RENEWABLE ENERGY

Lecture Notes

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Renewable Energy Lecture notes

Course No.	**: ENGG. 3204**
Course Title	**: RENEWABLE ENERGY**
Credits	**: (1 +0)**

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December 2018

Citation: *Sudheer, K.P, Sureshkumar, P.K, Sreekutty Suresh V, and Greeshma, K. 2018. Lecture Notes of Renewable Energy. Published by The Associate Dean, College of Horticulture, Vellanikkara, Kerala Agricultural University.*

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Supported through ICAR Development Grant

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Lecture No.1

Sources of energy, classification

Introduction

Energy plays a very important role in our lives, providing comfort, increasing productivity and allowing us to live the way we want to. Since the beginning of mankind, we have made use of wood, water, and fossil fuels as a means of heating and making machines work. Almost for all types of activities, we rely on one or another form of energy.

Amount of energy used by a society is an indicator of its economic growth and development. Without energy even our body would be unable to perform basic functions like respiratory, circulatory, or digestive functions to name a few. Plants would also be unable to complete the process of converting Carbon dioxide, water and minerals into food without the light from the Sun. Almost all the machines used for the production and manufacture of different types of items would be unable to operate without the use of a source of electrical energy. Almost everything we see around us, the clothes we wear, the food we eat, the houses we live in, the paper we write on, the vehicles we drive, all need energy to be created or transformed from some natural resource to the final product. Nowadays, the electrical energy has become so important that almost in all walks of life electricity is required. For example all electrical appliances in our homes and at our workplace require electricity. All the industries and factories run on electricity.

1.1.Sources of Energy

In simple terms we can say that anything out of which usable energy can be extracted is a source of energy. There is a variety of sources that provide us energy for different purposes. You must be familiar with coal, petrol, diesel kerosene and natural gas. Similarly you must have also heard about hydroelectric power, wind mills, solar panels, biomass etc.

1.1.1. Fossil Fuels – Conventional Source of Energy

A **fossil fuel** is a fuel formed by natural processes, such as anaerobic decomposition of buried dead organisms, containing energy originating in ancient photosynthesis. Millions of years ago the remains of dead plants and animals were buried under the ground. Over the years by the action of heat from the Earth‟s core and pressure from rock and soil, these buried and decomposed organic materials have been converted into fossil fuels.. Fossil fuels contain high percentages of carbon and include petroleum, coal, and natural gas. Coal, crude oil and natural gas are common examples of fossil fuels. They are used to run the vehicles, cooking, lighting, washing, to generate electricity, for making plastics and paints etc.

Advantages	Disadvantages
• Provide a large amount of thermal energy per unit of mass • Easy to get and easy to transport • Can be used to generate electrical energy and make products, such as Plastic, paints etc.	• Nonrenewable • Burning produces smog • Burning coal releases substances that can cause acid precipitation • Risk of oil spills • High cost

1.1.2 Energy from the Atom – Nuclear Energy

Nuclear power is the use of nuclear reactions that release nuclear energy to generate heat, which most frequently is then used in steam turbines to produce electricity in a nuclear power plant. Nuclear power can be obtained from nuclear fission, nuclear decay and nuclear fusion. The atoms of a few elements such as radium and uranium act as natural source of energy. In fact atoms of these elements spontaneously undergo changes in which the nucleus of the atom disintegrates. The energy stored in the nuclei of atoms can be released by breaking a heavy nucleus such as uranium into two lighter nuclei. The splitting of the nucleus of an atom into fragments that are roughly equal in mass with the release of energy is called nuclear fission.

When a free neutron strikes a Uranium (235) nucleus at a correct speed, it gets absorbed. A Uranium (235) nucleus on absorbing a neutron becomes highly unstable and splits into nuclei of smaller atoms releasing huge amount of energy in the process. During this process, a few neutrons are also released. These neutrons split other nuclei of the Uranium (235). The reaction continues rapidly and is known as the chain reaction. In this process a large amount of energy is released. This energy is used for boiling water till it becomes steam. Steam so generated is used to drive a turbine which helps in generating electrical energy.

Advantages	Disadvantages
• Very concentrated form of energy • Power plants do not produce smog	• Produces radioactive waste • Radioactive elements arenonrenewable

1.1.3 Sun - The Ultimate Source of Energy

Solar energy is energy derived from sun in the form of solar radiation. It is hardness by either direct sources (like solar cooker, solar steam systems, solar dryer, solar cells, etc.), or indirect sources (biomass production, wind, tidal, etc.). The output of the sun is 2.8 x 10^{23} Kwy^{-1}. The energy reaching the earth is 1.5x 10^{8} Kwy^{-1}. It is used for drying, cooking, heating, generating power etc.

Advantages	Disadvantages
• Almost limitless source of energy • Does not produce air pollution	• Expensive to use for large scale energy production • Only practical in sunny areas • It is intermittent in nature

1.1.4 Wind Energy

Wind power is another alternative energy source that could be used without producing by-products that are harmful to nature. Like solar power, harnessing the wind is highly dependent on weather and location. However, it is one of the oldest and cleanest forms of energy and the most developed of the renewable energy sources. There is the potential for a large amount of energy to be produced from windmill.

Advantages	Disadvantages
• Renewable • Relatively inexpensive to generate • Does not produce air pollution	• Only practical in windy areas • Produces less energy • Wind mill is big, bulky and inconvenient to use as compared to other forms of energy

1.1.5 Biomass Energy

Organic material made from plants and animals (microorganisms). Biomass has an existing capacity of over 7,000 MW. Biomass as a fuel consists of organic matter such as industrial waste, agricultural waste, wood, and bark. Biomass can also be used indirectly, since it produces methane gas as it decays or through a modern process called gasification. Methane can produce power by burning in a boiler to create steam to drive steam turbines or through internal combustion in gas turbines and reciprocating engines.

Advantages	Disadvantages
• Renewable • Cleaner burning than oil • Abundant	• It is dispersed and land intensive source • Produces smoke • It has low energy density

1.1.6 Geothermal Energy

Geothermal energy is energy derived by tapping the heat of the earth itself like volcano, geysers, hot springs (etc.). These volcanic features are called geothermal hotspots. Basically a hotspot is an area of reduced thickness in the mantlewhich expects excess internal heat from the interior of the earth to the outer crust.The heat from these geothermal hotspots is altered in the form of steam which is usedto run a steam turbine that can generate electricity.

Advantages	Disadvantages
• Reliable • Sustainable • Environmentally friendly • Abundant Supply	• High cost of investment • Emission of greenhouse gases during extraction of heat from ground

1.1.7 Ocean Tidal and Wave energy

Tidal power or tidal energy is a form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity.

