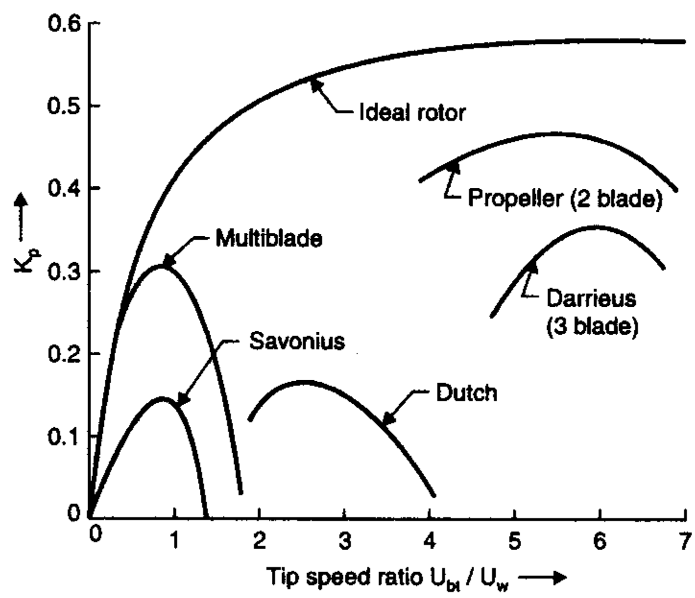


Fig. 10.4. $K_p$ of wind mills.

### 10.2.9. Wind-electric Generating Power Plant

Fig. 10.5 shows the various parts of a wind-electric generating power plant. These are :

1. Wind turbine or rotor
2. Wind mill head—it houses speed increaser, drive shaft, clutch, coupling etc.
3. Electrical generator
4. Supporting structure

— The most important component is the **rotor.** For an effective utilisation, all components should be properly designed and matched with the rest of the components.

— The wind mill head performs the following functions :

(*i*) It supports the rotor housing and the rotor bearings.

(*ii*) It also houses any control mechanism incorporated like changing the pitch of the blades for safety devices and tail vane to orient the rotor to face the wind, the latter is facilitated by mounting it on the top of the supporting structure on suitable bearings.

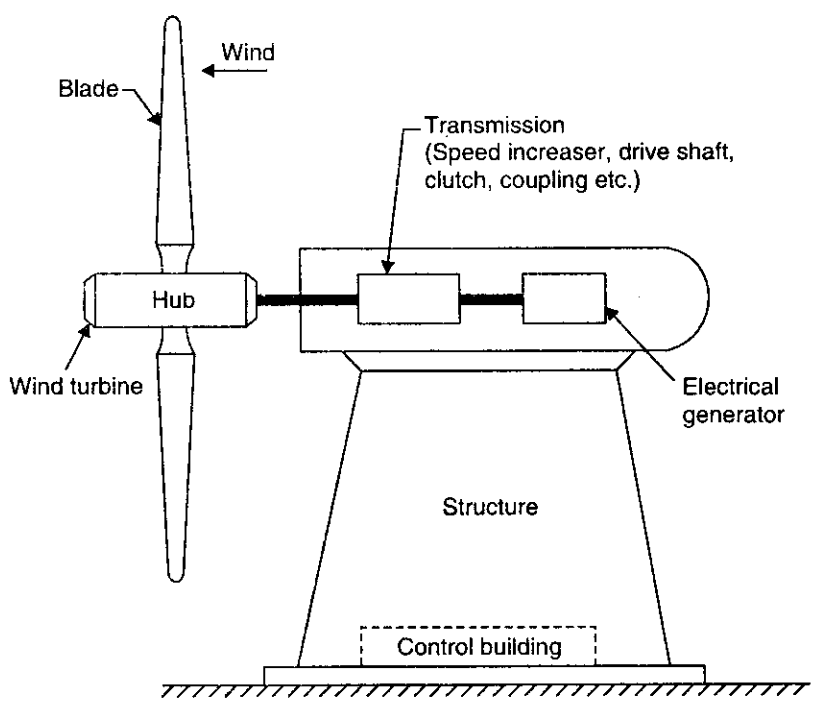


Fig. 10.5. Wind-electric generating power plant.

— The wind turbine may be located either *unwind* or *downwind* of the power. In the unwind location the wind encounters the turbine before reaching the tower. *Downwind rotors are generally preferred especially for the large aerogenerators.*

— The **supporting structure** is designed to withstand the wind load during gusts. Its type and height is related to cost and transmission system incorporated. Horizontal axis wind turbines are mounted on towers so as to be above the level of turbulence and other ground related effects.

### 10.2.10. Types of Wind Machines

Wind machines (***aerogenerators***) are generally *classified* as follows :

1. Horizontal axis wind machines
2. Vertical axis wind machines.

**Horizontal axis wind machines.** Fig. 10.6 shows a schematic arrangement of a horizontal axis machine. Although the common wind turbine with a horizontal axis is simple in principle, yet the design of a complete system, especially a large one that would produce electric power economically, is complex. It is of paramount importance that the components like rotor, transmission, generator and tower should not only be as efficient as possible but they must also function effectively in combination.

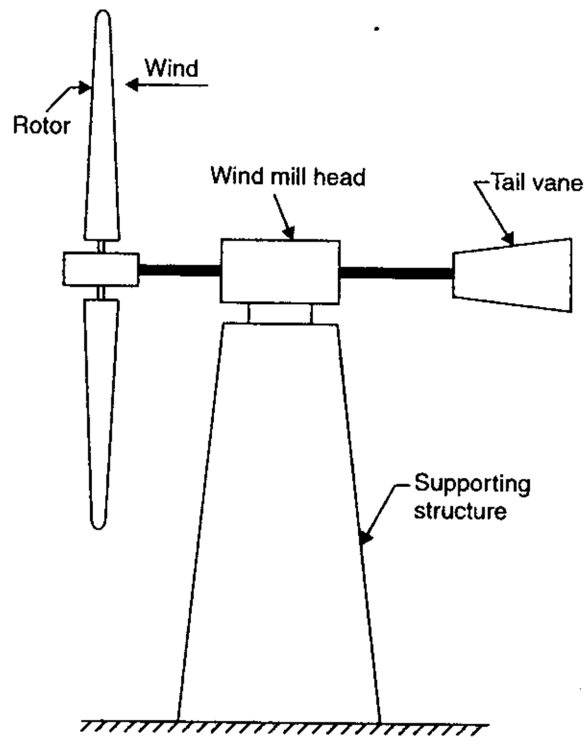


Fig. 10.6. Horizontal axis wind machine.

**Vertical axis wind machines.** Fig. 10.7 shows vertical axis type wind machine. One of the main advantages of vertical axis rotors is that they do not have to be turned into the windstream as

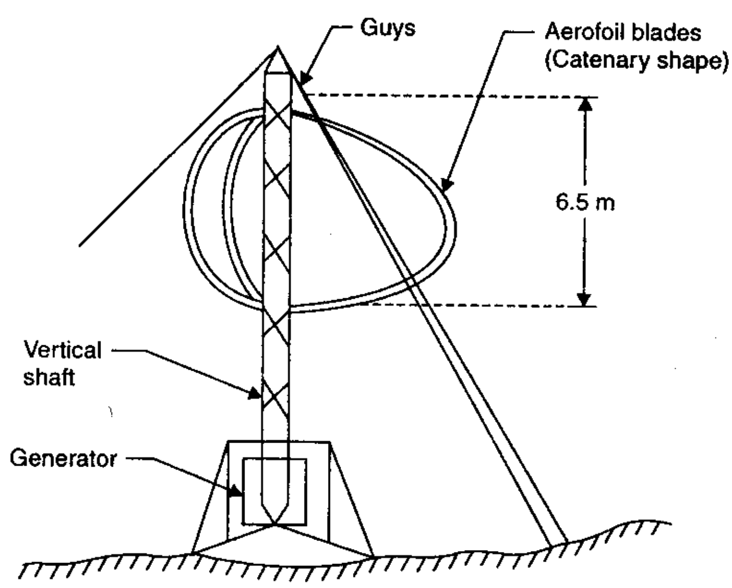


Fig.10.7. Vertical axis wind machine.

the wind direction changes. Because their operation is independent of wind direction, vertical axis machines are called *panemones*.

***Advantages of vertical axis wind machines :***

1. The rotor is not subjected to continuous cyclic gravity loads since the blades do not turn end over end (Fatigue induced by such action is a major consideration in the design of large horizontal axis machines).
2. Since these machines would react to wind from any direction, therefore, they do not need yawing equipment to turn the rotor into the wind.
3. As heavy components (*e.g.* gear box, generator) can be located at ground level these machines may need less structural support.
4. The installation and maintenance are easy in this type of configuration.

### 10.2.11. Utilisation Aspects of Wind Energy

Utilisation aspects of wind energy fall into the following three broad categories :

1. Isolated continuous duty systems which need suitable energy storage and reconversion systems.
2. Fuel-supplement systems in conjunction with power grid or isolated conventional generating units.
   - This utilisation aspect of wind energy is the *most predominant in use as it saves fuel and is fast growing particularly in energy deficient grids.*
3. Small rural systems which can use energy when wind is available.
   - This category has application in *developing countries with large isolated rural areas.*

### 10.2.12. Generating Systems

The wind turbine-generator unit comprising wind turbine, gears and generator, converts wind power into electrical power. Several identical units are installed in a wind farm. The total electrical power produced by the wind farm is fed into the distribution network or stand alone electrical load.

The choice of electrical system for an aeroturbine is guided by *three* factors :

(*i*) ***Type of electrical output :***

— D.C.

— Variable-frequency A.C.

— Constant-frequency A.C.

(*ii*) ***Aeroturbine rotational speed :***

— Constant speed with variable blade pitch.

— Nearly constant speed with simpler pitch-changing mechanism.

— Variable speed with fixed pitch blades.

(*iii*) ***Utilisation of electrical energy output :***

— In conjunction with battery or other form of storage.

— Interconnection with power grid.

#### 10.2.12.1. Constant speed-constant frequency (CSCF) system

Large scale electrical energy generated from wind is expected to be fed to the power grid to displace fuel generated kWh. For this application present economics and technological developments are heavily weighted in favour of CSCF system with alternator as the generating unit. It must be reminded here that to obtain high efficiencies the blade pitch varying mechanism and controls have to be installed.

— Wind turbines of electrical rating of *100 kW and above* are of constant-speed type and are coupled to synchronous generators (conventional type). The turbine rated at *less than 100 kW* is coupled to fairly constant speed induction generators connected to grid and so operating at constant frequency having their excitation VARs from the grid or capacitor compensators.

**10.2.12.2. Variable speed-constant frequency (VSCF) system**

Variable-speed drive is *typical for small wind generators* used in autonomous applications, generally producing variable frequency and variable voltage output.

The variable speed operation of wind electric system *yields higher outputs* for both low and high wind speeds. This results in higher annual energy yields per rated installed kW capacity. Both horizontal axis and vertical axis turbines will exhibit this gain under variable speed operation.

The following schemes are used *to obtain constant frequency output* :

(*i*) A.C.—D.C.—A.C. link.

(*ii*) Double output induction generator.

(*iii*) A.C. commutation generator.

With the advent of power switching technology (*viz* high power diodes and thyristors) and chip-based associated control circuitry, it has now become possible to use VSCF systems. VSCF and wind electrical systems and its associated power conditioning system operate as shown in Fig. 10.8.

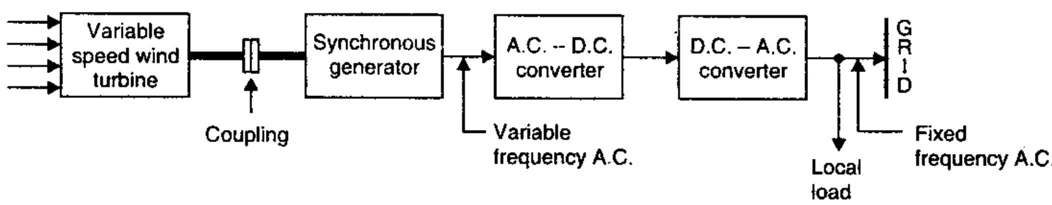


Fig. 10.8. Block schematic of VSCF wind electrical system.

VSCF wind electrical systems claim the following ***advantages*** :

1. Significant reduction in aerodynamic stresses, which are associated with constant-speed operation.
2. It is possible to extract extra energy in the high wind region of the speed-duration curve.
3. Complex pitch changing mechanism is not required.
4. Wind turbine/Aeroturbine always operates at maximum efficiency point (constant tip-speed ratio).

**10.2.12.3. Variable speed-variable frequency (VSVF) system**

The generator output is affected by the variable speed. The frequency of the induced voltage depends on the impedance of the load and speed of the prime mover. The variable voltage can be converted to constant D.C. using choppers or rectifier and then to constant A.C. by the inverters.

**10.2.13. Wind-Powered Battery Chargers**

One application of wind energy systems which is of considerable potential importance (to developing countries) is the use of small wind generators to charge batteries for powering lighting, radio communication and hospital equipment. Wind generators have been in use in Europe and North America since the 1920s, although their use declined considerably.

A battery charging system has to include the following :

(*i*) A wind powered generator

(*ii*) A converter

(*iii*) A container for the batteries.

Fig. 10.9 shows a set-up of wind powered battery charging system. It is worthnoting that 12 volt batteries, which are rechargeable using wind generators, can be used to power fluorescent tube lighting which is six times more efficient than tungsten filament lamps. Such lighting opens up a number of important development opportunities in areas which normally have no lighting.

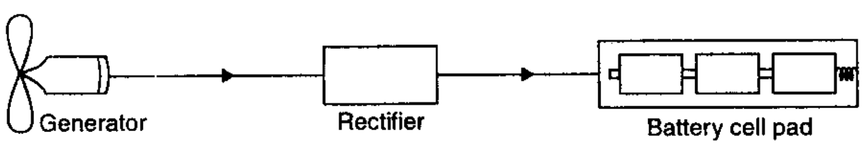


Fig. 10.9. Wind powered battery charging system.

For small wind generators the total system efficiency is made up as follows :

| | |
|---|---|
| Wind regime matching efficiency | 60% (approx.) |
| Rotor efficiency | 35% (approx.) |
| Generator and wiring efficiency | 70% (approx.) |
| Battery charge/discharge efficiency | 70% (approx.) |

Cumulatively, a total energy capture efficiency of about 10% is generally obtained from small wind generators utilized for battery charging.

Battery charging wind generators are produced in several countries, notably Australia, France, Sweden, Switzerland, the U.K., the U.S.A. and West Germany. In developing countries production is underway in China and has started in India.

### 10.2.14. Wind Electricity in Small Independent Grids

Refer Fig. 10.10. In such systems electricity consumption fluctuates constantly as does the availability of wind energy. The degree of coincidence of supply and demand can be calculated by statistical means and it has been found that electricity supply with an acceptable degrees of reliability cannot be based solely on wind energy. If an extensive grid does not exist, electricity storage (batteries) or a back-up system (diesel) is required. Loads for remote systems of upto 6 kWh/day equivalent to an average power consumption of 250 W with a duty cycle of 24 hours, can be provided with battery storage.

If a diesel and wind generator are used in conjunction with a grid, the *diesel generator should only be used when wind energy is absent*. Problems can occur, however, when the diesel generator is called on to change its output frequently as wind energy availability fluctuates. Besides decreasing the oil saving, diesel generation on this basis leads to more frequent overhauls of the generator. Both factors will increase costs. Several methods of overcoming these problems have been tried but there is not yet an established solution. Some development work has still to be done before wind generators can be run in parallel with diesel on a routine basis.

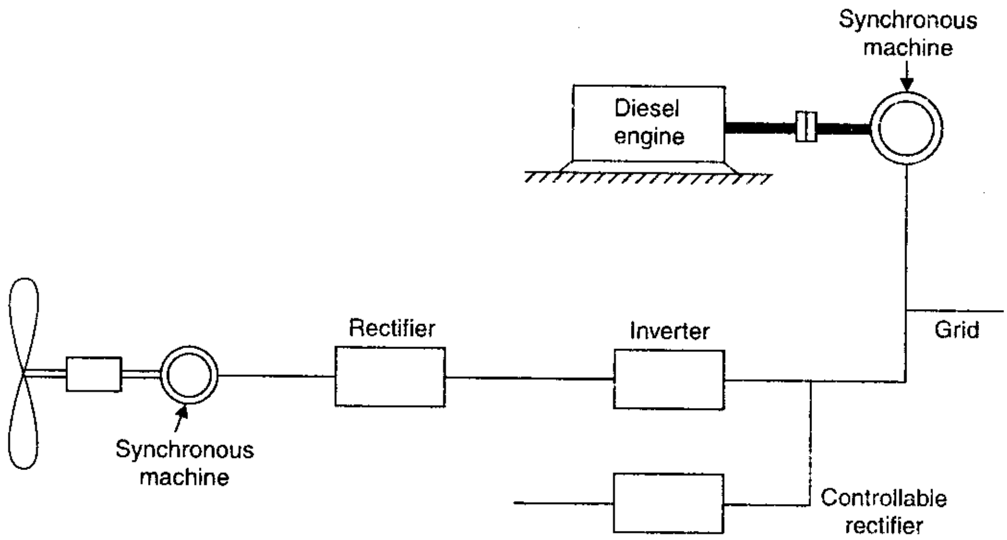


Fig. 10.10. Principle of combined wind/diesel power generation.

### 10.2.15. Wind Electricity Economics

Wind generator power costs are heavily linked to the characteristics of a wind resource in a specific location. The cost of supplied power declines as wind speeds increase, and the power supplied increases in proportion to the *cube of the wind speed.*

Matching available energy and load requirements is also important in wind energy economics. The correct size of wind generator must be chosen together with some kind of storage or co-generation with an engine or a grid to obtain the best economy. The ideal application is a task that can utilize a variable power supply, *e.g.* ice making or water purification.

Regarding the *economics*, the choice of interest rate obviously has a major effect on the overall energy cost. With low interest rates, capital intensive power sources such as solar and wind are favoured. Other factors bearing a strong influence on the economics of wind electricity are the standard of maintenance and service facilities and the cost of alternative energy supplies in the particular area.

### 10.2.16. Problems in Operating Large Wind Power Generators

The operation of large wind power generators entails the following *problems* :

1. **Location of site.** The most important factor is locating a site big enough which has a reasonable average high wind velocity.

Sourashtra and Coastal Regions in India are promising areas.

2. **Constant angular velocity.** A constant angular velocity is a must for generating A.C. (alternating current) power and this means very sensitive governing.

3. **Variation in wind velocity.** The wind velocity varies with time and varies in direction and also varies from the bottom to top of a large rotor (some rotors are as long as 50 meters). This causes fatigue in blades.

4. **Need of a storage system.** At zero velocity conditions, the power generated will be zero and this means some storage system will have to be incorporated along with the wind mill.

5. **Strong supporting structure.** Since the wind mill generator will have to be located at a height, the supporting structure will have to be designed to withstand high wind velocity and impacts. This will add to the initial costs of the wind mill.

6. **Occupation of large areas of land.** Large areas of land will become unavailable due to wind mill gardens (places where many wind mills are located). The whole area will have to be protected to avoid accidents.

Inspite of all these difficulties, interest to develop wind mills is there since this is a clean source of energy.

### 10.2.17. Considerations for Selection of Site for Wind Energy Conversion Systems

Following factors should be given due considerations while selecting the site for wind energy conversion systems :

1. Availability of anemometry data.
2. High annual average wind speed.
3. Availability of wind curve at the proposed site.
4. Wind structure at the proposed site.
5. Altitude of the proposed site.
6. Terrain and its aerodynamic.
7. Local ecology.
8. Distance to roads or railways.
9. Nearness of site to local centre/users.
10. Favourable land cost.
11. Nature of ground.

## 10.3. TIDAL POWER PLANTS—OCEAN ENERGY CONVERSION

### 10.3.1. Ocean Energy Sources—General Aspects

Ocean energy sources may be broadly divided into the following *four* categories :

1. Tidal energy.
2. Wave energy.
3. *Ocean thermal energy conversion (OTEC).
4. Energy emanated from the sun-ocean system from the mechanism of surface water evaporation by solar heating *i.e.* hydrological cycle.

### 10.3.2. Tidal Power Plants

#### 10.3.2.1. Introduction

*The periodic rise and fall of the water level of sea which are carried by the action of the sun and moon on water of the earth is called the* **'tide'**.

- Tidal energy can furnish a significant portion of all such energies which are renewable in nature. The large scale up and down movement of sea water represents an unlimited source of energy. If some part of this vast energy can be converted into electrical energy, it would be an important source of hydropower.
- The *main feature of the tidal cycle is the difference in water surface elevations at the high tide and at the low tide.* If this differential head could be utilized in operating a hydraulic turbine, the tidal energy could be converted into electrical energy by means of an attached generator.

*The ocean thermal energy concept was proposed as early as 1881 by the French physicist Jacques d' Arsonval.

**Tidal power :**

When a basin exists along the shores with high tides, the power in the tide can be hydro-electrically utilised. This can be realised by having a long dam across the basin and locating two sets of turbines underneath the dam. As the tide comes in water flows into the basin one set of turbines. At low tide the water flows out of the basin operating another set of turbines.

Let, $h$ = Tidal range from high to low (in m), and

$A$ = Area of water stored in the basin (in $m^2$).

Then, *energy stored* in the full basin is given as :

$$E = \rho g A \int_0^h x.dx$$

or,

$$E = \frac{1}{2} \rho g h^2 A \quad ...(10.3)$$

*Average power,*

$$P_{av.} = \frac{1}{2} \rho g h^2 A \Big/ \left(\frac{T}{2}\right) = \rho g h^2 \Big/ \left(\frac{A}{T}\right) \quad ...(10.4)$$

where, $T$ = Period of tidal cycle = 14 h 44 min, usually.

- Following are a few places which have been surveyed in the *world* as sites for tidal power :
  (*i*) San Jose (S. America) : 10.7 m, 777 $km^2$, 19,900 MW ;
  (*ii*) Sever (UK) : 9.8 m, 70 $km^2$, 8,000 MW ;
  (*iii*) Passanaquoddy Bay (N. America) : 5.5 m, 262 $km^2$, 1,800 MW.

In *India*, following are the major sites where preliminary investigations have been carried out :

(*i*) Bhavanagar ;
(*ii*) Navalakh (Kutch) ;
(*iii*) Diamond harbour ;
(*iv*) Ganga Sagar.

The basin in Kandla in Gujrat has been estimated to have a capacity of 600 MW.

— The total potential of Indian coast is around 9000 MW, which does not compare favourably with the sites in the American continent stated above. The technical and economic difficulties still prevail.

### 10.3.2.2. Components of Tidal Power Plants

The following are the components of a tidal power plant :

1. The dam or dyke (low wall) to form the pool or basin.
2. Sluice ways from the basins to the sea and *vice versa.*
3. The power house.

**Dam or dyke.** The function of dam or dyke is to form a barrier between the sea and the basin or between one basin and the other in case of multiple basins.

**Sluice ways.** These are used to fill the basin during the high tide or empty the basin during the low tide, as per operational requirement. These devices are controlled through gates.

**Power house.** A power house has turbines, electric generators and other auxiliary equipment. As far as possible the power house and sluice ways should be in *alignment* with the dam or dyke.

### 10.3.2.3. Classification and Operation of Tidal Power Plants

Tidal power plants are classified as follows :

1. **Single basin arrangement**

(*i*) Single ebb-cycle system (*ii*) Single tide-cycle system

(*iii*) Double cycle system.

2. **Double basin arrangement.**

In a *single basin arrangement* power can be generated only *intermittently*. In this arrangement only one basin interacts with the sea. The two are separated by a dam or dyke and the flow between them is through sluice ways located conveniently along the dam. The rise and fall of tidal water levels provide the potential head.

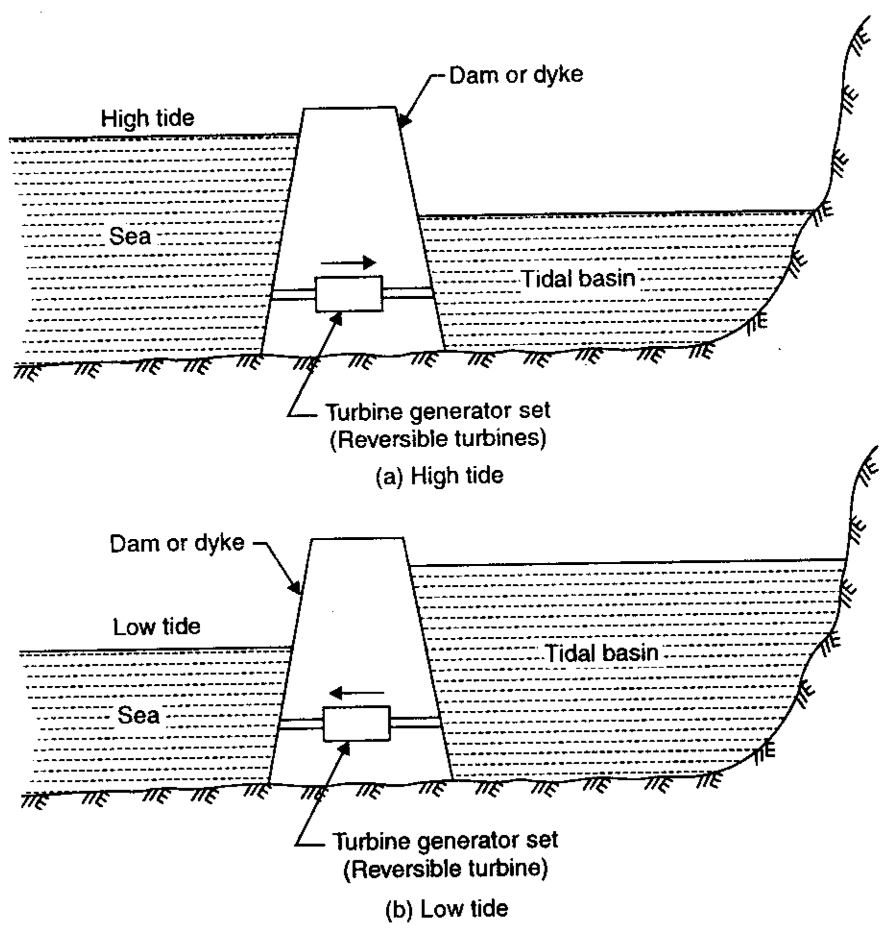


Fig. 10.11. General arrangement of tidal power plant.

Fig. 10.11 shows a general arrangement of single basin tidal power plant (double cycle system). Such plants generally use *reversible water turbines* so that power is generated on low tide as well high tide. The operation of the plant is as follows :

When the incoming tide sea level and tidal-basin level are equal, the turbine conduit is closed. When the sea level rises, and about half way to high tide the turbine valves are opened and the sea water flows into the basin through the turbine runner generating power. This also raises the level of water in the basin. The turbine continues to generate power until the tide passes through its high point and begins to drop. The water head then quickly diminishes till it is not enough to supply the no-load losses. By pass valve then quickly opens to let water into the basin to gain maximum water level. When sea and basin water level are again equal, the valves are closed as well as the turbine conduit. The basin level then stays constant while the tide continues to go out. After sufficient head has developed, the turbine valves are again opened and water now flows from basin to the sea, thereby generating power. The plant continues to generate power till the tide reaches its lowest level.

A *single basin plant cannot generate power continuously, though it might do so by using a pumped storage plant if the load it supplies fluctuates considerably*. A ***double basin scheme*** can provide power *continuously* or on demand, which is a *great advantage*. The drawback is that the civil works become more extensive. In the simplest *double-basin scheme* there must be a dam between each basin and the sea and also a dam between the basins, containing the power house. One basin is maintained always at a lower level than the other. The lower reservoir empties at low tide, the upper reservoir is replinshed at high tide. If the generating capacity is to be large, the reservoirs must be large which means that long dams would be required.

Fig. 10.12 shows a *tidal power plant-double basin operation*.

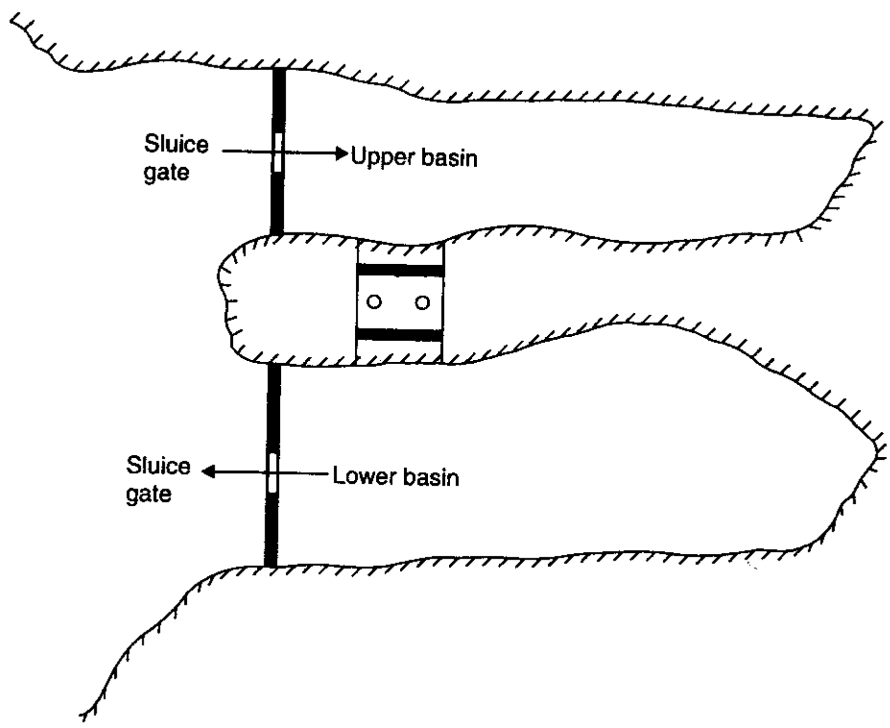


Fig. 10.12. Tidal power plant-double basin operation.

#### 10.3.2.4. Advantages and Limitations of Tidal Power Generation

***Advantages :***

1. Tidal power is completely independent of the precipitation (rain) and its uncertainty, besides being inexhaustible.
2. Large area of valuable land is not required.

3. When a tidal power plant works in combination with thermal or hydro-electric system peak power demand can be effectively met with.
4. Tidal power generation is free from pollution.

**Limitations :**

1. Due to variation in tidal range the output is not uniform.
2. Since the turbines have to work on a wide range of head variation (due to variable tidal range) the plant efficiency is affected.
3. There is a fear of machinery being corroded due to corrosive sea water.
4. It is difficult to carry out construction in sea.
5. As compared to other sources of energy, the tidal power plant is costly.
6. Sedimentation and silteration of basins are the problems associated with tidal power plants.
7. The power transmission cost is high because the tidal power plants are located away from load centres.

— The first commercial tidal power station in the World was constructed in France in 1965 across the mouth of La Rance Estuary. It has a high capacity of 240 MW. The average tidal range at La Rance is 8.4 m and the dam built across the estuary encloses an area of 22 km$^2$.

### 10.3.3. Wave Energy

***Wave energy*** *comes from the interaction between the winds and the surfaces of oceans.* The energy available varies with the size and frequency of waves. It is estimated that about 10 kW of power is available for every metre width of the wave front.

Wave energy when active is very concentrated, therefore, wave energy conversion into useful energy can be carried out at high power densities. A large variety of devices (*e.g. hydraulic accumulator wave machine ; high-level reservoir machine ; Dolphin-type wave-power machine ; Dam-Atoll wave machine*) have been developed for harvesting of energy but these are complicated and fragile in face of gigantic power of ocean storms.

**Advantages and Disadvantages :**

Following are the *advantages* and *disadvantages* of wave energy :

***Advantages :***

1. It is relatively pollution free.
2. It is a free and renewable energy source.
3. After removal of power, the waves are in placed state.
4. Wave-power devices do not require large land masses.
5. Whenever there is a large wave activity, a string of devices have to be used. The system not only produces electricity but also protects coast lines from the destructive action of large waves, minimises erosion and help create artificial harbour.

***Disadvantages :***

1. Lack of dependability.
2. Relative scarcity of accessible sites of large wave activity.
3. The construction of conversion devices is relatively complicated.
4. The devices have to withstand enormous power of stormy seas.
5. There are unfavourable economic factors such as large capital investment and costs of repair, replacement and maintenance.

**Problems associated with wave energy collection :**

The collection of wave energy entails the following *problems* :

1. The variation of frequency and amplitude makes it an unsteady source.
2. Devices, installed to collect and to transfer wave energy from far off oceans, will have to with stand adverse weather conditions.

- Uptil now no major development programme for taming wave energy has been carried but successfully through any country. Small devices are available, however, and are in limited use as power supplies for buoys and navigational aids. From the engineering development point of view, wave energy development is not nearly as far long as wind and tidal energy.

### 10.3.4. Ocean Thermal Energy Conversion (OTEC) Plant

The oceans cover about 70% of the global surface and are particularly extensive in the tropical zones. Therefore, most of the sun's radiations is absorbed by sea water. Thus warm water on the ocean's surface flows from the tropics towards poles. Cold water circulates at the ocean bottom from the poles to the tropics. Hence, in the tropical regions the water temperature is around **5°C** at a depth of 1000 m, whereas at the surface, it remains almost constant at **25°C** (for the first few metres because of mixing ; subsequently it decreases and asymptotically approaches the value at the lower level).

Thus, we can employ a *carnot-type process to generate power between these two steady temperatures.* Such plants are called **Ocean Thermal Energy Conversion Plants OTEC.**

All the systems being proposed for construction, now work on a *'Closed Rankine cycle'* (*Anderson cycle, vapour cycle) and use low boiling point working fluids like *ammonia, propane, R-12, R-22* etc. These systems would be located off shore on large floating platforms or inside floating hulls. The warm surface water is used for supplying the heat input in the boiler, while the cold water brought up from the ocean depths is used for extracting the heat in the condenser.

Fig. 10.13 shows a schematic diagram of an Ocean Thermal Energy Conversion plant—OTEC.

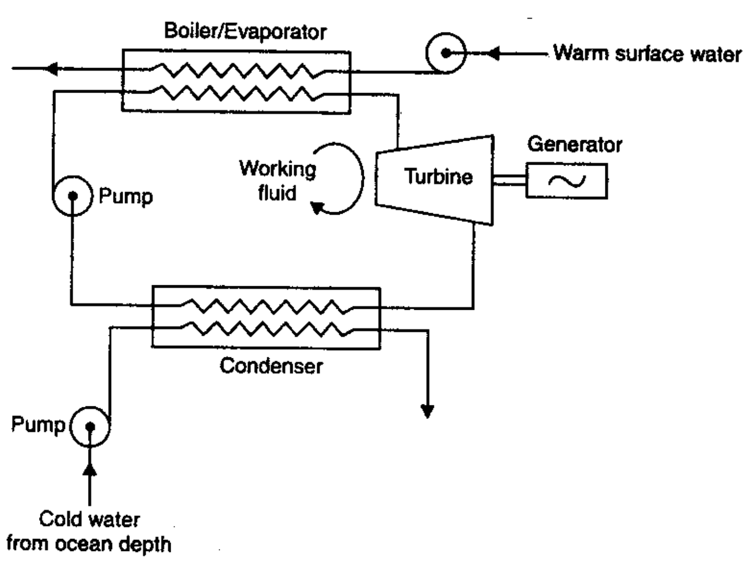


Fig. 10.13. Schematic layout of OTEC.

*The closed cycle OTEC concept was proposed by Barjot in 1926. The concept was further developed by Anderson in 1992.

It is obvious that the efficiency of the Rankine cycle will be *low* because of *small temperature difference* between the hot and cold streams. Allowing for very small temperature drops of 4 to 5°C across the boiler and the condenser, it can be shown that the Rankine cycle efficiency for most of the fluids under consideration will range *between 2 and 3 percent only*. Inspite of this, the concept of an OTEC system seems to be economically attractive because both the *collection and storage of solar energy is being done free by nature.*

- In *"Open cycle" (Claude cycle, steam cycle)*, the warm water is converted into steam in an evaporator. The steam drives steam-turbine generator to deliver electrical energy.
- *Cogeneration OTEC plants deliver electrical energy and fresh water.*

*The following points about OTEC are worth noting :*

1. Each of the possible working fluids *i.e. ammonia* and *propane* has *advantages* and *disadvantages.*
   — *"Ammonia"* has better operating characteristics than propane and it is much less inflammable. On the other hand ammonia forms *irritating* vapour and probably could not be used with copper heat exchanger.
   — *"Propane"* is compatible with most heat-exchanger materials, but is highly flammable and forms an explosive mixture with air.

- Ammonia has been used as the working fluid in successful tests of the OTEC concept with closed cycle systems.

2. Because of the low cycle efficiency the heat to be transferred in the boiler and condenser is large. In addition, the temperature difference between the sea water and the working fluid in these heat exchangers has to be restricted to very small values. For these reasons, very high flow rates are required for the sea water both in the boiler evaporator and the condenser. This results in high pumping power requirements and is reflected in the gross power outputs which are 20-50 percent higher than net power outputs.

   A second important consequence is that both the evaporator and condenser are much larger in size than similar components in conventional practice.

   The materials suggested for these heat exchangers are *titanium* or an *alloy of copper and nickel.* This is necessitated because of the corrosive nature of the sea water.
3. An examination of the break up of the OTEC system costs shows that the cost of heat exchangers plays an important role in costing ; they contribute about 30 to 40 percent of the total.

**Merits and Limitations of OTEC :**

Following are the *merits and demerits* of OTEC :

***Merits :***

1. It is clean form of energy conversion.
2. It does not occupy land areas.
3. No payment for the energy required.
4. It can be a steady source of energy since the temperatures are almost steady.

***Limitations :***

1. About 30 percent of the power generated would be used to pump water.
2. The system would have to withstand strong convective effect of sea water ; hurricanes and presence of debris and fish contribute additional hazard.
3. The materials used will have to withstand the highly corrosive atmosphere and working fluid.

4. Construction of floating power plants is difficult.
5. Plant size is limited to about 100 MW due to large size of components.
6. Very heavy investment is required.

As an **example** for a 150 MW plant :

— A flow of 500 $m^3/s$ would be required ;

— The heat exchangers area required will be about 0.5 $km^2$ ;

— A cold duct of 700 m length with a dia. of 25 m would be required.

## 10.4. SOLAR POWER PLANTS

### 10.4.1. Solar Energy—General Terms and Introduction

**General Terms**

**Solar Constant.** Solar constant is the energy from the sun, per unit time, received on a unit area of surface perpendicular to the radiation, in space, at the earth's mean distance from the sun. According to Thekaekara and Drummond (1971) the value of the solar constant is 1353 $W/m^2$ (1.940 $Cal/cm^2$ min, or 4871 $kJ/m^2$ hr.).

**Beam Radiation.** The solar radiation received from the sun without change of direction is called beam radiation.

**Diffuse Radiation.** It is the solar radiation received from the sun after its direction has been changed by reflection and scattering by the atmosphere.

**Air Mass.** It is the path length of radiation through the atmosphere, considering the vertical path at sea level as unity.

**Zenith Angle.** It is the angle between the beam from the sun and the vertical.

**Solar Altitude.** It is the angle between the beam from the sun and horizontal *i.e.*, (90-zenith angle).

**Solar or Short-wave Radiation.** It is the radiation originating from the sun, at a source temperature of about 6000°K and in the wavelength range of 0.3 to 3.0 μm.