- **Wave energy**, also known as ocean energy is defined as energy harnessed from oceanic waves. As the wind blows across the surface of the ocean, it creates waves and thus they can also be referred to as energy moving across the surface of the water
- **Tides** are defined as the rise and fall of sea level caused by the gravitational pull of the moon and the sun on the Earth. They are not only limited to the oceans, but can also occur in other systems whenever a gravitational field exists.
- **Ocean thermal energy (OTE)**is the temperature differences (thermal gradients) between ocean surface waters and that of ocean depths.Energy from the sun heats the surface water of the ocean. In tropical regions, surface water can be much warmer than deep water. This temperature difference can be used to produce electricity and to desalinate ocean water

Advantages	Disadvantages
• Running cost is negligible • Continuous power supply	• Low efficiency • High installation cost

1.2 Classification of energy sources

1.2.1 Based on usability

- **Primary resources :-**Primary sources can be used directly, as they appear in the natural environment: coal, oil, natural gas and wood, nuclear fuels (uranium), the sun, the wind, tides, mountain lakes, the rivers (from which hydroelectric energy can be obtained) and the Earth heat that supplies geothermal energy.

- **Secondary resources: -** They are derived from the transformation of primary energy sources: for example petrol that derives from the treatment of crude oil and electric energy obtained from the conversion of mechanical energy (hydroelectric plants, Aeolian plants), chemical plants (thermoelectric), or nuclear (nuclear plants). Electric energy is produced by electric plants, i.e. suitable installations that can transform primary energy (non-transformed) into electric energy.

1.2.2 Based on transaction

i. **Commercial Energy:-**The energy sources that are available in the market for a definite price are known as commercial energy. By far the most important forms of commercial energy are electricity, coal and refined petroleum products.

ii. **Non Commercial Energy:-**The energy sources that are not available in the commercial market for a price are classified as non-commercial energy. Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price and used especially in rural households. These are also called traditional fuels. Non-commercial energy is often ignored in energy accounting.

1.2.3 Based on energy storage or cycling time involved

i. **Renewable energy** (inexhaustible) are mostly biomass based and are available in unlimited amount in nature. Since these can be renewed over a relatively short period of time, energy sources that are replenished more rapidly are termed as renewable. These include firewood or fuel wood from forest, petro plants, plant biomass ie. agricultural waste like animal dung, solar energy, wing energy, water energy in the form of hydro-electricity and tidal energy and geothermal energy etc.

ii. **Non-renewable energy** (exhaustible) are available in limited amount and develop over a longer period of time. As a result of unlimited use, they are likely to be exhausted one day. These include coal, mineral, natural gas and nuclear power. Coal, petroleum and natural gases are common sources of energy being organic (biotic) in this origin. They are also called fossil fuels.

1.3.4 Based on traditional use

i. **Conventional energy sources:-** The sources of energy which have been in use for a long time, e.g., coal, petroleum, natural gas and water power.They are exhaust able except water and cause pollution when used, as they emit smoke and ash.

ii. **Non-conventional energy sources:-** The resources which are yet in the process of development over the past few years. It includes solar, wind, tidal, biogas, and biomass, geothermal.They are inexhaustible, pollution free, easy to maintain and less expensive due to local use.

Lecture No. 2

Properties of different types of renewable energy sources

2.1 Renewable energy is important because of the benefits it provides

a. **Environmental Benefits**

Renewable energy technologies are clean sources of energy that have a much lower environmental impact than conventional energy technologies.

b. Energy for Our Children's Children (Sustainability)

Renewable energy will not run out. Ever, other sources ofenergy are finite and will someday be depleted.

c. Jobs and the Economy

Most renewable energy investments are spent on materials and workmanship to build and maintain the facilities, rather than on costly energy imports. Renewable energy investments are usually spent within frequently in the same state, and often in the same town. This means your energy dollars stay home to create jobs and fuel local economies, rather than going overseas.

d. Energy Security

After the oil supply disruptions of the early 1970s, our nation has increased its dependence on foreign oil supplies instead of decreasing it. This increased dependence impacts more than just our national energy policy

2.2 Availability of renewable energy resources

- Renewable Energy sources are not depleted, and it is distributed over a wide geographical area, these resources are quickly renewed through natural process
- It won‟t create any environmental pollution problems
- The main advantage of using renewable resource is it is available throughout the year
- By an one time investment we can drew energy for many decades without affecting the environment

2.3 Advantages of renewable energy

- These sources of energy are renewable and there is no danger of depletion. These recur in nature and are in-exhaustible.
- The power plants based on renewable sources of energy don‟t have any fuel cost and hence negligible running cost.
- Renewable are more site specific and are used for local processing and application. There is no need for transmission and distribution of power.
- Renewables have low energy density and more or less there is no pollution or ecological balance problem.
- Most of the devices and plants used with the renewables are simple in design and construction which are made from local materials, local skills and by local people. The use of renewable energy can help to save foreign exchange and generate local employment.
- The rural areas and remote villages can be better served with locally available renewable sources of energy. There will be huge savings from transporting fuels or transmitting electricity from long distances.

2.4 Disadvantages of renewable energy

- Low energy density of renewable sources of energy need large sizes of plant resulting in increased cost of delivered energy.
- Intermittency and lack of dependability are the main disadvantages of renewable energy sources.
- Low energy density also results in lower operating temperatures and hence low efficiencies.
- Although renewables are essentially free, there is definite cost effectiveness associated with its conversion and utilization.
- Much of the construction materials used for renewable energy devices are themselves very energy intensive.
- The low efficiency of these plants can result in large heat rejections and hence thermal pollution.
- The renewable energy plants use larger land masses.

Lecture No.3

Types of biogas plants, constructional details, biogas production and utilization-problems

3.1 Biogas

Most organic materials undergo a natural anaerobic digestion in the presence of moisture and absence of oxygen and produce biogas.The biogas so obtained is a mixture of methane (CH_4): 55-65% and Carbon dioxide (CO_2) : 30-40%. The biogas contains traces of H_2, H_2S and N_2. The calorific value of biogas ranges from 5000 to 5500 Kcal/Kg (18.8 to 26.4 MJ /m^3).

Digestion is biological process that occurs in the absence of oxygen and in the presence of anaerobic organisms at temperatures (35-70ºC) and atmospheric pressure. The container in which, this process takes place is known as digester.

3.2 Types of biogas plants

Biogas plants basically are two types

3.2.1 Floating dome type

- The floating-drum plant with a cylindrical digester (KVIC model)

3.2.2 Fixed dome type

- The fixed-dome plant with a brick reinforced, moulded dome (Janata model)
- The fixed-dome plant with a hemisphere digester (Deenbandhu model)

3.2.1 Floating dome type

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

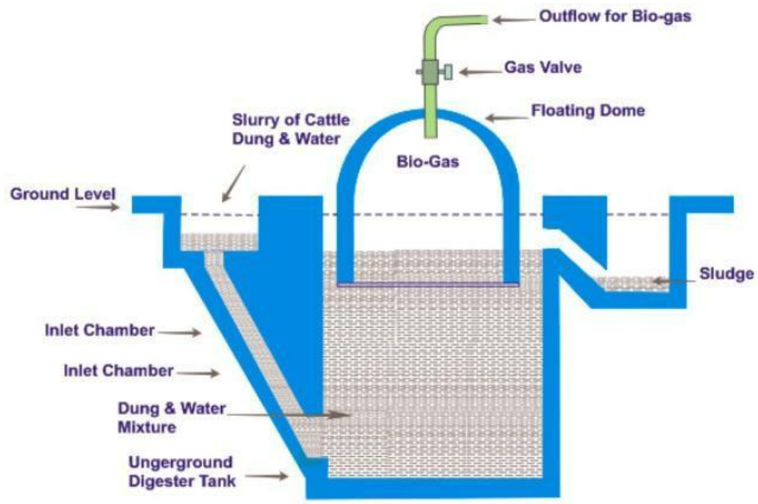


Fig 3.1 Floating dome type plant

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

Size:-Floating-drum plants are used chiefly for digesting animal and human feces on a continuous feed mode of operation, i.e. with daily input. They are used most frequently by small- to middle-sized farms (digester size: 5-15m^3) or in institutions and larger agro-industrial estates (digester size: 20-100m^3).

3.2.1.1 KVIC type biogas plant

This mainly consists of a digester or pit for fermentation and a floating drum for the collection of gas. Digester is 3.5-6.5 m in depth and 1.2 to 1.6 m in diameter. There is a partition wall in the center, which divides the digester vertically and submerges in the slurry when it is full. The digester is connected to the inlet and outlet by two pipes. Through the inlet, the dung is mixed with water (4:5) and loaded into the digester. The fermented material will flow out through outlet pipe. The outlet is generally connected to a compost pit. The gas generation takes place slowly and in two stages. In the first stage, the complex, organic substances contained in the waste are acted upon by a certain kind of bacteria, called acid formers and broken up into small-chain simple acids. In the second stage, these acids are acted upon by another kind of bacteria, called methane formers and produce methane and carbon dioxide.

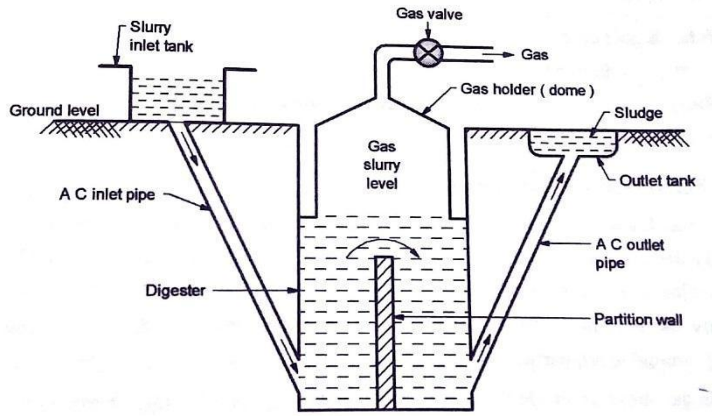


Fig 3.2 KVIC model biogas plant

Gas holder :-The gas holder is a drum constructed of mild steel sheets. This is cylindrical in shape with concave. The top is supported radically with angular iron. The holder fits into the digester like a stopper. It sinks into the slurry due to its own weight and rests upon the ring constructed for this purpose. When gas is generated the holder rises and floats freely on the surface of slurry. A central guide pipe is provided to prevent the holder from tilting. The holder also acts as a seal for the gas. The gas pressure varies between 7 and 9 cm of water column. Under shallow water table conditions, the adopted diameter of digester is more and depth is reduced. The cost of drum is about 40% of total cost of plant. It requires periodical maintenance. The unit cost of KVIC model with a capacity of 2 m^3/day costs approximately Rs.14, 000.

3.2.1.2 Advantages and Disadvantages of floating dome plants

Advantages	Disadvantages
• Simple, easily understood operation • Volume of stored gas is directly visible • The gas pressure is constant, determined by the weight of the gas holder • The construction is relatively easy, construction mistakes do not lead to	• High material costs of the steel drum • Susceptibility of steel parts to corrosion floating drum plants have a shorter life span than fixed-dome plants • Regular maintenance costs for the painting of the drum

major problems in operation and gas
yield.

3.2.2 Fixed-dome type plants

A fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank.

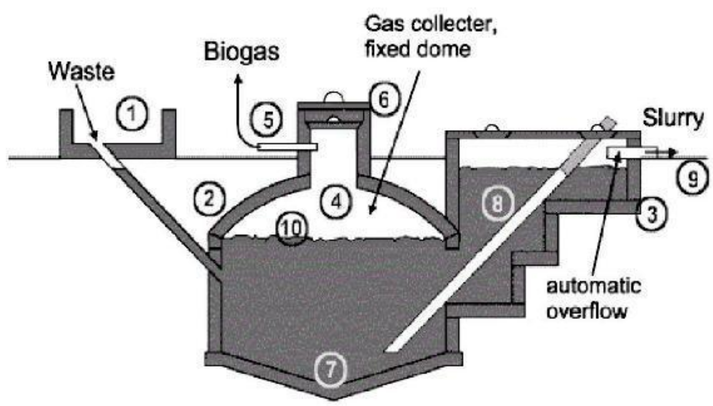


Fig 3.3 Fixed-dome type plants

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

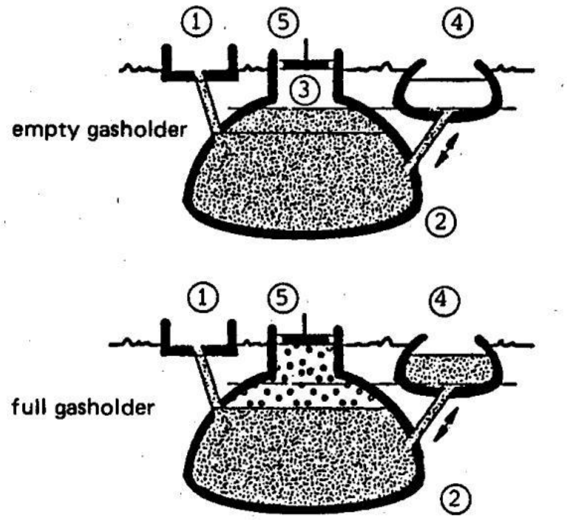


Fig 3.4 Basic function of a fixed-dome biogas plant

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

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

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

- Technical suitability (stability, gas- and liquid tightness)
- Cost-effectiveness
- Availability in the region and transport costs
- Availability of local skills for working with the particular building material.