**Long-wave Radiation.** Radiation originating from sources at temperatures near ordinary ambient temperatures and thus substantially all at wavelength greater than 3 μm.

**Declination.** It is the angular position of the sun at solar noon with respect to the plane of the equator (north positive).

**Solar Energy—Introduction**

The surface of the earth receives from the sun about $10^{14}$ kW of solar energy which is approximately five order of magnitude greater than currently being consumed from all resources. It is evident that sun will last for $10^{11}$ years. Even though the sun light is filtered by the atmosphere one square metre of the land exposed to direct sun light-receives the energy equivalent of about 1 H.P or 1 kW. However, this vast amount of solar energy reaching earth is not easily convertible and certainly is not "free".

There are two obvious obstacles to harnessing solar energy. *Firstly* it is not constantly available on earth. Thus some form of storage is needed to sustain a solar power system through the night and during periods when local weather conditions obscure the sun. *Second* the solar energy is diffused. Although the total amount of energy is enormous, the collection and conservation of solar energy into useful forms must be carried out over a large area which entails a large capital investment for the conversion apparatus.

Solar energy, therefore, most likely will be developed not because it is cheaper than alternative energy sources but because these alternative sources sooner or later (*i*) will be exhausted, (*ii*) will become increasingly move expensive, (*iii*) will continue to political and economical control by the nations possessing them and (*iv*) will produce undesirable yet incompletely understood environmental consequences, especially on large scale that will be required to meet projected demands even with controlled growth.

Solar energy has some good advantages in comparison to the other sources of power. Solar radiation does not contaminate environment or endanger ecological balance. It avoids major problems like exploration, extraction and transportation.

**10.4.2. Collectors in Various Ranges and Applications**

Following list gives the thermal applications of solar energy and possible temperature ranges :

1. **Long temperature**
   ($t$ = 100°C)
   (*i*) Water heating
   (*ii*) Space heating
   (*iii*) Space cooling
   (*iv*) Drying
   } ... Flat plate

2. **Medium temperature**
   (100 to 200°C)
   (*i*) Vapour engines and turbines
   (*ii*) Process heating
   (*iii*) Refrigeration
   (*iv*) Cooking
   } ... Cylindrical Parabola

3. **High temperature**
   (> 200°C)
   (*i*) Steam engines and turbines
   (*ii*) Stirling engine
   (*iii*) Thermo-electric generator
   } ... Parabolloid Mirror arrays

The above classification of low, medium and high temperature ranges is some what arbitrary. Heating water for domestic applications, space heating and cooling and drying of agricultural products (and industrial products) is generally at temperature below 100°C, achieved using flat plate collectors with one or two glass plate covers. Refrigeration for preservation of food products, heating for certain industrial processes, and operation of engines and turbines using low boiling organic vapours is possible at some what higher temperature of 100 to 200°C and may be achieved using focusing collectors with cylindrical-parabola reflectors requiring only one directional diurnal tracking. Conventional steam engines and turbines, stirling hot air engines, and thermoelectric generators require the solar collectors to operate at high temperatures. Solar collectors operating at temperature above 200°C generally consist of parabolloid reflector as an array of mirrors reflecting to a central target, and requiring two directional diurnal tracking.

The concentrators or focusing type collectors can give high temperatures than flat plate collectors, but they entail the following shortcomings/limitations.

1. Non-availability and high cost of materials required. These materials must be easily shapeable, yet have a long life ; they must be light weight and capable of retaining their brightness in tropical weather. Anodised aluminium and stainless steel are two such materials but they are expensive and not readily available in sufficient quantities.

2. They require direct light and are not operative when the sun is even partly covered with clouds.

3. They need tracking systems and reflecting surfaces undergo deterioration with the passage of time.

4. These devices are also subject to similar vibration and movement problems as radar antenna dishes.

**Comparison between Flat plate and Focusing collectors :**

1. The absorber area of a concentrator system is smaller than that of a flat-plate system of the same solar energy collection area and the *insolation intensity is therefore greater.*

2. Because the area from which heat is lost to the surroundings per unit of the solar energy collecting area is less than that for a flat plate collector and because the insolation on the absorber is more concentrated, the working fluid can attain higher temperatures in a concentrating system than in a flat-plate collector of the same solar energy collecting surface.

3. Owing to the small area of absorber per unit of solar energy collecting area, selective surface treatment and/or vacuum insulation to reduce heat losses and *improve collector efficiency are economically feasible.*

4. Since higher temperatures can be achieved, the focusing collector *can be used for power generation.*

5. *Little or no anti-freeze is required* to protect the absorber in a concentrator system whereas the entire solar energy collection surface requires anti-freeze protection in a flat-plate collector.

6. Out of the beam and diffuse solar radiation components, only beam component is collected in case of focusing collectors because diffuse component cannot be reflected and is thus lost.

7. *Costly orienting systems* have to be used to track the sun.

8. Non-uniform flux on the absorber whereas flux in flat-plate collectors is uniform.

### 10.4.3. Flat Plate Collectors

#### 10.4.3.1. Description

Fig. 10.14 shows a Flat Plate Collector which consists of four essential components :

1. **An absorber plate.** It intercepts and absorbs solar radiation. This plate is usually metallic (Copper, aluminium or steel), although plastics have been used in some low temperature applications. In most cases it is coated with a material to enhance the absorption of solar radiation. The coating may also be tailored to minimise the amount of infrared radiation emitted.

A heat transport fluid (usually air or water) is used to extract the energy collected and passes over, under or through passages which form an integral part of the plate.

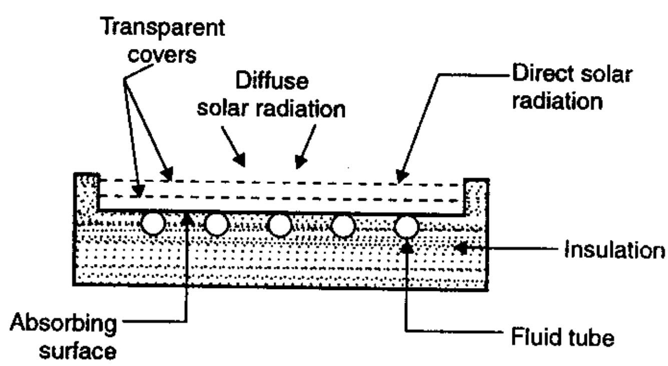


Fig. 10.14. Flat plate solar collector.

2. **Transparent covers.** These are one or more sheets of solar radiation transmitting materials and are placed above the absorber plate. They allow solar energy to reach the absorber plate while reducing convection, conduction and re-radiation heat losses.

3. **Insulation beneath the absorber plate.** It minimises and protects the absorbing surface from heat losses.

4. **Box like structure.** It contains the above components and keeps them in position.

Various types of flat plate collectors have been designed and studied. These include tube in plate, corrugated type, spiral wound type etc. Other criteria is single exposure, double exposure or exposure and reflector type. The collector utilizes sheets of any of the highly conducting material *viz.* copper, aluminium, or galvanized iron. The sheets are painted dead black for increasing the absorbtivity. The sheets are provided with one or more glass or plastic covers with air gap in between to reduce the heat transfer losses. The sides which are not exposed to solar radiation are well insulated. The whole assembly is fixed in air tight wooden box which is mounted on simple device to give the desired angle of inclination. The dimensions of collectors should be such as to make their handling easy. The collector will absorb the sun energy (direct as well as diffused) and transfer it to the fluid (air, water or oil) flowing within the collector. Basically, a flat plate collector is *effective* most of time, *reliable* for good many years and also *inexpensive.*

Use of flat mirrors in the flat plate collectors improves the output, permitting higher temperatures of operation. Side mirrors are used either at north and south edges or at east and west edges of the collector or a combination of both. The mirrors may be of reversible or non-reversible type.

### 10.4.3.2. Analysis

Consider an object exposed to sun radiations of intensity $P$, per unit area at the surface of the body. These radiations, will partly be absorbed by the body, while the remaining will be partly transmitted and rest reflected. If we take the incident radiations equal to unity, then, the absorbed, reflected, and transmitted parts of energy will add up to unity. There parts are called *absorption* co-efficient, *reflection* co-efficient and *transmission* co-efficient and represented by the symbols $\alpha$, $\rho$ and $\tau$ respectively.

Using the above symbols we can write

$$\alpha + \rho + \tau = 1 \quad \text{...}(i)$$

The absorbed part of the solar radiations, which is equal to $\alpha$ is responsible for increasing the temperature of the body. However, the body also loses energy by conduction, convection and radiation. The equilibrium temperature of the body will be that at which the heat loses from the body are equal to the absorbed radiations. For analysis purposes, if we represent the body by a flat plate and assume that the convection and conduction loses are negligible to begin with, then at equilibrium temperature, the absorbed solar radiations should be equal to the radiation losses from the flat plate. The radiation losses are equal to $\varepsilon\sigma T^4$, where $\varepsilon$ and $T$ are the emission co-efficient and absolute temperature respectively of flat plate and $\sigma$ is the Boltzman's constant.

Therefore, at equilibrium,

$$\alpha P = \varepsilon\sigma T^4 \quad \text{...}(ii)$$

or

$$\frac{\alpha P}{\varepsilon} = \sigma T^4 \quad \text{...}(iii)$$

From equation (*iii*), it is evident that comparatively higher equilibrium temperature will be obtained where the quantity $\frac{\alpha}{\varepsilon}$ *i.e.*, the ratio of absorption co-efficient to emission co-efficient of the flat plate is more. However, this has been demonstrated by an equation obtained under idealised condition. In the realistic conditions too, its nature will remain the same, but it will get modified by other influencing factors.

The collectors for which ratio is equal to unity are called **'Neutral collectors'** and those for which the ratio is greater than unity are called **'Selective collectors'.**

The amount of energy collected, however, does not depend on $\frac{\alpha}{\varepsilon}$ ratio. It primarily depends on higher value of $\alpha$. So to obtain higher energy collection, one should use such flat plate where absorption co-efficient is as high as possible.

A flat plate painted black is placed on a well insulated base. If it is exposed to solar radiations where $P = 800$ W/m$^2$, a typical summer value for a tropical region, we obtain from equation (*iii*) the equilibrium temperature as 70°C. Inspite of the simplifications here, it is a fair estimate of the temperature reached by a black plate left for a time in the tropical sun.

This method can be refined by including the convection losses and the energy gain as a result of absorption of diffused radiations by the flat plate.

If $P'$ is the intensity of the diffused radiations and $\alpha'$ the absorption co-efficient, then equation (*ii*) becomes

$$\alpha P + \alpha' P' = h_c(T - T_a) + \varepsilon\sigma T^4 \quad ...(iv)$$

This is valid, where the base is insulated, hence conduction losses are neglected. Here $T_a$ is the atmospheric temperature and $h_c$ is the convection heat transfer co-efficient.

### 10.4.4. Focusing (or Concentrating) Collectors

The main types of focusing or concentrating collectors are as follows :

1. Parabolic trough collector
2. Mirror strip collector
3. Fresnel less collector
4. Flat plate collector with adjustable mirrors
5. Compound parabolic concentrator.

Fig. 10.15 (*a*) shows the principle of the parabolic trough collector which is often used in focusing collectors. Solar radiation coming from the particular direction is collected over the area of

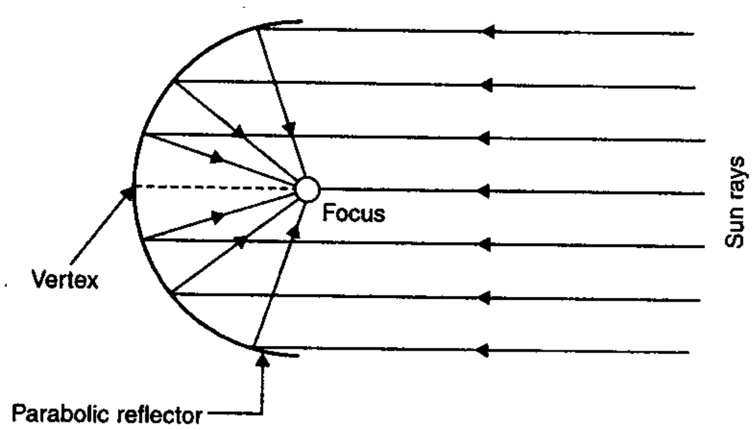


Fig. 10.15. (*a*) Cross-section of parabolic trough collector.

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 [Fig. 10.15. (*b*)].

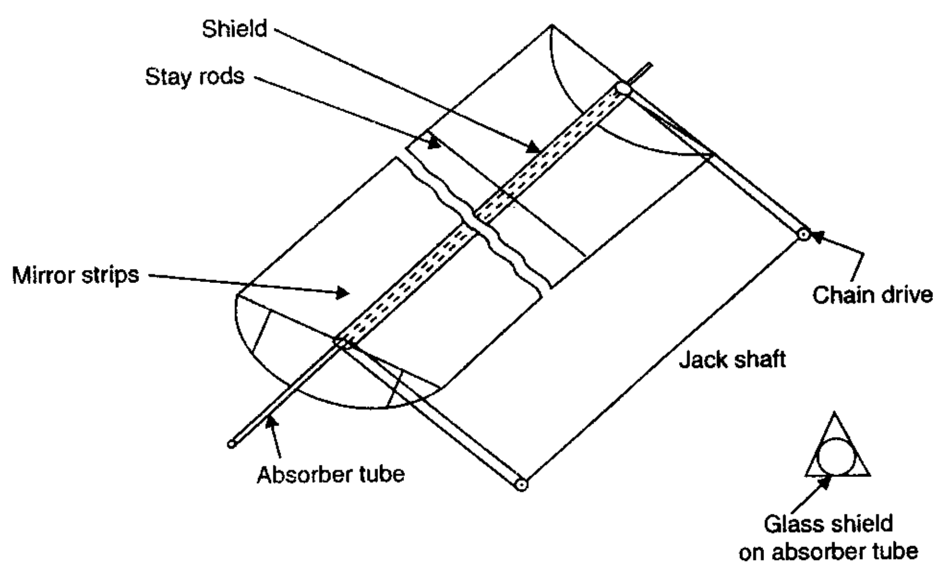


Fig. 10.15. (*b*) Cylindrical parabolic system.

### 10.4.5. Solar Pond Technology

Refer to Fig. 10.16.

The vertical configuration of salt-gradient solar pond normally consists of following *three zones* :

1. Adjacent the surface there is a *homogeneous convective zone* that serves as a buffer zone between environmental fluctuations at the surface and conductive heat transport from the layer below. This is the *upper convective zone* (UCZ).

2. At the bottom of the pond there is another convective zone, the lower convective zone or LCZ. This is the layer with the *highest salt concentration* and where the high temperatures are built up.

3. For given salinites and temperatures in the upper and lower convective zones, there exists a stable *intermediate gradient zone*. This zone keeps the two convective zones apart and gives the solar pond its unique thermal performance. This intermediate zone provides excellent insulation for the storage layer, while simultaneously transmitting the solar radiation. To maintain a solar pond in this non-equilibrium stationary state, it is necessary to replace the amount of salt that is transported by molecular diffusion from the LCZ to the UCZ. This means that salt must be added to the LCZ, and fresh water to the UCZ whilst-brine is removed. The brine can be recycled, divided into water and salt (by solar distillation) and returned to the pond.

The major heat loss occurs from the surface of the solar pond. This heat loss can be prevented by spreading a plastic grid over the pond's surface to prevent disturbance by the wind. Disturbed water tends to lose heat transfer faster than when calm.

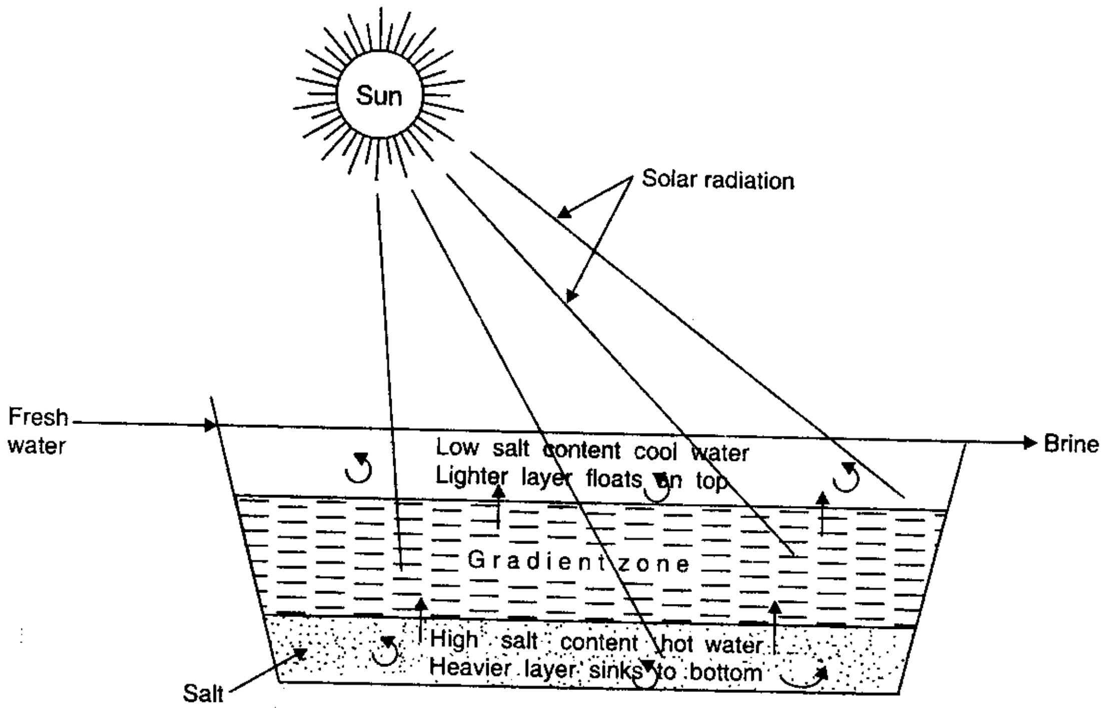


Fig. 10.16. Principle of solar pond.

Due to the excessively high salt concentration of the LCZ, a *plastic liner* or impermeable soil must be used to *prevent infiltration* into the nearby ground water or soil. The liner is a factor that increases the *cost* of a solar pond. A site where the soil is naturally impermeable, such as the base of a natural pond or lake, or can be made impermeable by compaction or other means, will allow considerably lower power costs.

The optical transmission properties and related collection efficiency vary greatly and depend on the following :

(*i*) Salt concentration.

(*ii*) The quantity of suspended dust or other particles.

(*iii*) Surface impurities like leaves or debris, biological material like bacteria and algae.

(*iv*) The type of salt.

It becomes obvious that much higher efficiencies and storage can be achieved *through the utilization of refined or pure salt* whenever possible, as this *maximizes optical transmission.*

The solar pond is an effective collector of diffuse, as well as direct radiation, and will gather useful heat even on cloudy or overcast days. Under ideal conditions, the pond's absorption efficiency can reach 50% of incoming solar radiation, although actual efficiencies average about 20% due to heat losses. Once the lower layer of the pond reaches over 60°C the heat generated can be drawn off through a heat exchanger and used to drive a low temperature organic Rankine cycle (ORC) turbine. This harnesses the pressure differentials created when a low boiling point organic fluid (or gas) is boiled by heat from the pond *via* a heat exchanger and cooled by a condenser to drive a turbine to generate electricity. The conversion efficiency of an organic Rankine cycle turbine driving an electric generator is 5—8% (which mean 1—3% from insolation to electricity output).

### 10.4.6. Low Temperature Thermal Power Generation

#### 10.4.6.1. Solar pond electric power plant

A low temperature thermal electric power production scheme using solar pond is shown schematically in Fig. 10.17. The energy obtained from a solar pond is used to drive a Rankine cycle heat engine. Hot water from the bottom level of the pond is pumped to the evaporator where the organic working fluid is vapourized. The vapour then flows under high pressure to the turbine where it expands and work thus obtained runs an electric generator producing electricity. The exhaust vapour is then condensed in a condenser and the liquid is pumped back to the evaporator and the cycle is repeated.