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

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

3.2.2.1 Advantages and Disadvantages of fixed dome plants

Advantages	Disadvantages
• Low initial costs and long useful life-span • No moving or rusting parts involved • Basic design is compact, saves space and is well insulated • Construction creates local employment. • The underground construction saves space and protects the digester from temperature changes	• Masonry gas-holders require special sealants and high technical skills for gas-tight construction • Gas leaks occur quite frequently; fluctuating gas pressure complicates gas utilization • Amount of gas produced is not immediately visible, plant operation not readily understandable • Fixed dome plants need exact planning of levels; excavation can be difficult and expensive in bedrock.

3.2.3 Types of Fixed Dome Plants

3.2.3.1 Janata model

The design of this plant is of Chinese origin but it has been introduced under the name “Janata biogas plant” by Gobar Gas Research Station, Ajitmal in view of its reduced cost. This is a plant where no steel is used, there is no moving part in it and maintenance cost is low. The plant can be constructed by village mason taking some pre-explained precautions and using all the indigenously available building materials. Good quality of bricks and cement should be used to avoid the afterward structural problems like cracking of the dome and leakage of gas.

Substrates other than cattle dung such as municipal waste and plant residues can also be used in janata type plants.

The plant consists of an underground well sort of digester made of bricks and cement having a dome shaped roof which remains below the ground level is shown in Fig 3.5.At almost middle of the digester, there are two rectangular openings facing each other and coming up to a little above the ground level, act as an inlet and outlet of the plant. Dome shaped roof is fitted with a pipe at its top which is the gas outlet of the plant. The principle of gas production is same as that of KVIC model. The biogas is collected in the restricted space of the fixed dome, hence the pressure of gas is much higher, which is around 90 cm of water column.

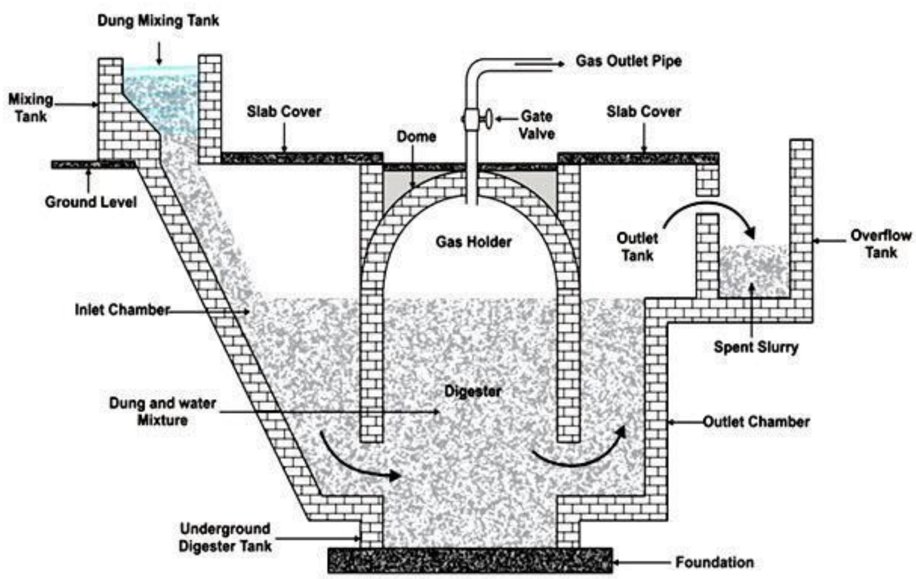


Fig 3.5Janta model biogas plant

3.2.3.2 Deenbandhu Model

Deenbandhu model biogas plant was developed by AFPRO (Action for Food Production, New Delhi) in 1984. The world Deenbandhu is meant as the friend of the poor. This plant is designed on the principle that the surface area of biogas plants is reduced (minimized) to reduce their installation cost without sacrificing the efficiency of the plant. The design consists of segments of two spheres of different diameters, joined at their bases. The structure thus formed act as the digester as fermentation chamber as well as the gas storage chamber. The higher compressive strength of the brick masonry and concrete makes it preferable to go in for a structure which could always be kept under compression. A spherical structure loaded from the convex side will be under compression and therefore, the internal load will not have any residual effect on the structure.

The digester is connected with the inlet pipe and the outlet tank. The upper part above the normal slurry level of the outlet tank is designed to accommodate the slurry to be displaced out of the digester with the generation and accumulation of biogas and is called outlet displacement chamber. The size of these plants is recommended up to 6 m^3 per day. The different components of Deenbandhu model biogas plant are show in Fig. 3.6.

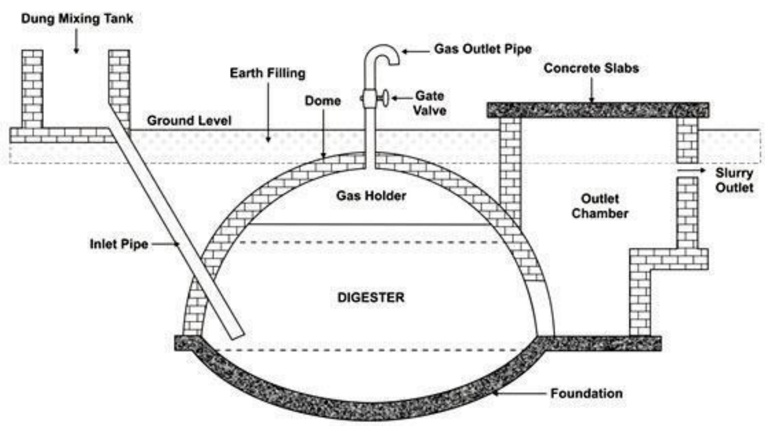


Fig 3.6 Deenbandhu model biogas plant

3.3 Comparison among KVIC, Janta and Deenbandhu biogas plants

Comparison among the above mentioned biogas plants is explained in Table 3.1

Table 3.1 Comparison between KVIC, Janata and Deenbandhu biogas plants

KVIC	Janata	Deenbandhu
The digester of this plant is a deep well shaped masonry structure. In plants of above 3m^3capacity a partition wall is provided in middle of the digester	Digester of this plant is a shallow well shaped masonry structure, No partition wall is provided	Digester is made of segments of two spheres: one for the bottom and other for the top

Gas holder is generally made of mild steel. It is inverted into the digester and goes up and down with formation and utilization of gas	Gas holder is an integral part of the masonry structure of the plant. Slurry from the gas storage portion is displaced out with the formation of gas and comes back when it is used	The structure described above includes digester and the gas storage chamber. Gas is stored in the same way as in the case of Janata plants
The gas is available at a constant pressure of about 10 cm of water column	Gas pressure varies from 0 to 90 cm of water column	Gas pressure varies from 0 to 75 cm of water column
Inlet and outlet connections are provided through A.C pipes	Inlet and outlet tanks are large masonry structures designed to store the slurry displaced out of the digester with the formation of gas	Inlet connection is through A.C pipe. Outlet tank is a large masonry tank designed to store slurry displaced out of the digester with the formation of gas
Gas storage capacity of the plant is governed by the volume of gas holder and is 50% of gas produced per day	It is the combined volume of inlet and outlet displacement chambers and is 50% of gas produced per day	It is the volume of outlet displacement chamber and is 33% of gas produced per day
The floating mild steel gas holder needs regular care and maintenance to prevent the gas holder from getting worn out because of corrosion. It also has short life span.	There is no moving part and hence no recurring expenditure. It also has long working life	There is no moving part and hence no recurring expenditure. It also has a long working life
Installation cost is very high	It is cheaper than the KVIC type plants	It is much cheaper than KVIC and Janata type plants

Digester can be constructed locally but the gasholder needs sophisticated workshop facilities	Entire plant can be built by a trained mason using locally available materials	Entire plant can be built by a trained mason using locally available material

3.4 Design procedure for a biogas digester

A biogas plant may be designed based on the energy requirement or on the feed material available. Generally standard designs are available for the common biogas plant designs. However, it is advisable to understand the basic procedure.

The following example shows the design for cooking requirement for a medium family.

Gas requirement Gas required for cooking for 6 people	=	6 X 0.30 (@ 0.30 m^3 / day / person)
	=	1.8 m^3/day
	=	~ 2 m^3/day
Cow dung requirement		
1 kg of wet cow dung yields	=	0.035 m^3
	=	= 2.0/0.035
	=	57 kg
	=	60 kg
Average cow dung yield from 1 cattle	=	12 kg (wet)
So, number of animals required	=	60/12
	=	5 animals
Digester dimensions		
Amount of slurry fed (1:1 ratio of slurry: water)	=	60+60 litre/day
	=	120 litres/day
(Sp. Gravity of slurry is assumed to be 1.0)	=	0.12 m^3/day

The plant can also be designed as per the dung availability. If 5 cows are available, Then,

Dung production per cow	=	12 kg/day
Total dung production	=	12 * 5 = 60 kg
Assuming Sp. Gravity as 1, volume	=	60 litre
Daily slurry volume by mixing with water	=	120 litres/day
Retention time	=	35 days
Volume of the digester required	=	0.12 * 35
Using a ratio of 1 to 1.1 for height to diameter,	=	4.2 m^3

$$\pi D2 * (1.1D) / 4 = 4.2\ m^3$$

Diameter D can be found from the above relation

Design of gas holder

Gas produced daily = 2 m^3

It is assumed that the gas produced during the night is used up for cooking the breakfast and lunch in the morning. The gas produced in the day time after the morning cooking is used for cooking dinner in the evening. So the storage requirement is only 50% of daily gas production.

Gas to be stored = 1 m^3

Diameter of he gas holder will be slightly less than the diameter of he digester so as to ensure its free movement.

$$\pi D2 * H / 4 = 1\ m^3$$

We can find the height of gas holder, H from the above relation ship

3.5 Utilization of biogas

Biogas generated from anaerobic digestion processes is a clean and environmentally friendly renewable fuel. But it is important to clean, or upgrade, biogas before using it to increase its heating value and to make it useable in some gas appliances such as engines and boilers. Biogas can potentially be used in many types of equipment, including:

- Internal Combustion (Piston) Engine – Electrical Power Generation, Shaft Power
- Gas Turbine Engine (Large) – Electrical Power Generation, Shaft Power
- Microturbine Engine (Small) – Electrical Power Generation
- Stirling Heat Engine – Electrical Power Generation
- Boiler (Steam) Systems

- Hot Water Systems
- Process Heaters (Furnaces)
- Space or Air Heaters
- Gas Fired Chiller - Refrigeration
- Absorption Chiller - Refrigeration
- Combined Heat and Power (CHP) - Large and Small Scale – Electrical Power and Heat
- Fuel Cells – Electrical Power, Some Heat

There are a variety of end uses for biogas. Except for the simplest thermal uses such as odor flaring or some types of heating, biogas needs to be cleaned or processed prior to use. With appropriate cleaning or upgrade, biogas can be used in all applications that were developed for natural gas. The three basic end uses for biogas are:

a. Production of heat or steam

The most straightforward use of biogas is for thermal (heat) energy. In areas where fuels are scarce, small biogas systems can provide the heat energy for basic cooking and water heating. Gas lighting systems can also use biogas for illumination. Conventional gas burners are easily adjusted for biogas by simply changing the air-to-gas ratio. The demand for biogas quality in gas burners is low, only requiring a gas pressure of 8 to 25 mbar and maintaining H2S levels to below 100 ppm to achieve a dew point of 150 degrees C.

b. Electricity Generation or Combined Heat and Power (CHP)

Combined heat and power systems use both the power producing ability of a fuel and the inevitable waste heat. Some CHP systems produce primarily heat, and electrical power is secondary (bottoming cycle). Other CHP systems produce primarily electrical power and the waste heat is used to heat process water (topping cycle). In either case, the overall (combined) efficiency of the power and heat produced and used gives a much higher efficiency than using the fuel (biogas) to produce only power or heat. Other than high initial investments, gas turbines (micro-turbines, 25-100 kW; large turbines, >100 kW) with comparable efficiencies to spark-ignition engines and low maintenance can be used for production of both heat and power. However, internal combustion engines are most cmmonly used in CHP applications. The use of biogas in these systems requires removal of both H2S (to below 100 ppm) and water vapor.

c. Vehicle fuel

Gasoline vehicles can use biogas as a fuel provided the biogas is upgraded to natural gas quality in vehicles that have been adjusted to using natural gas. Most vehicles in this category have been retro-fitted with a gas tank and a gas supply system in addition to the normal petrol fuel system. However, dedicated vehicles (using only biogas) are more efficient than these retro-fits.