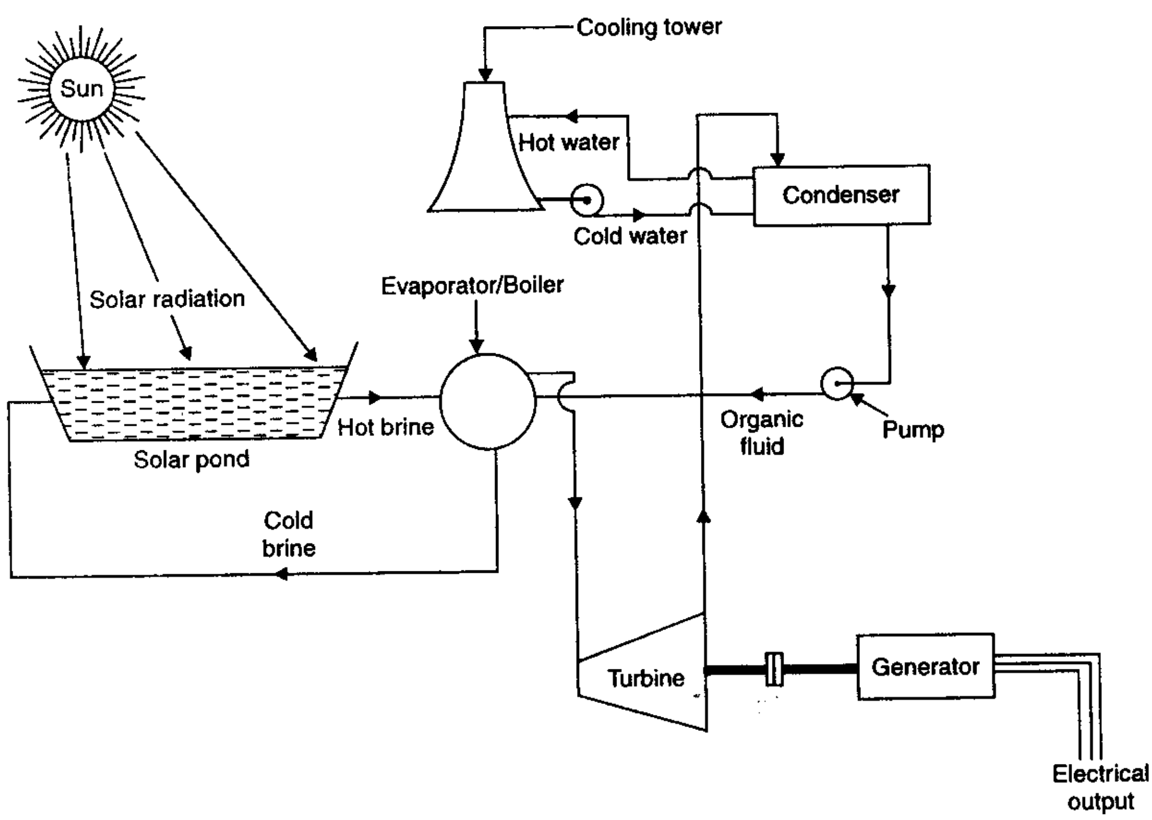


Fig. 10.17. Solar pond electric power plant.

In Australia a 2000 sq. m. solar pond equipped with a 20 kW engine has been installed.

#### 10.4.6.2. Low temperature solar Power Plant

Fig. 10.18 shows a schematic diagram of a low temperature solar power plant. In this system an array of flat plate collectors is used to heat water to about 70°C and then this heat is used to boil butane in a heat exchanger. The high pressure butane vapour thus obtained runs a butane turbine which in tern operates a hydraulic pump. The pump pumps the water from well which is used for irrigation purposes. The exhaust butane vapour (from butane turbine) is condensed with the help of water which is pumped by the pump and the condensate is returned to the heat exchanger (or boiler).

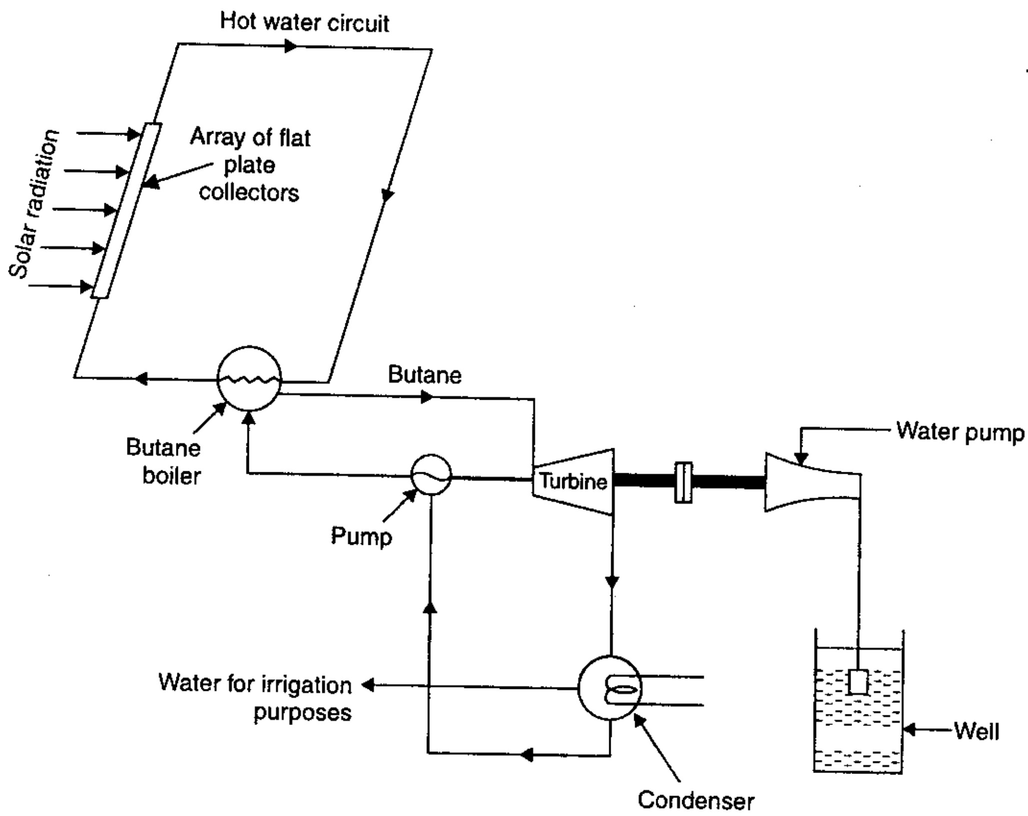


Fig. 10.18. Low temperature solar power plant.

### 10.4.7. Medium Temperature Systems Using Focusing Collectors

A circular or rectangular parabolic mirror can collect the radiation and focus it on to a small area, a mechanism for moving the collector to follow the sun being necessary. Such devices are used for *metallurgical research* where *high purity and high temperatures are essential*, an example being

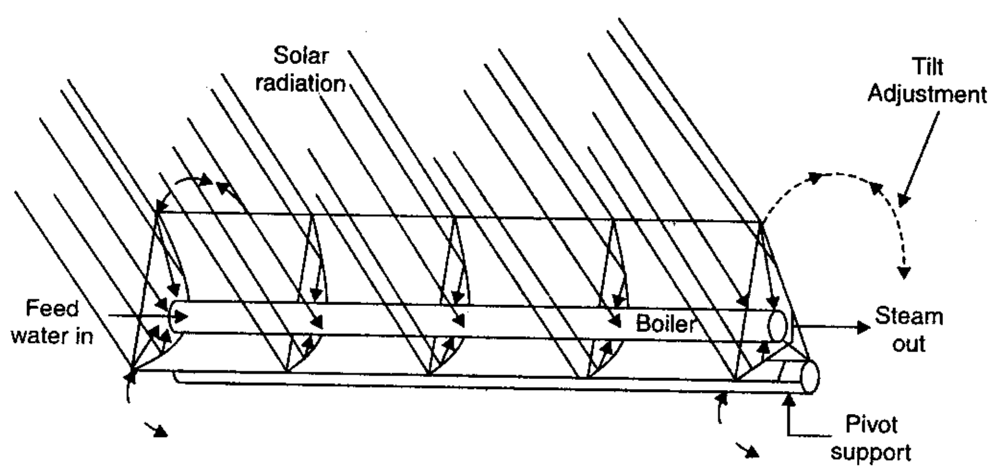


Fig. 10.19. Concave solar energy collector focuses sun's rays on boiler at focal point.

a 55 m diameter collector giving about 1 MW (th) at Mont Louis in Pyrenees. Smaller units having 20 m diameter reflector can give temperatures of 300°C over an area of about 50 m$^2$. The collector efficiency is about 50%. On a small scale, units about 1 m diameter giving temperatures of about 300°C have been used for cooking purposes.

Fig. 10.19 shows a concave solar energy collector focusing sun's rays on boiler at a focal point. Generation of steam at 250°C could give turbine efficiencies up to 20-25 per cent.

### 10.4.8. High Temperature Systems—Solar Farm and Solar Power Plant

For a large scale production of process-heat the following two concepts are available :

1. **The solar farm.** It consists of a whole field covered with parabolic trough concentrators.
2. **The solar tower.** It consists of a central receiver on a tower and a whole field of tracking.

In case of a '*solar farm*' temperature at the point of focus can reach several hundred degrees celsius. Fig. 10.20 shows a solar tower system.

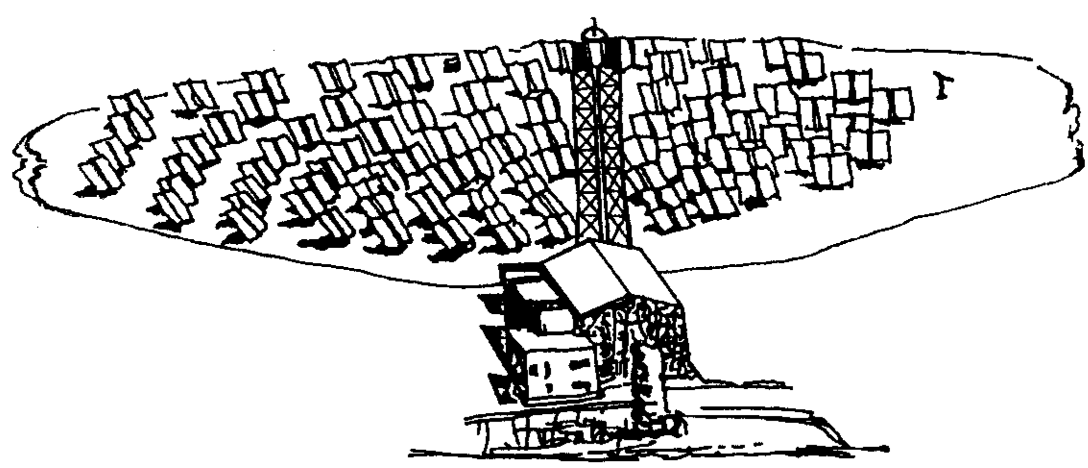

Fig. 10.20. Solar tower system.

In case of central receiver "*solar tower*" concentrators, temperature can reach thousands of degrees celsius, since a field of reflectors (heliostats) are arranged separately on sun-tracking frames to reflect the sun on to a boiler mounted on a central tower (Fig. 10.21, 10.22).

With both systems ('solar farm' and 'solar tower'), *a heat transfer fluid or gas is passed through the point or line of insolation concentration to collect the heat and transfer it to the point of use. Such heat can be used either directly in industrial or commercial processes or indirectly in electricity production via. steam and a turbine.*

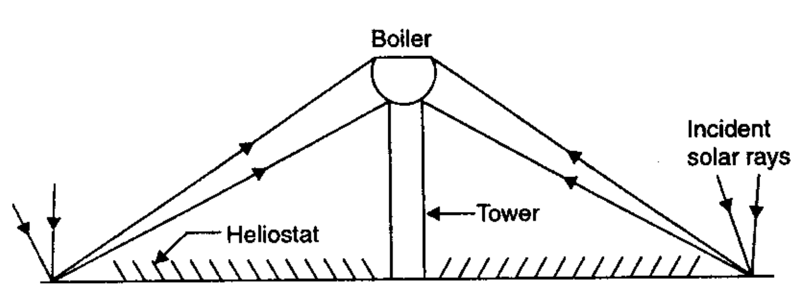


Fig. 10.21

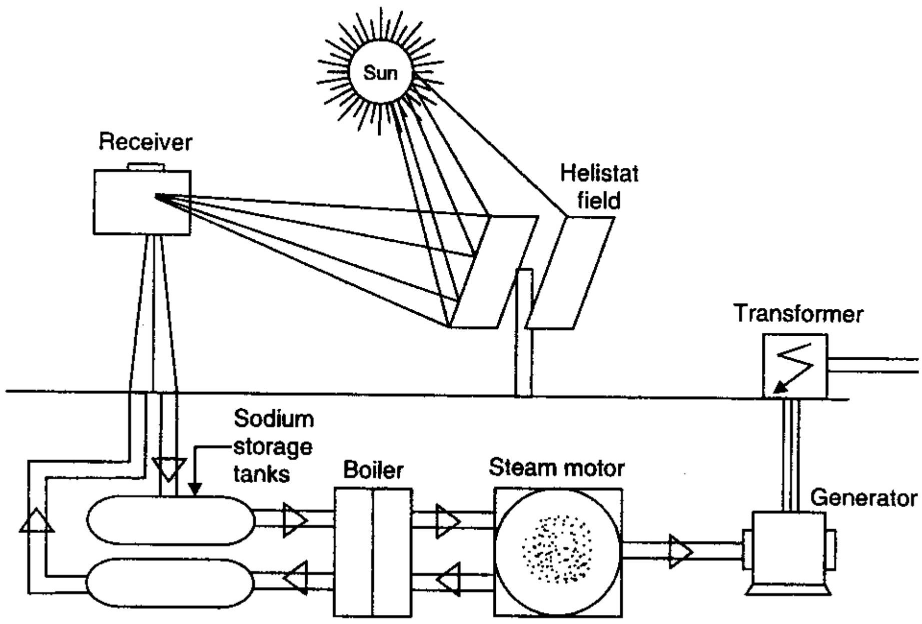


Fig. 10.22. Diagram of solar tower power plant.

The solar technologies such as the above two systems that produce very hot water or steam are currently still under development and, in general, these technologies are not cost competitive with conventional power sources such as oil or gas.

## 10.5. GEOTHERMAL POWER PLANTS

### 10.5.1. Geothermal Energy

As we travel down earth's surface radially, there exists a temperature gradient of 0.03°C per metre. Thus a 30°C increase in temperature can be obtained per kilometre depth from the earth's crust. *There are many local hot spots just below the surface where the temperatures are much higher than expected.* Ground water, when comes into contact with these hot spots, either dry or wet steam is formed. By drilling holes to these locations, hot water and steam can be tapped and these can be used for power generation or space heating.

Geothermal energy is primarily energy from the earth's own interior, it is classified as *renewable* because the earth's interior is and will continue in the process of cooling for the indefinite future. Hence, geothermal energy from the earth's interior is almost inexhaustible as solar or wind energy, so long as its sources are actively sought and economically tapped. Geothermal energy can be used for *heat* and *power generation*. Geothermal energy is present over the entire extent of earth's surface except that it is nearer to the surface in the volcanic areas. Heat transfer from the earth's interior is by *three primary means* :

(*i*) Direct heat conduction ;

(*ii*) Rapid injection of ballistic magma along natural rifts penetrating deep into earth's mantle ; and

(*iii*) Bubble like magma that buoys upwards towards the surface.

Fig. 10.23 shows a schematic diagram depicting how hot springs are produced through hot magma (molten mass), the fractured crystalline rocks, the permeable rocks and percolating ground water.

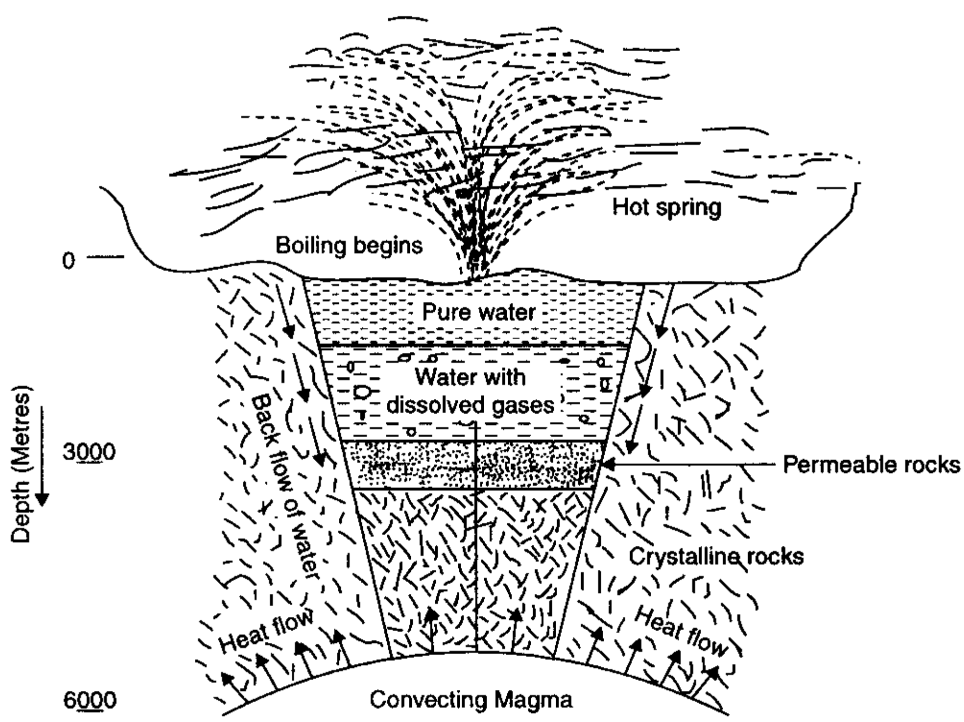


Fig. 10.23. Hot spring system structure.

### 10.5.2. Geothermal Sources

The following five general categories of geothermal sources have been identified :

1. Hydrothermal convective systems

(*i*) Vapour-dominated or dry steam fields.

(*ii*) Liquid-dominated system or wet steam fields.

(*iii*) Hot-water fields.

2. Geopressure resources.

3. Petro-thermal or hot dry rocks (HDR).

4. Magma resources.

5. Volcanoes.

The hydro-thermal convective systems are best resources for geothermal energy exploitation at present. Hot dry rock is also being considered.

Fig. 10.24 shows a dry-steam open system used in Larderello (Italy) and Greyser (U.S.A.).

Fig. 10.25 shows a flash steam open type system used in Cerro Prietol Mexico, Otake (Japan).

Fig. 10.26 shows a hot water closed (Binary) system under development in U.S.S.R. and U.S.A.

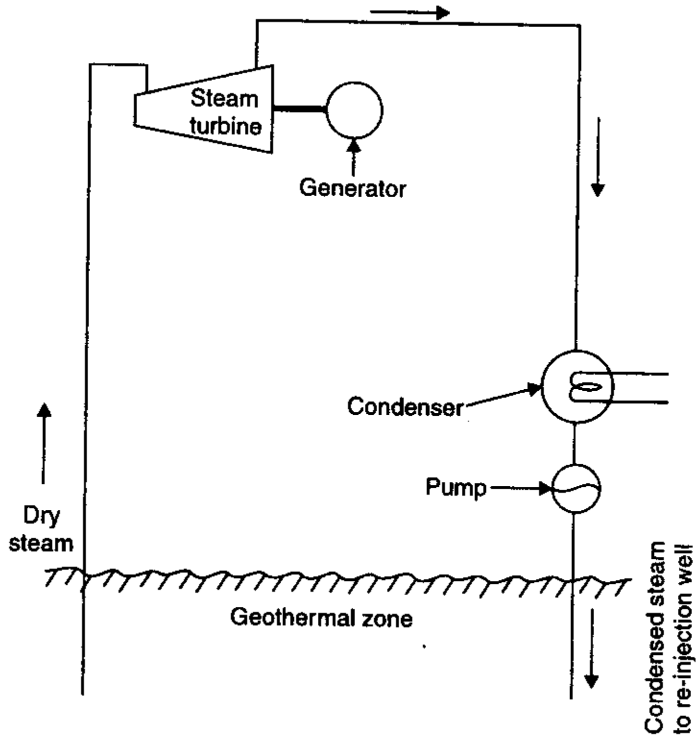


Fig. 10.24. Dry-steam open system.

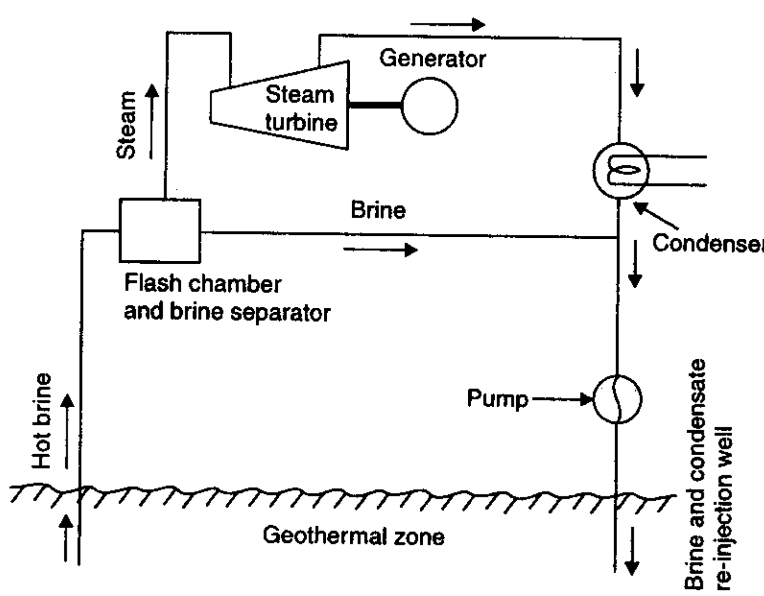


Fig. 10.25. Flash steam open type system.

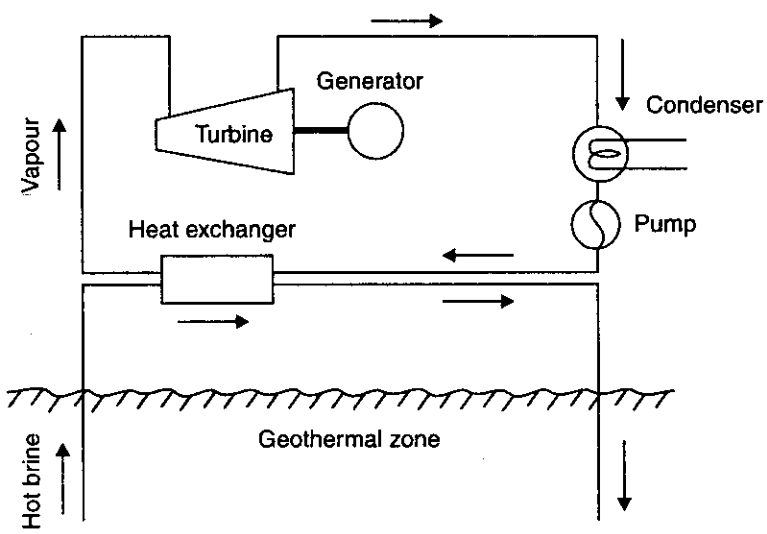


Fig. 10.26. Hot water closed (Binary) system.

### 10.5.3. Geothermal Power Estimates

Although geothermal power estimates vary very widely yet rough estimate is given below :

| *Depth* | *Total stored energy* (approximately) |
|---|---|
| 3 km | $8 \times 10^{21}$ joules |
| 10 km | $4 \times 10^{22}$ joules |

— The energy stored in hot springs = 10 per cent of the above quantities.

— If the above energy is extracted from a 3 km belt, with 1% thermal energy recovery factor, at a uniform rate of over 50 years period, thermal power of 50 GW is obtained. With a thermal electric conversion efficiency of 20% only 10 GW of electric power will be obtained.

### 10.5.4. Environmental Problems

Geothermal power plants create some environmental problems which are peculiar to them alone. The effluent will be salty and may contain sodium and potassium compounds. Additionally, in some cases lithium, fluorine, boron and arsenic compounds may be present. Such effluents cannot be discharged into the existing water courses unless properly treated without risking severe pollution problems. Some effluents contain boron, fluorine and arsenic. All these are *very harmful to plants and animal life in concentrations as low as two parts per million. Suitable waste treatment plants to prevent degradation of water quality will have to be installed to treat these new and increased sources of pollution.*

### 10.5.5. Applications of Geothermal Energy

The following are the three main applications of the steam and hot water from the wet geothermal reservoirs :

1. Generation of electric power.
2. Space heating for buildings.
3. Industrial process heat.

The major benefit of geothermal energy is its *varied application and versatility*.

- ***Geothermal plants** have proved useful for "base-load power plants". These kind of plants are primarily entering the market where modest sized plants are needed with low capital cost, short construction period and life-long fuel (i.e. geothermal heat).*

### 10.5.6. Advantages and Disadvantages of Geothermal Energy over Other Energy Forms

***Advantages of Geothermal Energy :***

1. Geothermal energy is cheaper.
2. It is versatile in its use.
3. It is the least polluting as compared to other conventional energy sources.
4. It is amenable for multiple uses from a single resource.
5. Geothermal power plants have the highest annual load factors of 85 per cent to 90 per cent compared to 45 per cent to 50 per cent for fossil fuel plants.
6. It delivers greater amount of net energy from its system as compared to other alternative or conventional systems.
7. Geothermal energy from the earth's interior is almost as inexhaustible as solar or wind energy, so long as its sources are actively sought and economically tapped.

***Disadvantages :***

1. Low overall power production efficiency (about 15% as compared to 35 to 40% for fossil fuel plants).
2. Drilling operation is noisy.
3. Large areas are needed for exploitation of geo-thermal energy.
4. The withdrawal of large amounts of steam or water from a hydro-thermal reservoir may result in surface subsidence or settlement.

### 10.5.7. Geothermal Energy in India and Abroad

Some progress is being made in India on tapping geothermal energy on a commercial scale. Engineers from the Geological Survey of India have drilled about 50 shallow wells for steam in the Puga valley of the Ladakh region in Jammu and Kashmir. It may be possible to operate a 5 MW power station at the site. The Puga valley at an altitude of 4500 metres above sea level has the most promising geothermal field. The area extends to about 40 square kilometres out of which 5 sq. km is active. A combination of wet and dry steam to the tune of 170 tonnes of hot water per hour and 20 tonnes/hour of dry steam (superheated steam suitable for running steam turbines) is available. This is enough to run a small power station to light the homes of local population. The geothermal heat can also be used for space heating in the Puga valley as the temperature in this area, especially during winter months, goes down to 35 degrees below freezing point. There are no other energy sources in Ladakh region and coal, petroleum etc. have to be transported from Srinagar. It can also be used for poultry farming, mushroom cultivation and pashmina wool processing which need a warmer climate. In addition, there are good deposits of borax and sulphur in this area. Sulphur in elemental form is found only in this region in the whole of India.

There are many *hot water springs* in India. Hot water springs represent heat energy coming out of the earth from a large body of molten rock that has been pushed up into upper crust of the earth by geological forces. In North they occur in Ladakh and Himachal Pradesh. In western parts they are found in the Cambay region of Gujrat and Maharashtra. They are also found in the Singhbhum region of Bihar while there are some in Assam. The water from a hot spring at Garampani, near Jawai, in Assam is so hot is summer that rice kept in muslin bag gets worked in no time.

The Geological Survey of India has so far identified about 350 hot spring sites which can be explored as sources of geothermal energy. The engineers have commissioned an experimental 1 kW generator running on geothermal energy in the Puga area. This is the first production of electricity from a hot water spring in India.

Many countries with hot springs in their territories have realised their potential for power and heat production. Countries like Italy, Iceland, New Zealand, the USA and the USSR have achieved remarkable progress in the application of geothermal energy.

The Italian power plant at Landerello was started in 1904 on a small scale but now it produces 540 MW of electricity. This is equivalent to burning 1.5 million tonnes of oil in a year. New Zealand started exploration in 1950 and the Wairakei power station now produces 175 MW, which is equal to 0.7 million tonnes of oil per year. The power production in California, the USA, began in 1960 and has already touched 50 MW. In the Philippines the drillers struck high pressure, high temperature steam at about 200 m only at Tiwi, a tiny sleepy village nestled at the base of the volcano Malino, in 1967. By January, 1976, the first geothermal power plant at Tiwi began producing 55 MW. A geothermal plant with a capacity of 11 MW has been in operation for nearly 20 years in USSR. The construction of another power plant at Mutnovsky with a capacity of 200 MW is in progress.

## 10.6. BIOGAS PLANTS-BIOMASS

### 10.6.1. Introduction to Biomass

**Biomass** *is an organic matter from plants, animals and micro-organism grown on land and water and their derivatives.* The energy obtained from biomass is called **biomass energy**.

Biomass is considered as a renewable source of energy because the organic matter is generated every day. Coal, petroleum oil and natural gas do not come in the category of 'biomass', because they are produced from dead, burried biomass under pressure and temperature during millions of year. Biomass can also be considered a form of solar energy as the latter is used indirectly to grow these plants by *photosynthesis*'.

**Biomass resources :**

In our country, there is a great potential for application of biomass as an alternate source of energy. We have plenty of agricultural and forest resources for reproduction of biomass.

The following are the biomass resources:

1. *Concentrated wastes :*
   (*i*) Municipal solid (*ii*) Sewage wood products
   (*iii*) Industrial waste (*iv*) Manure at large lots.
2. *Dispersed waste residue :*
   (*i*) Crop residue (*ii*) Logging residue
   (*iii*) Disposed manure.
3. *Harvested biomass :*
   (*i*) Standing biomass (*ii*) Biomass energy plantations.

The biomass sources are highly dispersed and bulky and contain large amount of water (50 to 90%). Thus, it is not economical to transport them over long distances, and as such conversion into usable energy must take place close to the source, which is limited to particular regions. However, biomass can be converted to liquid or gaseous fuels thereby increasing its energy density and making transportation feasible over long distances.

### 10.6.2. Biomass Conversion Processes

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

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

**1. Direct combustion :**

***Combustion** is the process of burning in presence of oxygen to produce heat, light and byproducts.* Complete combustion to ashes is called ***incineration.***

— Wood, dung, vegetable waste can be dried and burnt to provide heat or converted into low calorific value gas by ***pyrolysis.*** In the pyrolysis process, the organic material is converted to gases, solids and liquids by heating to 500 to 900°C in the *absence of oxygen.*

— The combustion of biomass is more difficult than other fuels, since it contains relatively higher moisture content. Biomass is free from toxic metals and its ash.

- The technology of *"fluidised bed combustion"* may be used for the efficient combustion of forestry and agricultural waste material such as sawdust, wood chips, hog fuel, rice husks, straws, nutshells and chips.

— In fluidised bed combustion of biomass, the *biomass is fed into a bed of hot inert particles,* such us sand kept in fluidised state with air at sufficient velocity from below. The operating temperature is normally controlled within the range 750-950°C ; ideally it is kept as high as possible in order to maximise the rate of combustion and heat transfer but low enough to avoid the problem of sintering of the bed particles. *The rapid mixing and turbulence within the fluidised bed enables efficient combustion to be achieved with high heat releases, as well as effective transfer,* than in a conventional boiler. This can result in more compact boiler with less number of tubes.

**2. Thermochemical conversion :**

- Biomass is decomposed in thermochemical processes having various combinations of temperatures and pressures.
- Thermochemical conversion takes two forms : *Gasification* and *liquefaction.*
- *"Gasification"* takes place by heating the biomass with limited oxygen to produce low heating value gas or by reacting it with steam and oxygen at high pressure and temperature to produce medium heating value gas. The latter may be used as fuel directly or used in *"liquefaction"* by converting it to methanol (methyl alcohol), or ethanol (ethyl alcohol) or it may be converted to high heating value gas.

3. **Biochemical conversion.** In biochemical conversion there are two principal conversion processes :

(*i*) Anaerobic digestion ; (*ii*) Fermentation.

(*i*) ***Anaerobic digestion.*** This process involves microbial digestion of biomass.

- The process and end products depend upon the microorganisms cultivated and culture conditions. (An *anaerobe* is a microscopic organism that can live and grow without external oxygen or air ; it extracts oxygen by decomposing the biomass at low temperatures upto 65°C, in presence of moisture).
- This process generates mostly *methane* ($CH_4$) and $CO_2$ gas with small impurities such as hydrogen sulphide.
- The output gas obtained from anaerobic digestion can be directly burnt, or upgraded to superior fuel gas (methane) by removal of $CO_2$ and other impurities. The residue may consist of protein-rich sludge and liquid effluents which can be used as annual feed or for soil treatment after certain processing.

(*ii*) ***Fermentation.*** *It is the process of decomposition of organic matter by microorganisms especially bacteria and yeasts.*

- It is a well established and widely used technology for the conversion of grains and sugar crops into ethanol (ethyl alcohol). Ethanol can be blended with gasoline (petrol) to produce gasohol (90% petrol and 10% ethanol). Processes have been developed to produce various fuels from various types of fermentations.

### 10.6.3. Biogas Plants

#### 10.6.3.1. Biogas

The main source for production of biogas is wet cow-dung. Some of the other sources are :

(*i*) Sewage
(*ii*) Crop residue
(*iii*) Vegetable wastes
(*iv*) Water hyacinth
(*v*) Alga
(*vi*) Poultry droppings
(*vii*) Pig-manure
(*viii*) Ocean kelp.

Biogas, a mixture containing 55-65% methane, 30-40% carbon dioxide and the rest being the impurities hydrogen (hydrogen sulphide and some nitrogen), can be produced from the decomposition of animal, plant and human waste. It is a clean but slow-burning gas and usually has a heating value about 18 kJ/m$^3$. It can be used directly in cooking, reducing the demand for firewood. Moreover, the material from which the biogas is produced retains its value as fertilizer and can be returned to soil.

Biogas is produced by digestion, pyrolysis or hydrogasification. **Digestion** is a biological process that occurs in the absence of oxygen and in the presence of anaerobic organisms at ambient pressures and temperatures of 35-70°C. The container in which this digestion takes place is known as the *digester.*

#### 10.6.3.2. Biogas applications

Biogas is a flammable fuel gas with 60% $CH_4$ and rest $CO_2$. The gas can be upgraded by removal of $CO_2$ with water scrubbing and the gas with high heating value can be used in I.C. engine. The main *applications of biogas* are:

(*i*) Cooking.

(*ii*) Domestic lighting and heating.

(*iii*) I.C. engines.

(*iv*) Fuel cells–electricity can be produced by using biogas in a fuel cell with air as oxidant. The electrolyte is usually potassium hydroxide (KOH).

#### 10.6.3.3. Types of biogas plants

***Biogas plant*** *converts wet biomass into biogas (methane) by the process of anaerobic fermentation.* The bacteria called *anaerobe* carries out digestion of biomass without oxygen and produces methane ($CH_4$) and carbondioxide ($CO_2$). Biogas plants are very popular in India particularly in rural areas. Cow dung, agricultural waste etc. is converted to methane.

A typical biogas plant has :

— Digester ;
— Inlet tank ;
— Outlet tank ;
— Stirrer etc.

The biogas plants are built in several sizes, small (0.5 m$^3$)/day) to very large (2500 m$^3$/day). Accordingly, the configurations are simpler to complex.

Biogas plants are *classified* as follows :

1. *Continuous type :*
   - Single stage type
   - Two stage type.
2. *Batch type*
3. *Fixed dome type* (Janata model or chinese model)
4. *Modified fixed dome type.* This type of plant has an additional displacement tank and water seal gas tank.
5. *Flexible bag type.*
6. *Floating dome type.*

**10.6.3.4. Janata model gobar gas plant**

***Constructional features.*** This plant consists of the following parts :

Refer to Fig. 10.27.

1. Foundation
2. Digester
3. Dome
4. Inlet Chamber
5. Outlet Chamber
6. Mixing Tank
7. Gas outlet pipe.

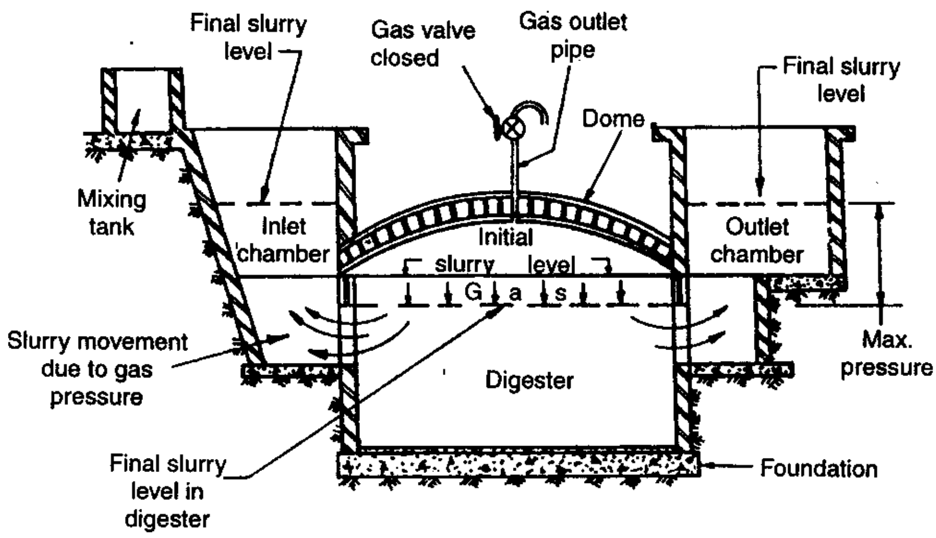


Fig. 10.27. Janata Model gobar gas plant.

***Foundation.*** The foundation is the amply compacted base of the digester made of cement concrete and brick ballast. Its construction is so carried out that it may provide a stable foundation to the digester walls and bear full load of slurry filled in the digester. It should be waterproof so that no percolation or water leakage takes place.

***Digester.*** It is underground cylindrical wall portion made of bricks, sand and cement. It is this place where fermentation of dung takes place. It is also sometimes called 'fermentation tank'. Two rectangular openings facing each other are provided for inflow and outflow at almost middle of its height.

***Dome.*** It is a hemispherical roof of the digester ; has a fixed height and forms the *critical part* in the construction of Janata gobar gas plant. The gas gets collected in the space of the dome and exerts pressure on the slurry in the digester.

***Inlet chamber.*** An inlet chamber has a bell mouth shape and is made of bricks, cement and sand. It has its top opening at the ground level. Its outlet wall is made inclined/slopy to enable the daily cattle dung feed to move easily into the digester.

***Outlet chamber.*** It is that part of the plant through which digested slurry moves out of the digester at a predetermined height. It has a small rectangular cross-section and above this it becomes larger to a defined height. For easy cleaning of the digester two steps are provided in it which enable a man to climb down. Its top opening is also at the ground level. Just near the top opening is provided a small outlet through which the digested/spent slurry flows to a compost pit.

***Mixing tank.*** It is this tank where gobar and water are mixed properly in the ratio of 1 : 1 to make slurry which is then poured into the inlet chamber.

***Gas outlet pipe.*** It is a small piece of G.I. Pipe which is fitted at the top of the dome for conveying the gas to the points of use. A valve is fitted at its end to regulate the flow of gas to the gas connections.