Lecture No.4

Agricultural wastes, principles of combustion, pyrolysis and gasification

4.1 Biomass

Plant matter created by the process of photosynthesis is called biomass (or) all organic materials such as plants, trees and crops are potential sources of energy and are collectively called biomass.The term biomass is also generally understood to include human waste, and organic fractions of sewage sludge, industrial effluents and household wastes. The biomass sources are highly dispersed and bulky and contain large amounts of water (50 to 90%). Thus, it is not economical to transport them over long distances, and conversion into usable energy must takes place close to source, which is limited to particular regions.

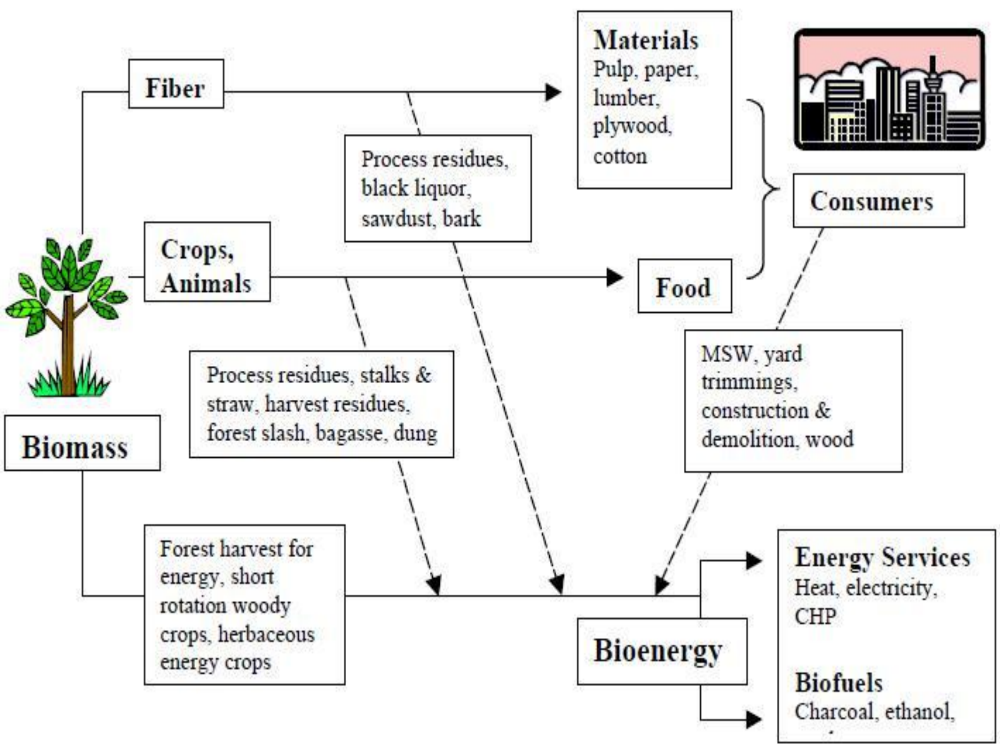


Fig. 4.1 Schematic diagram of utilization of biomass

4.1.2 Biomass Conversion

Biomass can either be utilized directly as a fuel, or can be converted into liquid or gaseous fuels, which can also be as feedstock for industries. Most biomass in dry state can be burned directly to produce heat, steam or electricity. On the other hand biological conversion technologies utilize natural anaerobic decay processes to produce high quality fuels from biomass. Various possible conversion technologies for getting different products from biomass is broadly classified into three groupsviz. (i) thermo-chemical conversion, (ii) bio-chemical conversion and (iii) oil extraction.

Thermo-chemical conversion includes processes like combustion, gasification and pyrolysis. Combustion refers to the conversion of biomass to heat and power by directly burning it, as occurs in boilers. Gasification is the process of converting solid biomass with a limited quantity of air into producer gas, while pyrolysis is the thermal decomposition of biomass in the absence of oxygen. The products of pyrolysis are charcoal, condensable liquid and gaseous products.

Combustion, gasification and pyrolysis are all thermochemical processes to convert biomass into energy. In all of them, the biomass is heated to evaporate water and then to cause pyrolysis to occur and to produce volatiles.

Thermal conversion processes for biomass involve some or all of the following processes:

Pyrolysis: Biomass +heat → charcoal , gas and oil

Gasification: Biomass +limited oxygen → fuel gas

Combustion: Biomass +stoichiometric O_2 → hot combustion products

4.1.3 Combustion

Combustion is a process whereby the total or partial oxidation of carbon and hydrogen converts the chemical energy of biomass into heat. This complex chemical reaction can be briefly described as follows:

Burning fuel = Products from reaction + heat

During the combustion process, organic matter decomposes in phases, i.e. drying, pyrolysis/gasification, ignition of volatile substances and charcoal combustion. Generally speaking, these phases correspond to two reaction times: release of volatile substances and respective combustion, followed by charcoal combustion.

Wood, agricultural residues, wood pulping liquor, municipal solid waste (MSW) and refuse derived fuel are examples of feed stocks for combustion. Combustion requires high temperatures for ignition, sufficient turbulence to mix all of the components with the oxidant, and time to complete all of the oxidation reactions. The moisture content of the feedstock should be low and pre-drying may be necessary in some cases.

Biomass combustion starts by heating and drying the feedstock. After all of the moisture has been removed, temperature rises for pyrolysis to occur in the absence of oxygen. The major products are hydrogen, CO, CO_2, CH_4 and other hydrocarbons. In the end, char and volatile gases are formed and they continue to react independently. The volatile gases need oxygen in order to achieve a complete flame combustion. Mostly CO_2 and H_2O result from complete combustion. When combusting biomass in a furnace, hot gases are released. They contain about 85% of the fuel‟s potential energy. The heat can be used either directly or indirectly through a heat exchanger, in the form of hot air or water. Boiler used for biomass combusting transfers the produced heat into steam. The steam can be used for producing electricity, mechanical energy or heat.

4.1.4 Gasification

Gasification is a process whereby organic matter decomposes through thermal reactions, in the presence of stoichiometric amounts of oxidising agents. The process generates a combustible gas mix, essentially composed of carbon monoxide, hydrogen, carbon dioxide, methane, steam and, though in smaller proportions, other heavier hydrocarbons and tars. The process is aimed at converting the energy potential of a solid fuel into a gas product, whose energy content has the form of chemical energy with the capacity to generate work.

Gasification is carried out in two steps. First, the biomass is heated to around 600 degrees. The volatile components, such as hydrocarbon gases, hydrogen, CO, CO_2, H_2O and tar, vaporize by various reactions. The remaining by-products are char and ash. For this first endothermic step, oxygen is not required. In the second step, char is gasified by reactions with oxygen, steam and hydrogen in high temperatures. The endothermic reactions require heat, which is applied by combusting some of the unburned char. Main products of gasification are synthesis gas, char and tars. The content depends on the feedstock, oxidizing agent and the conditions of the process. The gas mainly consists of CO, CO_4, H_2O, CH_4 and other hydrocarbons. The synthesis gas can be utilized for heating or electricity production. It can also be used for the production of ethanol, diesel and chemical feed stocks.

4.1.5 Pyrolysis

In pyrolysis, biomass is heated in the absence of air. The process results liquid, solid and gaseous fractions, mainly gases, bio-oil and char. The gases and the bio-oil are from the volatile fraction of biomass, while the char is mostly the fixed carbon component. In the first step, temperature is increased to start the primary pyrolysis reactions. As a result, volatiles are released and char is formed. Finally, after various reactions, pyrolysis gas is formed. The main product of slow pyrolysis, a thousands of years old process, is char or charcoal. In slow pyrolysis biomass is heated to around 500 degrees for 5 to 30min.Fast pyrolysis results mainly in bio-oil. The biomass is heated in the absence of oxygen and the residence time is 0, 5 to 5s. Vapours, aerosols and char are generated through decomposition. After cooling, bio-oil is formed. The remaining non condensable gases can be used as a source of energy for the pyrolysis reactor. Calculated by weight, fast pyrolysis results in 60%-75% liquid bio-oil, 15%-25% solid char, and 10%-20% non-condensable gases.

Table 4.1 Comparison between pyrolysis, combustion and gasification

Process	Pyrolysis	Combustion	Gasification
Main products	oil, tar (liquid/vapour), CO_2,H_2O, combustible gas(es)as:CO,H_2, CH_4 and char	heat, flue gas and gases as: CO_2, H_2O, N_2.	gases as: CO_2, H_2O and N_2) in case air was thegasifying agent),heat, tar and combustiblegas as: CO, H_2 and CH_4
Carbon conversion, %	≈75	>99	80-95
Oxygen stoichiometry	nil	>1, typically 1.3 for solid fuels.	0-1, typically 0.2-0.4.
Chemical reactivity of main product	reactive, combustible	non-reactive	stable, combustible.

Physical existence	Solid, liquid and gas	gas	gas
High heating value (HHV), MJ/kg	16-19	nil	5-20
Oxidant	non	air	air, pure oxygen, steam or their combinations
Operating temperature, °C	500-800	850-1200	550-900 with air gasification. 1000-1600 with other gasifying agents
Operating pressure	higher than or atmospheric	atmospheric	atmospheric
Pollutants	particulates, tars and compounds of chloride, nitrogen and sulfur	particulates and compounds of chloride, nitrogen and sulfur	particulates, tars and compounds of chloride, nitrogen and sulfur

Lecture No.5

Types of gasifiers, producer gas and its utilization

5.1 Gasifiers

Gasification of wood and other agricultural cellulosic residues was a common practice at the beginning of this century to produce low calorie fuel gas. Gasifiers can be suitably used for thermal decomposition of a wide range of feed materials from forestry products, agricultural residues, and aquatic biomass to municipal solid wastes.

However, some important points which should be taken into consideration while undertaking any biomass gasification system:

- A gasifier itself is of little use. It is used either to generate a combustible gas to provide heat or to generate a fuel gas which can be used in an internal combustion engine as a petroleum oil substitute.
- Some of the gaseous, liquid and solid products of combustion are not only harmful to engines and burners, but also to human beings. That is why these gases are not used as cooking gas.
- A gasifier must have an effective gas cleaning train if the gas is to be used for internal combustion engines. A maximum limit of 5-15 mg solids and tar per kg of gas may be allowed for the use of the gas in an internal combustion engine.
- A gasification system may not be of much advantage to generate a combustible gas, as far as fossil fuel savings, economies and ease of operation are concerned.

5.1.1 Types of gasifiers

`Gasifiers are generally classified on the basis of the physical conditions of the feed stocks in the reactors. The gasifiers may be grouped into the following types:

(a) Dense phase reactors

(b) Lean phase reactors

(a) Dense phase reactors

In dense phase reactors, the feedstock fills most of the space in the reactor. They are common, available in different designs depending upon the operating conditions, and are of three types: downdraft, updraft, and cross-draft.

i) Downdraft or co-current gasifiers

The downdraft (also known as co-current) gasifier is the most common type of gasifier. In downdraft gasifiers, the pyrolysis zone is above the combustion zone and the reduction zone is below the combustion zone. Fuel is fed from the top. The flow of air and gas is downwards (hence the name) through the combustion and reduction zones. The term co-current is used because air moves in the same direction as that of fuel, downwards. A downdraft gasifier is so designed that tar, which is produced in the pyrolysis zone, travels through the combustion zone, where it is broken down or burnt. As a result, the mixture of gases in the exit stream is relatively clean. The position of the combustion zone is thus a critical element in the downdraft gasifier, its main advantage being that it produces gas with low tar content, which is suitable for gas engines.

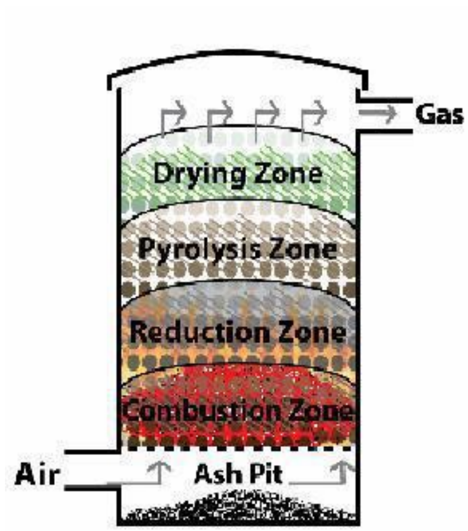


Fig. 5.1 Downdraft gasifier

ii) Updraft or counter-current gasifier

In updraft gasifiers (also known as counter-current), air enters from below the grate and flows upwards, whereas the fuel flows downwards. An updraft gasifier has distinctly defined zones for partial combustion, reduction, pyrolysis, and drying. The gas produced in the reduction zone leaves the gasifier reactor together with the products of pyrolysis from the pyrolysis zone and steam from the drying zone. The resulting combustible producer gas is rich in hydrocarbons (tars) and, therefore, has a higher calorific value, which makes updraft gasifiers more suitable where heat is needed, for example in industrial furnaces. The producer gas needs to be thoroughly cleaned if it is to be used for generating electricity.