**Site selection.** While selecting the construction of Janata gobar gas plant the following points should be given due consideration.

— The surface should be plane/even and be at a higher elevation so that during rainy season the water level is at least at 3 m depth. The higher level will discourage water logging and ensure easy discharge of spent slurry from the outlet chamber. Preferably this place should be beyond the reach of children.

— The site should be as far as possible near the cattle shed and points of gas utilisation.

— It should be at least 2 metres away from the foundation of the house/building.

— The sun light should be available during whole of the day round the year.

— The site should be at least 10-15 metres away from the any water drinking source.

— There should not be any big tree near the plant whose roots may cause any harm with the passage of time.

— There should be an easy availability of water near the plant.

— To avoid carrying spent slurry to a very far distance there should be some space for making compost pit.

— The earth should have adequate bearing stress to avoid any possibility of caving in or collapse of the plant.

**Nature of soil and corresponding precautions :**

1. ***Soil formed of clay :***

| | |
|---|---|
| — Related problem | Easy expansion and contraction of soil as the moisture content increases and decreases. |
| — Precautions | Do not disturb the primitive soil ; Or Take measures for excess or less of water ; Or Drain the surface water. |

2. ***Non-uniform soil structure :***

*e.g.* partly soft soil and partly rocky

| | |
|---|---|
| — Related problem | Crack may appear in digester wall due to uneven settlement. |
| — Precautions | Provide a uniform kind of soil under the digester ; Or<br>— Remove a portion of the soft, soil and put lime concrete and rubble in its place ; Or<br>— Remove a part of the rock and add medium and coarse sand, cinders, clay or clay gravel. |

3. ***Soil with high water table :***

| | |
|---|---|
| — Related problem | There is an upward force on the digester due to pressure of ground water. |
| — Precautions | Construct the plant in low water seasons.<br>— Dig a trench around the digester to collect the water ; this water may be occassionally pumped out.<br>— Divert the ground water, if possible, to other places *e.g.*, well points.<br>— Increase the strength of the base of the digester by increasing its thickness. It will counter act the buoyancy force of ground water. |

**Initial loading of the plant.** After completion of the plant it is to be charged with cattle dung and water in the ratio of 1 : 1. Since Janata Plant is designed for 50 days retention period, therefore initial loading will comprise of 50 times of gobar needed for daily feed. Naturally to arrange such a large quantity of gobar by farmers who have a few cattle is a problem. This difficulty can be overcome if the gobar is collected regularly during the period of construction of plant and by the time the plant is completed the large quantity of gobar collected can be then fed.

— Before feeding into the digester the dung should be properly mixed with water in the ratio of 1 : 1 in the mixing tank to get the slurry.

— The slurry is then fed to the digester upto the step provided on the Outlet chamber. Thereafter the fermentation starts.

— Initially allow the gas which comprises of large percentage of a carbondioxide, oxygen and hydrogen sulphide to escape since it will not burn.

— The gas obtained after this release will have a right combination of methane (60%) and carbondioxide (40%) and burn with odourless blue flame in the gas chulha/burner/stove.

— Now, at this stage start feeding the plant with dung slurry.

— Regular, proper and careful feeding will ensure flawless gas service.

**How does the plant function ?**

— The cattle dung and water are mixed properly in the ratio 1 : 1 to form slurry which is then filled in the digester upto the height of its cylindrical portion.

— As soon as the fermentation of dung picks up the generated gas starts accumulating in the dome. This gas then exerts pressure on the slurry and displaces it into the Inlet and Outlet chambers. Consequently the slurry level in the digester falls and rises in the Outlet chamber.

— This fall in the level of slurry continues (if the outlet pipe valve is closed) till the slurry level reaches the upper ends/edges of the Inlet and Outlet gates.

— After this stage any further accumulation of gas would exert pressure and start escaping through these gates into the atmosphere. This condition is indicated by *bubbling* and froth formation on the surface of the slurry in the inlet and outlet chambers.

— The quantity of usable gas can be determined by calculating the increase in slurry volume in the inlet and outlet chambers.

— In the event of using gas the slurry level in the digester rises while that in the inlet and outlet comes down.

— The increase in gas pressure due to increased generation in comparison to its utilisation will push/displace the slurry up in the inlet and outlet chambers while the decrease in pressure is balanced by the return flow of slurry back in the digester.

— During the process approximately equivalent quantity of spent/digested slurry (top layer slurry) is discharged from the outlet chamber through the outlet opening ; this is so because fresh/undigested slurry which is fed into the inlet chamber is heavier than the digested/spent slurry and settles down in the digester.

**Chemistry of gas generation.** In gober gas plant the feed which comprises mainly of cattle dung is subjected to anaerobic fermentation as a result of which is produced combustible gas and fully matured organic manure which is superior to green manure available from dung otherwise. The whole process of feeding fresh slurry of dung and water and extraction of spent slurry in gobar gas plant is continuous one.

The cattle dung (and other fermentable materials like night soil, poultry or piggery droppings etc.) when confined in a place where there is no air gives rise to mainly two types of bacteria *viz. Acid forming bacteria* and *Gasifying bacteria.*

Acid forming bacteria convert carbohydrates, proteins, fats into volatile acids and carbon dioxide is produced during the process. This phase is also known as liquification phase and is brought about by a set of *saprophytic bacteria* of means of extracellular enzyme. These bacteria are less sensitive and can exist, develop and multiply in wide range of conditions.

Liquification phase is followed by gasification phase which is actively carried out by *methane bacteria*. They work upon volatile acid produced during the previous phase, with the help of intracellular enzyme and convert it into methane and carbon-dioxide.

The whole process of gobar generation is governed by the factors *viz*. Temperature of substrate. Loading rate, Solid concentration, Detention period, pH value, Nutrients concentration and Toxic substance etc.

The composition of the gas produced varies with the type of fermentable material used. In case of cattle dung on an average the gas produced consists of 55 to 60% methane and 40 to 45% corbondioxide with little quantity of hydrogen, hydrogen sulphide. With night soil the percentage may be : Methane = 65%, carbon-dioxide 34%, hydrogen sulphide = 0.6% and other gas 0.4%.

**Diphasic anaerobic digestion.** To tide over the problems generally associated with maintaining optimum fermentation conditions inside the digester, diphasic anaerobic digestion seems to be probable solution. In this system two separate digesters are used which separate the hydrogen and acid formation phases from methane formation phase ; this separation of phases is brought out by kinetic control. The acid phase is operated at low retention times so that only the fast growing acidogens of first hydrolysis and acid forming stages are retained in the digester and methogens are washed out. The methane phase takes place in a separate digester with the acid phase effluent as the feed material.

This system facilitates provision of optimum environment conditions for growth of two physiologically different types of bacteria which in turn ensures *higher efficiency of the process with subsequent reduction in the size of digester and their cost.* In this process system monitoring is also rendered easier.

**How to accelerate gas generation.** The gas production is usually satisfactory during summer season but it falls considerably during coldest months of the year. *The gas production can be enhanced / accelerated by following the tips given below :*

— Add about 1 litre of cattle urine daily for every 5 kg slurry fed to the plant. It will augment the fermentation process and eventually increase gas production. The urine can be collected in the sump connected through a drain to the animal shed.
— Feed back about 10% of the fresh spent/digested slurry to the plant. The micro-organisms available in the spent slurry will stimulate fermentation.
— Prepare the dung slurry with hot water. Water may be kept exposed to Sun during the day and be used in the evening to produce slurry. This process will prove helpful in increasing the temperature of slurry in the digester and subsequently actify the bacteria to generate more gas.
— Cover the plant with rice straw or gunny bags during late evenings and nights ; it will check fall of temperature and keep the bacteria active in gas generation.
— Add 1 kg of powdered leaves for every 50 kg dung fed to the plant ; it will help creating warmer environment suitable to bacteria for actified fermentation.
— Addition of poultry droppings (5 to 10%) and piggery waste helps to bring about increase in gas generation.
— Provision of a compost pit around the plant assists in keeping the plant warm due to which gas generation is improved.

**10.6.3.5. Advantages and disadvantages of 'Fixed dome type' and 'Movable drum type' plants**

A. **Fixed dome type plants :**

***Advantages :***

1. No maintenance problems due to absence of moving parts.
2. Low cost.
3. Low operating cost.
4. Longer working life.
5. Due to underground construction, heat insulation is better and therefore, rate of gas production is uniform during night and day.
6. Quantity of gas produced is higher than movable drum type plants.
7. No corrosion problem.
8. Space above the plant can be used for other purposes.

***Disadvantages :***

1. Variable gas pressure.
2. Problem of scum formation.
3. For construction work skilled masons are required.

B. **Movable drum type plants :**

***Advantages :***

1. Gas pressure is constant.
2. Less scum problem.
3. No danger of explosion since there is no possibility of mixing of biogas and external air.
4. No gas leakage problem.

***Disadvantages :***

1. High cost.
2. High maintenance cost.

3. There is a loss of heat through gas holder.
4. The outlet pipe, which should be flexible, requires regular attention.

#### 10.6.3.6. Guidlines for fixing optimum size of a biogas plant

The following *guidline* may be used to fix optimum size of biogas plant :

1. Type of waste.
2. Daily rate of waste to be digested.
3. Digestion period.
4. Method of stirring, if any.
5. Arrangement for raw waste feeding and discharge of digested slurry.
6. Climatic conditions.
7. Mix of raw waste.
8. Water table and sub-soil conditions.
9. Type of dome.

## 10.7. DIRECT ENERGY CONVERSION SYSTEMS

The energy conversion devices that have been in use for a long time are those that accept energy as heat and produce mechanical work, which is transformed into electric power distribution at large. *Direct energy conversion devices convert naturally available energy into electricity without an intermediate conversion into mechanical energy.* (The energy source may be thermal, solar or chemical). Until now, their use has been confined to small scale, special purpose applications, since the voltage output available with them is rather small and no inexpensive device that is reliable like a turbine or alternator has been built.

Under this topic the following systems will be discussed :

1. Thermoelectric conversion system
2. Thermionic conversion system
3. Photovoltaic power system
4. Magnetohydrodynamic system
5. Electrostatic mechanical generators
6. Electro Gas-Dynamic Generators (EGD)
7. Fuel cells
8. Nuclear batteries.

### 10.7.1. Thermoelectric Conversion System

The quest for a reliable, silent, energy converter with no moving parts that transforms heat to electrical power has led engineers to reconsider a set of phenomena called the *Thermoelectric effects*. These effects, known for over a hundred years, have permitted the development of small, self contained electrical power sources.

**Seebeck (thermoelectric) effect.** The German Scientist Seebeck (in 1822) discovered that *if two dissimilar materials* are joined to form a loop and the two junctions maintained at different temperatures, an e.m.f. will be set up around the loop. The magnitude of e.m.f. will be $E = \alpha \Delta T$ where $\Delta T$ is the temperature difference between the two junctions and $\alpha$ is the *Seebeck co-efficient*. This effect has long been used in *thermocouples to measure temperatures.*

This phenomenon offers one method of producing electrical energy directly from the heat of combustion, but its *thermal efficiency* is very low, of the order of 1 to 3 per cent. In any heat engine, the efficiency of thermoelectric generator depends upon the temperature of hot and cold junctions.

**Thermoelectric Power Generator**

Fig. 10.28 shows a schematic diagram of a thermoelectric power generator. The thermocouple material A and B are joined at the hot end, but the other ends are kept cold ; an electric voltage or electromotive force is then generated between the cold ends. A D.C. (Direct Current) will flow in a circuit or load connected between these ends. The flow of current will continue as long as the heat is supplied to the hot junction and removed from the cold ends. For a given thermocouple, the voltage and electric power output are increased by increasing the temperature difference between the hot and cold ends.

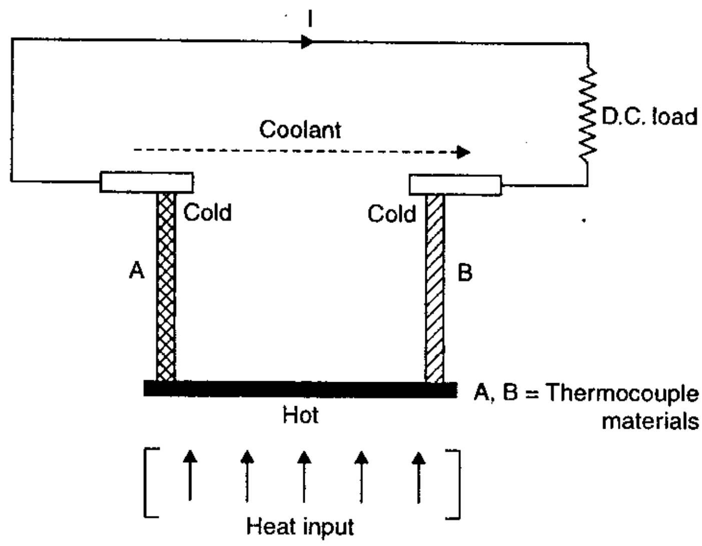


Fig. 10.28. Thermoelectric generator.

In a practical thermoelectric converter, several thermocouples are convected in series to *increases both voltage and power* as shown in Fig. 10.29. If the output voltage is insufficient to operate a particular device or equipment, it can be increased, with little loss of power, by an inverter transformers combination. The direct current generated by the thermocouples is first changed into alternating current of essentially the same average by means of an inverter. The alternating current

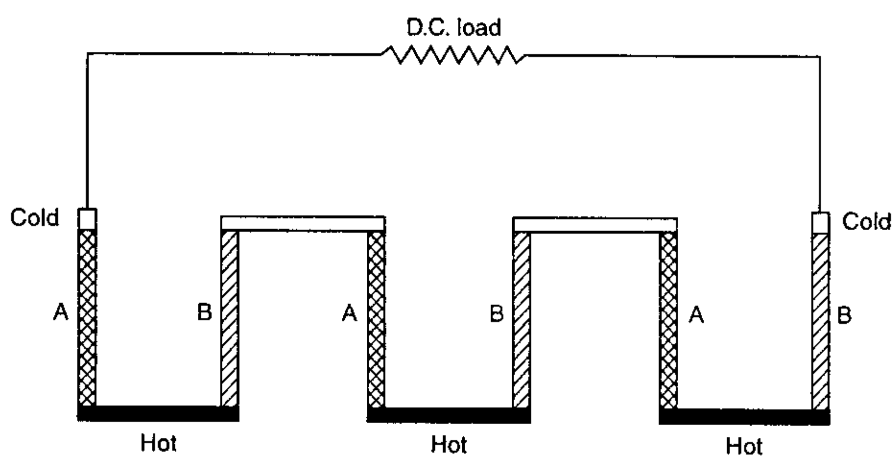


Fig. 10.29. Thermocouples in series (to increase voltage).

and voltage in then increased to the desired value with the help of a transformer. The high voltage alternating current can be reconverted into direct current if required, by the use of a rectifier.

The source of heat for a thermoelectric generator may be a small oil or gas burner, a radio-isotope or direct solar radiation.

A typical couple operating with hot and cold junction temperatures of 600°C and 200°C could be designed to give about 0.1 V and 2 A *i.e.*, about 0.5 W, so that a 1 kW device could require about 5000 couples in series.

Taking into account mechanical characteristics, stability under operating conditions and ease of fabrication, Bismuth telluride appears to be most suitable material. It can be alloyed with such materials as Bismuth selenide, Antimony telluride, lead selenide and tin telluride to give improved properties.

Research is being carried out on the possibility of using thermoelectric devices within the core of a nuclear reactor. The hot junction would be located on the fuel element and the cold junctions in contact with the coolants.

**Note.** A thermoelectric converter is a form of *heat engine* which takes up heat at an *upper temperature* (hot junction) converts it partly into electrical energy and discharges the remaining part at a *lower temperature* (cold junction). The efficiency of a thermocouple, as is the case with other heat engines, increases by increasing the upper temperature and decreasing the lower temperature. Since the lower temperature is usually that of environment the efficiency of a thermocouple, practically, depends upon the *hot junction temperature*.

**Thermoelectric materials and their selection :**

The following materials find use in the making of thermoelectric elements :

| *Material* | *Formula* | *Figure of merit, Z (°K⁻¹)* |
|---|---|---|
| Lead telluride | PbTe | $1.5 \times 10^{-3}$ |
| Bismuth telluride (doped with Sb or Se) | $Bi_2 Te_3$ | $4 \times 10^{-3}$ |
| Germanium telluride (with bismuth) | Ge Te | $1.5 \times 10^{-3}$ |
| Cesium sulphide | Ce S | $1.0 \times 10^{-3}$ |
| Zinc antimonide (doped with silver) | Zn Sb | $1.5 \times 10^{-3}$ |

where $Z$ is an *index used in rating thermoelectric converters*. It depends on the properties of thermoelectric materials used. A high value of $Z$ is obtained by using materials of :

(*i*) *Large Seebeck co-efficient* (*ii*) *Small thermal conductivity*

(*iii*) *Small electrical resistivity.*

In recent times, the most commonly used material for thermoelectric converters is *lead telluride* [a compound of lead and tellurim, containing small amounts of either bismuth (*N*-type) or sodium (*P*-type)]. The efficiency of such a thermoelectric converter is, however, only about 5 to 7 per cent.

Taking into account mechanical characteristics, stability under operating conditions and ease of fabrication, Bismuth telluride appears to be amply suitable material. It can be alloyed with such materials as Bismuth selenide, Antimony telluride, Lead selenide and tin telluride to give improved properties.

Research is being made to find more efficient thermocouple materials. For high temperature applications, semiconductors based on silicon-germanium and compounds of selenium appear to be promising.

To achieve higher efficiency, thermoelectric material should have a high value of $Z$ and be able to operate upto very high temperature. The following points are worthnothing in this regard :

1. The component thermal conductivity of semiconductor should be as low as possible.

2. The mobility of current carriers (electrons or holes, should be as high as is compatible with condition 1).
3. One of the arms should consist of a purely hole type and the other of a purely electronic type semiconductor.
4. In the low temperature zone the impurity concentration should be lower than in the higher temperature zone.
5. So that the thermoelectric material may not crack under the effect of stresses it should possess the following properties :
   (*i*) It should be able to resist chemical influences such as oxidation etc.
   (*ii*) It should have good mechanical strength.
   (*iii*) It should be amply elastic.

### 10.7.2. Thermionic Conversion System

**Introduction**

A thermionic converter can be analyzed from at least three different points of view :

1. In terms of *thermodynamics*, it may be viewed as a heat-engine that uses an electron gas as a working substance.

2. In terms of *electronics*, it may be viewed as a *diode* that transforms heat to electricity by the law of thermionic emission.

3. In terms of *thermoelectricity*, it may be viewed as a thermocouple in which an evacuated space or a plasma has been substituted for one of the conductors.

Regardless of the point of view adopted in analysis, a *thermionic converter works because of the phenomenon of 'thermionic emission'. Thermionic emission implies emission of electrons from the metal when it is heated.*

**Work function ($\phi$)**

It is defined as *the energy required to extract an electron from the metal.* It is measured in *electron volts*. The value of work function varies with the *nature of the metal and its surface condition*.

A thermionic converter, in principle, consists of two metals or electrodes with different work functions sealed into an evacuated vessel. The electrode with a large work function is maintained at a higher temperature than one with the smaller work function.

**Thermionic generators.** Refer Fig. 10.30.

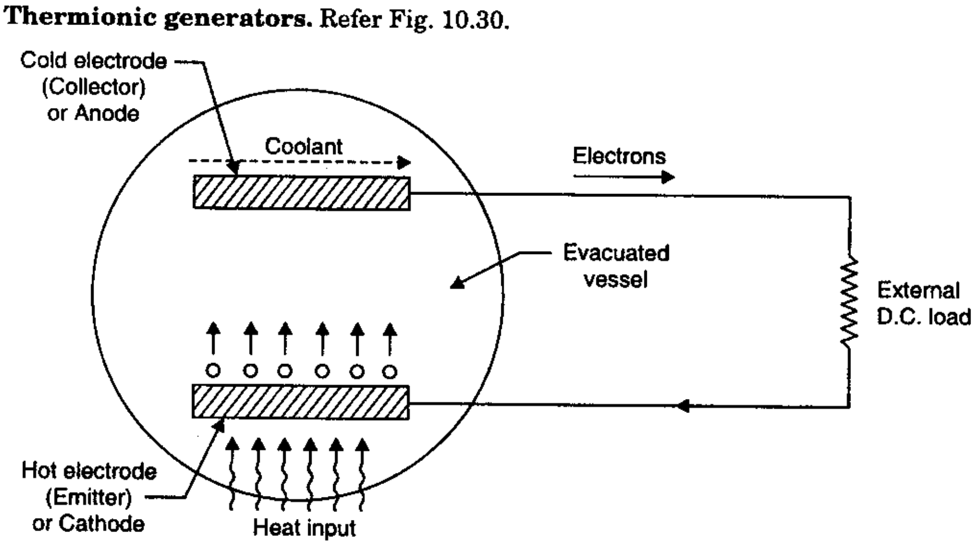


Fig. 10.30. Thermionic generator.

A thermionic converter/generator comprises a *heated cathode* (electron *emitter*) and an *anode* (electron *collector*) separated by a *vacuum*, the electrical output circuit being connected between the two as shown in Fig. 10.30. The heat which is supplied to the cathode raises the energy of its electrons to such a level that it enables them to escape from the surface and flow to the anode. *At the anode the energy of electrons appears partially as heat, removed by cooling and partially as electrical energy delivered to the circuit.* Although the distance between anode and cathode is only about *one millimetre*, the negative space charge with such an arrangement hinders the passage of the electrons and *must be reduced*, this can be achieved by introducing positive ions into the interelectrode space, cesium vapour being valuable source of such ions.

In order to materialise a substantial electron emission rate (per unit area of emitter), and hence a significant current output as well as a high efficiency, the emitter temperature in a thermionic converter containing cesium should be *at least 1000°C,* the efficiency is then 10 per cent. Efficiency as high as 40 per cent can be obtained by operating at still higher temperatures. Although temperature has little effect on the voltage generated, the increase in current (per unit emitter area) associated with a temperature increase results in increase in power. Electric power ($P$) is the product of voltage ($E$) and current ($I$) *i.e.*, $P = EI$.

*Anode* materials should have a *low work function e.g. barium and strontium oxides* while that of the *cathode* should be *considerably higher, tungsten impregnated with a barium compound* being a suitable material. Even with these materials temperatures upto 2000°C will be required to secure for the generator itself, efficiencies of 30-35 per cent. Electrical outputs of about 6 W/cm$^2$ of anode surface are envisaged with about 13 W/cm$^2$ removed by coolant.

A thermionic generator, in principal can make use of any fuel (may be fossil fuel, a nuclear fuel or solar energy) subject to the condition that sufficiently high temperatures are obtainable. The thermionic conversion can be utilized in several different situations-remote locations on the earth and in space.

**Thermionic converter materials.** The problem of developing materials suitable for use in thermionic converters ranks next to the space charge control problem in the development of efficient thermionic generators. Following properties are desirable in materials suitable for converters :

**Emitter.** A good emitter will :

(*i*) have high-electron emission capability coupled with a low rate of deterioration.

(*ii*) have *low emissivity*, to reduce heat transfer by radiation from the emitter.

(*iii*) be such that in the event some of it vapourizes and subsequently condenses on the collector it will not poison the collector (that is, change the collector properties, thereby making it less effective).

The relative importance of these properties is dependent upon the type of converter being designed. It should be noted that efficiency is a much slower rising function of electron emission capability if space charge is present than if there is no space charge.

The work function may be reduced considerably by an absorbed single layer of foreign atoms. This comes about by the establishment of a dipole layer at the surface. The layer can be formed by atoms or molecules. This is essentially what happens in a cesium converter, which is designed so that cesium condenses on the emitter or collector.

**Collector.** The *main criteria for choosing a collector material is that it should have as low a work function as possible.* Because the collector temperature is held below any temperature that will cause significant electron emission, its actual emission characteristics are of no consequence. The lower the collector work function ($\phi_c$), however the less energy the electron will have to give up as it enters the collector surface. In practice the lowest value of $\phi_c$ that can be maintained stably is about 1.5 eV. For applications in which it is desirable to maintain the collector at elevated temperatures (greater than 900°K) such as space applications, an optimum value of $\phi_c$ may be determined. Molybdenum has been widely used as a collector ; it is frequently assumed to have a work function of 1.7 eV.

### 10.7.3. Photovoltaic Power System

**Photovoltaic generators-Historical background.** Edmond Becquerel in 1839 noted that a voltage was developed when light was directed onto one of the electrodes in an electrolytic solution. The effect was first observed in a solid in 1877 by W.G. Adams and R.E. Day, who conducted experiments with selenium. Other early workers with solids included Schottky, Lange and Grandahl, who did pioneering work in producing photovoltaic cells with selenium and cuprous oxide. This work led to the development of photoelectric exposure meters. 1954 researchers turned to the problem of utilizing the photovoltaic effect as a source of power. In that year several groups including the workers at Bell Telephone Laboratories achieved conversion efficiencies of about 6 per cent by means of junctions of *P*-type and *N*-type semiconductors. These early junctions, commonly called *P-N* junctions, were made of cadmium sulphide and silicon. Later workers in the area have achieved efficiencies more than 20 per cent by using improved silicon *P-N* junctions.

**Photovoltaic cell.** Solar energy can be directly converted to electrical energy by means of *photovoltaic effect* which is defined as the *generation of an electromotive force as a result of the absorption of ionizing radiation.* Energy conversion devices which are employed to convert sunlight into electricity by the use of the photovoltaic effect are called *solar cells.* A single converter cell is called a solar cell or a *photovoltaic cell.* To increase the electrical power output a number of such cells are combined and the combination is called a *solar array* (or solar module).

In a photovoltaic cell sensitive element is a *semiconductor* (not metal) which generates voltage in proportion to the light or any radiant energy incident on it. The most commonly used photovoltaic cells are barrier layer type like iron-selenium cells or Cu—$CuO_2$ cells.

Fig. 10.31 shows a typical widely used photo-voltaic cell—"*Selenium cell*". It consists of a metal electrode on which a layer of selenium is deposited ; on the top of this a barrier layer is formed which is coated with a very thin layer of gold. The latter serves as a translucent electrode through which light can impinge on the layer below. Under the influence of this light, a negative charge will build up on the gold electrode and a positive charge on the bottom electrode.

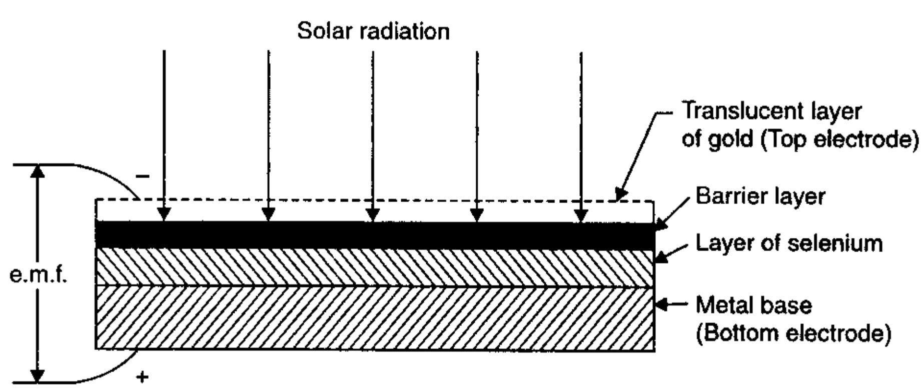


Fig. 10.31. Photovoltaic cell.

Photovoltaic cells are widely used in the following fields :

(*i*) Automatic control systems ;

(*ii*) Television circuits ;

(*iii*) Sound motion picture and reproducing equipment.

**Basic photovoltaic system for power generation**

Fig 10.32 shows a basic photovoltaic system integrated with the utility grid. With the help of this system the generated electrical power can be delivered to the local load.

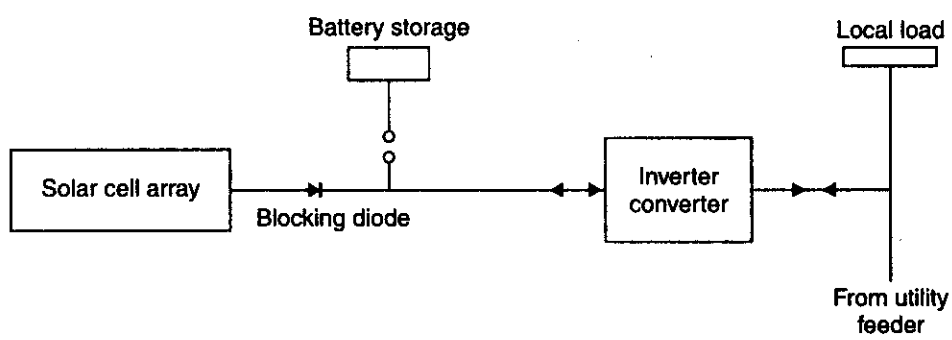


Fig. 10.32. Basic photovoltaic system integrated with power grid.

This system consists of the following :

1. Solar array
2. Blocking diode
3. Battery storage
4. Inverter converter
5. Switches and circuit breakers.

— The *solar array* (large or small) converts the insolation to useful D.C. electrical power.

— The *blocking diode* confines the electrical power generated by the solar array to flow towards the battery or grid only. In the absence of blocking diode the battery would discharge back (through the solar array) during the period when there is no insolation.

— *Battery storage* stores the electrical power generated through solar array.

— *Inverter/converter* (usually solid state) converts the battery bus voltage to A.C. of frequency and phase to match that needed to integrate with the utility grid. Thus it is typically a D.C., A.C. inverter.

— *Switches and circuit breakers* permit isolating parts of the system, as the battery.

**Limitations of photovoltaic energy converters**

The major factors which prohibit real photovoltaic converters from achieving the higher efficiencies are :

1. Reflection losses on the surface.
2. Incomplete absorption.
3. Utilization of only part of the photon energy for creation of electron hole pairs.
4. Incomplete collection of electron-hole pairs.
5. A voltage factor.
6. A curve factor related to the operating unit at maximum power.
7. Additional delegation of the curve due to internal series resistance.

**Fabrication of Cells :**

A. ***Silicon Cells***

Silicon cells are most widely used. Next to oxygen, silicon is the most abundant element on earth, the pure silicon used in cell manufacture is extracted from sand which is mostly silicon dioxide ($SiO_2$). The silicon required for solar cell use, because of its high purity, is expensive.

The fabrication of silicon cells include the following steps :

(*i*) The pure silicon is placed in an induction furnace where boron is added to melt. This turns the crystal resulting from the melt into *P*-type material.

(*ii*) A small seed of single crystal silicon is dipped into the melt and withdrawn at a rate slower than 10 cm per hour, the resulting inset looks like a medium sized carrot. The rate of growth and other conditions are adjusted so that the crystal that is pulled is a single crystal.

(*iii*) Wafers are then sliced from the grown crystal by the use of a diamond cutting wheel. The slices are then lapped, generally by hand, to remove the saw marks and strained regions.

(*iv*) After a fine lap the slabs are etched in hydrofluoric acid or nitric acid to complete the first phase of preparation of the cells. We now have thin slices of*P*-type silicon with a carefully finished surface.

(*v*) The wafers are then sealed in a quartz tube partly filled with phosphorous pentoxide and the arrangement is placed in a diffusion furnace where temperature is carefully controlled ; this process causes the phosphorous to diffuse into the *P*-type silicon to a depth of about $10^{-4}$ cm to $10^{-5}$ cm.

(*vi*) The cells are then etched in a concentrated acid to remove unwanted coatings that formed during manufacture. Wax or Teflon masking tape is used to protect the surfaces not to be etched.

**B. *Thin film solar cells***

These cells have the following advantages :

(*i*) The material cost is low.

(*ii*) The manufacturing cost is low (possibly avoiding the need for single crystal growth).

(*iii*) High power-to-weight ratios.

(*iv*) Low array costs, because the number of connections needed will be greatly reduced.

The example of this type of cell is cadmium sulphide (CdS) cells. CdS cells having areas of 50 $cm^2$ have been made by evaporating the semiconductor on to a flexible substrate such as kapton, a metallized plastic substrate. A barrier layer of copper sulphide is then deposited on top of the CdS. Power to weight ratios of 200 watts/kg are claimed for such cells. These cells have low efficiency and instability.

**Advantages and disadvantages of Photovoltaic solar energy conversion**

***Advantages :***

(*i*) There are no moving parts.

(*ii*) Solar cells are easy to operate and need little maintenance.

(*iii*) They have longer life.

(*iv*) They are highly reliable.

(*v*) They do not create pollution problem.

(*vi*) Their energy source is unlimited.

(*vii*) They can be fabricated easily.

(*viii*) The have high power to weight ratio.

(*ix*) They can be used with or without sun tracking, making possible a wide range of application possibilities.

(*x*) They have ability to function unattended for long periods as evident in space programme.

***Disadvantages :***

(*i*) The cost of a solar cell is quite high.

(*ii*) The output of a solar cell is not constant, it varies with the time of day and weather.

(*iii*) Amount of power generated is small.

**10.7.4. Magnetohydrodynamics (MHD) System**

**Introduction.** Magnetohydrodynamics (MHD), as the name implies, is concerned with the flow of a conducting fluid in the presence of magnetic and electric field. The fluid may be gas at elevated temperature or liquid like sodium or potassium.

MHD generator is a device *which converts heat energy of a fuel directly into electrical energy without a conventional electric generator*. MHD converter system is a heat engine whose efficiency, like all heat engine, is increased by supplying the heat at the highest practical temperature and rejecting it at the lowest practical temperature. MHD generation looks the most promising of the direct conversion techniques for the large scale production of electric power.

***Principle of MHD Power Generation :***

Faraday's law of electromagnetic induction states that when a conductor and a magnetic field move in respect to each other, an electric voltage is induced in the conductor. The conductor need not be a solid—it may be a *gas or liquid*. The magnetohydrodynamic (MHD) generator uses this principle by forcing a *high-pressure high temperature combustion gas* through a strong magnetic field.

Fig. 10.33 shows the comparison between a *turbogenerator* and the *MHD generator*.

**MHD systems**

The broad classification of the MHD systems is as follows :

1. Open cycle systems
2. Closed cycle systems
   (*i*) Seeded inert gas systems
   (*ii*) Liquid metal systems.

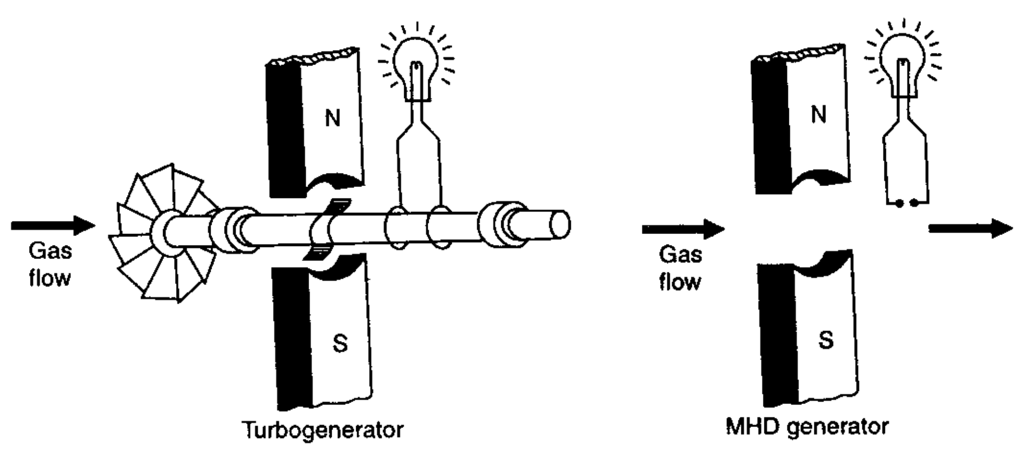


Fig. 10.33. Comparison between the conventional turbogenerator and the MHD generator.

**Open Cycle MHD systems**

Fig. 10.34 shows an open cycle MHD system. Here the fuel (such an oil, coal, natural gas) is burnt in the combustion chamber, air required for combustion is supplied from *air preheater*. The hot gases produced by the combustion chamber are then seeded with a small amount of an ionized

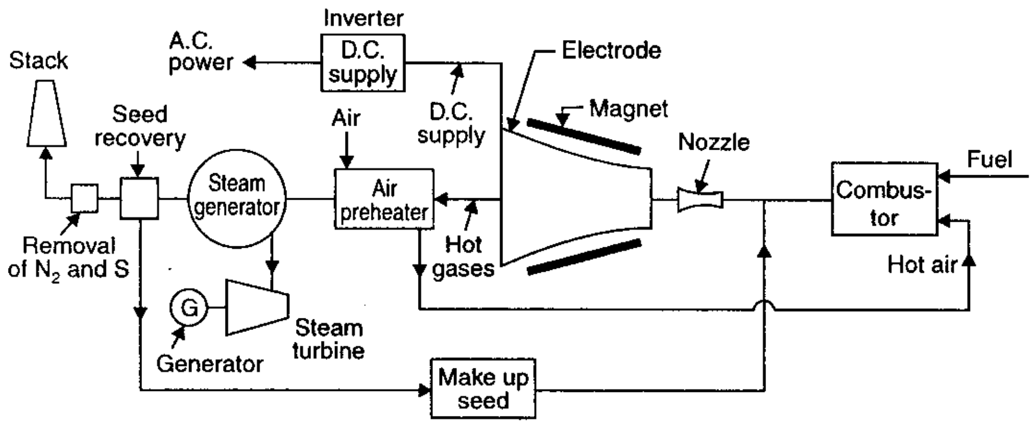


Fig. 10.34. Open cycle MHD system.

alkali metal (cesium or potassium) to increase the electrical conductivity of the gas. The ionization of potassium (generally potassium carbonate is used as seed material) takes place due to gases produced at temperature of about 2300-2700°C by combustion. The hot pressurised working fluid so produced leaves the combustion chamber and passes through a convergent divergent nozzle. The gases coming out the nozzle at high velocity then enter the MHD generator. The expansion of the hot gases take place in the generator surrounded by powerful magnents. The MHD generator produces direct current. By using an *inverter* this direct current can be converted into alternating current.

**Closed cycle MHD systems**

A liquid metal closed cycle system is shown in Fig. 10.35. A liquid metal (potassium) is used as working fluid in this system. The liquid potassium after being heated in the breeder reactor is passed through the nozzle where its velocity is increased. The vapour formed due to nozzle action are separated in the separator and condensed and then pumped back to the reactor as shown in Fig. 10.35. Then the liquid metal with high velocity is passed through MHD generator to produce D.C. power. The liquid potassium coming out of MHD generator is passed through the heat exchanger (boiler) to use its remaining heat to run a turbine and then pumped back to the reactor.

This system entails many constructional and operational difficulties.

**Advantages of MHD systems**

1. More reliable since there are no moving parts.
2. In MHD system the efficiency can be about 50% (still higher expected) as compared to less than 40% for most efficient steam plants.
3. Power produced is free of pollution.
4. As soon as it is started it can reach the full power level.
5. The size of plant is considerably smaller than conventional fossil fuel plants.
6. Less overall operational cost.
7. The capital cost of MHD plants is comparable to those of conventional steam plants.

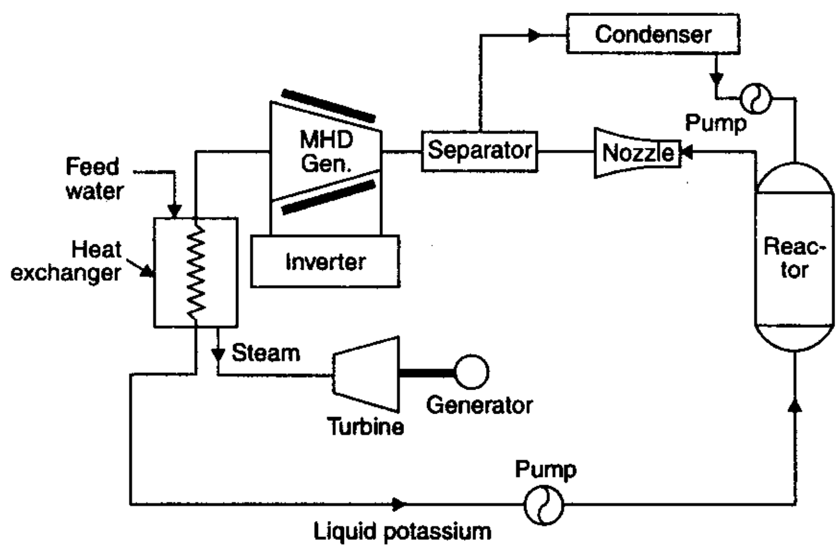


Fig. 10.35. Closed cycle (liquid metal) system.

8. Better utilization of fuel.
9. Suitable for peak power generation and emergency service.

**Drawbacks of MHD system**

1. MHD systems suffer from the reverse flow (short circuits) of electrons through the conducting fluids around the ends of the magnetic field. This loss can be reduced by (*i*) increasing aspect ratio (*L*/*d*) of the generator, (*ii*) by permitting the magnetic field poles to extend beyond the end of electrodes and (*iii*) by using insulated vans in the fluid ducts and at the inlet and outlet of the generator.

2. There will be high friction losses and heat transfer losses. The friction loss may be as high as 12% of the input.

3. The MHD system operates at very high temperatures to obtain high electrical conductivity. But the electrodes must be relatively at low temperatures and hence the gas in the vicinity of the electrodes is cooler. This increases the resistivity of the gas near the electrodes and hence there will be a very large voltage drop across the gas film. By adding the seed material, the resistivity can be reduced.

4. The MHD system needs very large magnets and this is a major expense.

5. Coal, when used as a fuel, poses the problem of molten ash which may short circuit the electrodes. Hence oil or natural gas are considered to be much better fuels for this system. This restriction on the use of fuel makes the operation more expensive.

### 10.7.5. Electrostatic Mechanical Generators

Electrostatic mechanical generators convert mechanical energy, usually mechanical potential energy of a fluid directly into electrical energy.

Fig. 10.36 shows the principle of working of liquid drop electrostatic mechanical generator. In this, *the gravitational potential energy of water droplets is directly converted into electrical energy.* The electric charge is transferred from one electrode to another by an insulated belt. All these electrostatic devices are having the characteristic of fairly low currents and very high voltages. This is yet only a laboratory model and commercial power generation has yet to be done.

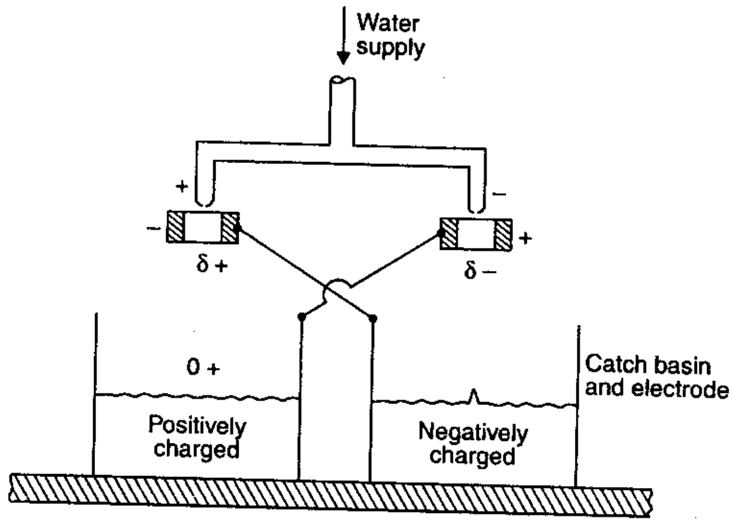


Fig. 10.36. Liquid drop electrostatic mechanical generator.

### 10.7.6. Electro Gas-dynamic Generators (EGD)

The EGD generator uses the potential energy of a high pressure gas to carry electrons from a low potential electrode to a high potential electrode, thereby doing work against an electric field. A schematic diagram of EGD is shown in Fig. 10.37.

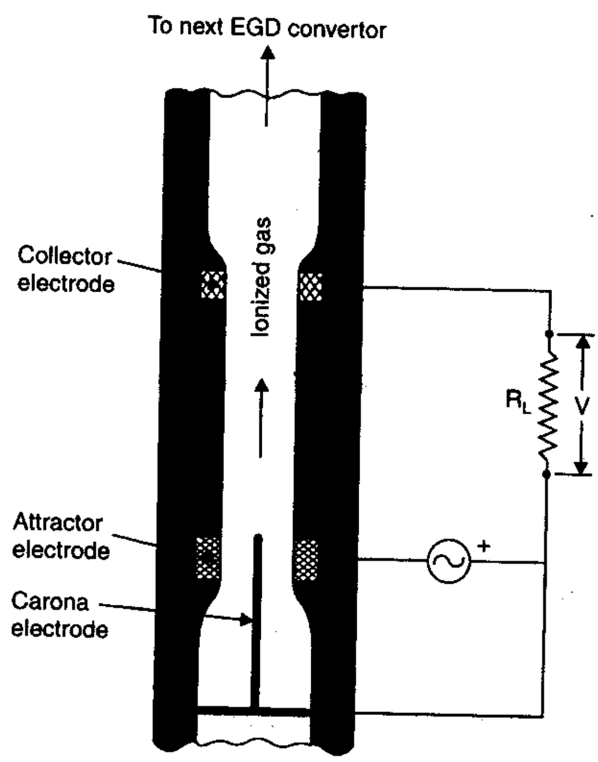


Fig. 10.37. Gas duct in an EGD convertor.

Carona electrode at the entrance of the duct generates electrons. This ionised gas particles are carried down the duct with the neutral atoms and the ionized particles are neutralised by the collector electrode, at the end of the insulated duct. The working fluid in these systems are commonly, either combustion gases produced by burning of fuel at high pressures or it is a pressurised reactor gas coolant. The maximum power output from EGD is about 10 to 30 W per channel. Hence, several thousand channels are connected in series and parallel. The voltage produced is very high, of the order of 1,00,000 to 2,00,000 V. Thus, it needs very good high voltage insulators. (Beryllium Oxide, Beo, is generally used).

EGD can produce a high efficiency equal to MHD-steam combination.

**Advantages of EGD over MHD systems :**

1. EGD systems operate at relatively low temperatures.
2. No need for injection and recovery of seed material.
3. It is self contained since it does not need a steam generator.
4. Energy can be extracted till the gases reach almost the stack temperature.
5. Does not need large quantities of condenser cooling water.

EGD and MHD hold the prospects of offering the best solutions for high efficiency, large capacity systems for the production of electricity.

### 10.7.7. Fuel Cells

*A fuel cell is an electrochemical device in which the chemical energy of a conventional fuel is converted directly and efficiently into low voltage, direct-current electrical energy.* One of the chief advantages of such a device is that because the conversion, at least in theory, can be carried out isothermally, the Carnot limitation on efficiency does not apply. A fuel cell is often described as a primary battery in which the fuel and oxidizer are stored external to the battery and fed to it as needed.

Fig. 10.38 shows a schematic diagram of a fuel cell. *The fuel gas diffuses through the anode and is oxidized, thus releasing electrons to the external circuit ; the oxidizer diffuses through the cathode and is reduced by the electrons that have come from the anode by way of the external circuit.*

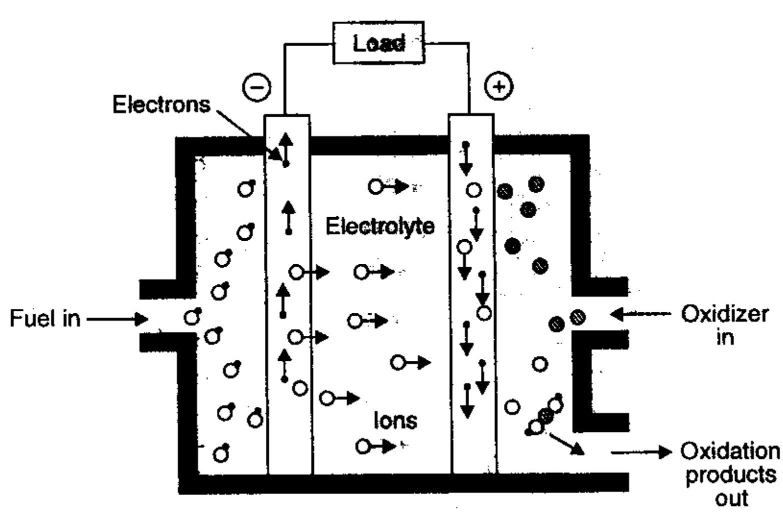


Fig. 10.38. Schematic of a fuel cell.

The fuel cell is a device that keeps the fuel molecules from mixing with the oxidizer molecules, permitting, however, the transfer of electrons by a metallic path that may contain a load.

Of the available fuels, *hydrogen* has so far given the most promising results, although cells consuming coal, oil or natural gas would be economically much more useful for large scale applications.

Some of the possible reactions are :

| | | |
|---|---|---|
| Hydrogen/oxygen | 1.23 V | $2H_2 + O_2 \longrightarrow 2H_2O$ |
| Hydrazine | 1.56 V | $N_2H_4 + O_2 \longrightarrow 2H_2O + N_2$ |
| Carbon (coal) | 1.02 V | $C + O_2 \longrightarrow CO_2$ |
| Methane | 1.05 V | $CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$ |

**Hydrogen-oxygen cell :**

The hydrogen-oxygen device shown in Fig 10.39 is typical of fuel cells. It has three chambers separated by two porous electrodes, the *anode* and the *cathode*. The middle chamber between the electrodes is filled with a strong solution of potassium hydroxide. The surfaces of the electrodes are chemically treated to repel the electrolyte, so that there is minimum leakage of potassium hydroxide into the outer chambers. The gases diffuse through the electrodes, undergoing reactions as shown below :

$$4KOH \longrightarrow 4K^+ + 4(OH)^-$$

**Anode** : $2H_2 + 4(OH)^- \longrightarrow 4H_2O + 4e^-$

**Cathode** : $O_2 + 2H_2O + 4e^- \longrightarrow 4(OH)^-$

Cell reaction $2H_2 + O_2 \longrightarrow 2H_2O$

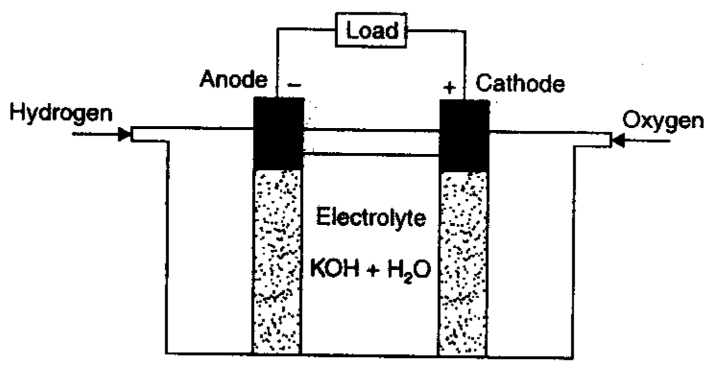


Fig. 10.39. Hydrogen-oxygen fuel cell.

The water formed is drawn off from the side. The electrolyte provides the $(OH)^-$ ions needed for the reaction, and remains unchanged at the end, since these ions are regenerated. The electrons liberated at the anode find their way to the cathode through the external circuit. *This transfer is equivalent to the flow of a current from the cathode to the anode.*

Such cells when properly designed and operated, have an open circuit voltage of about 1.1 volt. Unfortunately, their life is limited since the water formed continuously dilutes the electrolyte. Fuel efficiencies as high as 60%—70% may be obtained.

**Advantages and disadvantages of Fuel cells**

***Advantages :***

1. Conversion efficiencies are very high.
2. Require little attention and less maintenance.

3. Can be installed near the use point, thus reducing electrical transmission requirements and accompanying losses.
4. Fuel cell does not make any noise.
5. A little time is needed to go into operation.
6. Space requirement considerably less in comparison to conventional power plants.

***Disadvantages :***

1. High initial cost.
2. Low service life.

**Applications of Fuel cells :**

The applications of fuel cell relate to :

1. Domestic use
2. Automotive vehicles
3. Central power stations
4. Special applications.

**Note.** The human body functions essentially like a fuel cell. Living things take in food (fuel) and oxygen to produce both thermal energy and work output. They are not heat engines.

### 10.7.8. Nuclear Batteries

A nuclear battery works on the principle that *beta emitter can produce the electrical energy.*

Nuclear batteries *are of the following two kinds* : (*i*) *High voltage* atomic battery and (*ii*) *Low voltage* atomic battery.

#### 10.7.8.1. High voltage atomic battery

Fig. 10.40 shows the schematic diagram of a high voltage atomic battery.

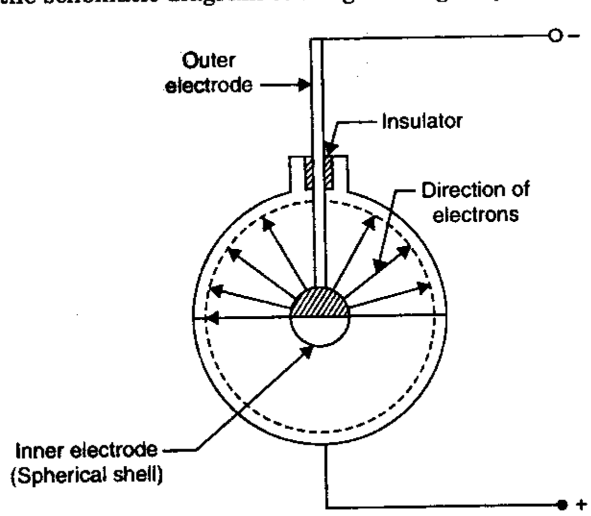


Fig. 10.40. High voltage atomic battery.

It consists of an inner spherical electrode on the surface of which is deposited a powerful beta emitting (*i.e.*, fast electrons) substance. This is surrounded by another spherical condenser and the inner surface of this condenser becomes negatively charged. This acts as the outside electrode and is properly insulated at the opening. The inner and outer electrodes become the – ve and + ve terminals of the battery.

$Sr^{90}$ isotope can be used since its half life is 28 years. These batteries perform independent of the temperature unlike the accumulators whose electrolyte freezes at low temperatures. These also supply a *very steady constant potential.*

This has yet to be developed on a commercial scale.

**10.7.8.2. Low voltage atomic battery**

Fig. 10.41 shows a low voltage battery.

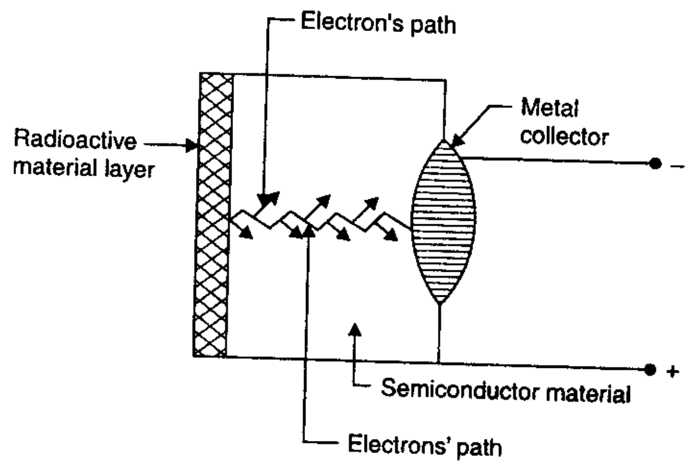


Fig. 10.41. Low voltage atomic battery

In this $Sr^{90}$ (beta emitter) is deposited on the surface of a semiconductor (germanium or silicon) at one end and the other end is having a metallic collector. The semiconductor has the characteristic of undirectional current flow. The fast electrons pass through the semiconductor and strike the metallic disc at the other end and the two ends of the semiconductor become the – ve and + ve terminals of the battery. The power produced by this battery is a few microwatts at a potential difference of 1/10 volt. This power is sufficient to *feed a small radio.*

## HIGHLIGHTS

1. The periodic rise and fall of the water level of sea which are carried by the action of sun and moon on water of the earth is called the *tide.*
2. In a single basin arrangement power can be generated only intermittently.
3. The solar farm consists of a whole field covered with parabolic trough concentrators and a 'solar tower' consists of a central receiver on a tower and a whole field of tracking.
4. "If two dissimilar materials are joined to form a loop and the two junctions maintained at different temperatures, an e.m.f. will be set up around the loop". This is called *Seebeck effect.*
5. A thermionic converter works because of the phenomenon of 'thermionic emission'.
6. 'Photovoltaic effect' is defined as the generation of an electromotive force as a result of absorption of ionizing radiation.
7. 'MHD generator' is device which converts heat energy of a fuel directly into electrical energy without a conventional electric generator.
8. A 'fuel cell' is an electrochemical device in which the chemical energy of a conventional fuel is converted directly and efficiently into low voltage, direct current electrical energy.

## THEORETICAL QUESTIONS

1. List the various non-conventional energy sources.
2. Explain with a real diagram a wind electric generating power plant.
3. Write a shot-note no 'Wind Electricity Economics'.
4. Name the components of a tidal power plant.
5. Give the classification of tidal power plants.
6. Give the working of a single basin tidal power plant.
7. What are the advantages and limitations of tidal power generation ?
8. Explain with the help of a neat diagram a solar pond electric power plant.
9. Describe the working of a 'solar tower plant'.
10. Give the working a geothermal plant.
11. What is 'Thermoelectric effect' ?
12. Write a short note on 'Thermoelectric generator'.
13. Define work function.
14. Explain with a neat diagram the working of a 'Thermoelectric generator'.
15. What is a photovoltaic cell ?
16. How are silicon cells fabricated ?
17. Write down the advantages and disadvantage of 'Photovoltaic solar energy conversion'.
18. Describe open cycle MHD system.
19. What is a fuel cell ?
20. Describe a hydrogen-oxygen cell.
21. State the advantages and disadvantages of fuel cells.
22. Write short notes on the following :
    (*a*) Working of MHD generator.
    (*b*) Fuel cells and its applications.
23. Describe with the help a neat sketch, the working of a solar power plant. What are its salient features ?

## COMPETITIVE EXAMINATIONS QUESTIONS

1. (*a*) Write a short note on the possibility of the utilization of solar energy for power generation in India.
   (*b*) Discuss briefly the advantages of combined working of different types of power plants.
   (*c*) Write short notes on base load stations and peak load stations.
2. (*a*) Narrate the elements of cost of power.
   (*b*) Define diversity factor and state the advantages of diversity of load in a power system.
   (*c*) Describe how power is generated by MHD.
3. Write short notes on the following :
   (*a*) Working of MHD generator ; (*b*) Fuel cells and its application ;
   (*c*) Free piston engine plants.
4. (*a*) Describe, with the help of a neat sketch, the working of a solar power plant. What are its salient features ?
   (*b*) What is the function of circuit breaker in a power plant ? Explain its principle of working. What are the different types of circuit breakers commonly used ?
5. Write short notes on the following :
   (*a*) Hydrology and its importance in selecting the site for a hydel power station ;
   (*b*) Moderator and Coolant of a nuclear reactor ;
   (*c*) Solar power and its uses.
6. Write short notes on the following :
   (*i*) MHD generator ; (*ii*) Solar collectors ;
   (*iii*) Electrical protection devices in power plant ;
   (*iv*) Pneumatic ash handling system.