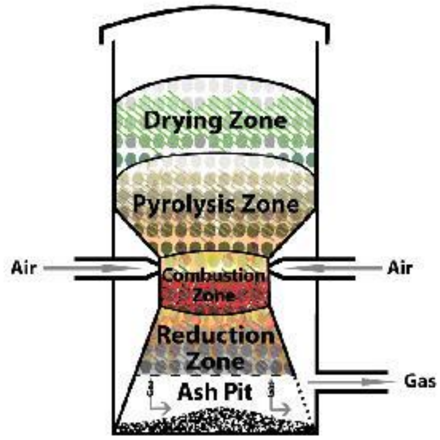


Fig 5.2 Up-draft gasifier

iii) Cross-draft gasifier

In a cross-draft gasifier, air enters from one side of the gasifier reactor and leaves from the other. Cross-draft gasifiers have a few distinct advantages such as compact construction and low cleaning requirements. Also, cross-draft gasifiers do not need a grate; the ash falls to the bottom and does not come in the way of normal operation.

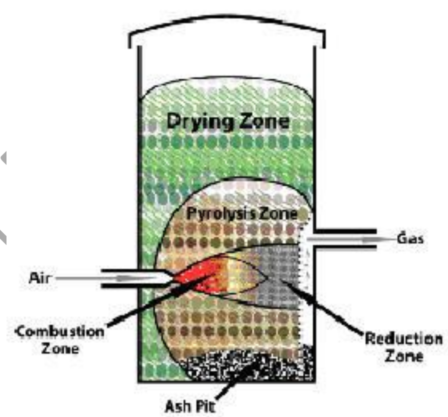


Fig. 5.3 Cross-draft gasifier

b) Lean phase reactors

Lean phase gasifiers lack separate zones for different reactions. All reactions – drying,combustion, pyrolysis, and reduction – occur in one large reactor chamber. Lean phase reactors are mostly of two types, fluidized bed gasifiers and entrained-flow gasifiers.

i) Fluidized bed gasifiers

In fluidized bed gasifiers, the biomass is brought into an inert bed of fluidized material (e.g. sand, char, etc.). The fuel is fed into the fluidized system either above-bed or directly into the bed, depending upon the size and density of the fuel and how it is affected by the bed velocities. During normal operation, the bed media is maintained at a temperature between 550 °C and 1000 °C. When the fuel is introduced under such temperature conditions, its drying and pyrolyzing reactions proceed rapidly, driving off all gaseous portions of the fuel at relatively low temperatures. The remaining char is oxidized within the bed to provide the heat source for the drying and devolatilizing reactions to continue. Fluidized bed gasifiers are better than dense phase reactors in that they produce more heat in short time due to the abrasion phenomenon between inert bed material and biomass, giving a uniformly high (800–1000 °C) bed temperature. A fluidized bed gasifier works as a hot bed of sand particles agitated constantly by air. Air is distributed through nozzles located at the bottom of the bed.

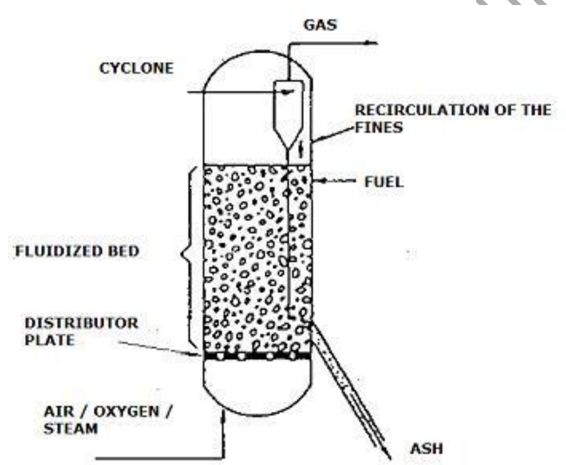


Fig. 5.4 Fluidized bed gasifiers

ii) Entrained-flow gasifiers

In entrained-flow gasifiers, fuel and air are introduced from the top of the reactor, and fuel is carried by the air in the reactor. The operating temperatures are 1200–1600 °C and the pressure is 20–80 bar. Entrained-flow gasifiers can be used for any type of fuel so long as it is dry (low moisture) and has low ash content. Due to the short residence time (0.5–4.0 seconds), high temperatures are required for such gasifiers. The advantage of entrained-flow gasifiers is that the gas contains very little tar.

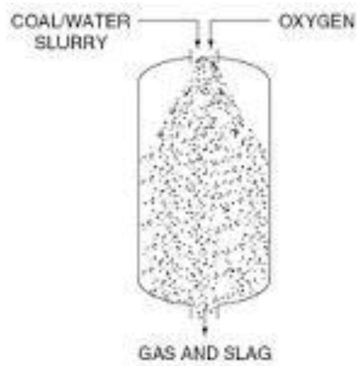


Fig. 5.5 Entrained-flow gasifiers

Some of the advantages and disadvantages of different types of gasifiers are shown in Table 5.1.

Table 5.1 Advantages and disadvantages of different gasifier types

Gasifier	Advantages	Disadvantages
Updraft	Simple design	Simple design
	High amount of tar and pyrolysis	High amount of tar and pyrolysis
	High fuel to gas conversion efficiency	
	Accepts fuels with higher moisture content	
	Accepts fuels of different sizes	
Downdraft	Low tar Limited scale-up	Limited scale-up
	Best option for usage in gas engines	At low temperatures, more tar produced
		High amounts of ash and dust
		Fuel requirements are strict
Cross-draft	Applicable for small-scale operations	High amount of tar produced
	Due to high temperatures, gas cleaning requirements are low	
Fluidized bed	Compact construction	Gas stream contains fine particles ofdust
	Uniform temperature profile	Complex system due to low biomass hold up in the fuel bed

	Accepts fuel size variation	Variety of biomass can be used but fuel flexibility is applicable for biomass of 0.1 cm to 1 cm size
	High ash melting point of biomass does not lead to clinker formation	
Entrained-flow	Applicable to large systems	High investment
	Short residence time for biomass	Strict fuel requirements

5.2 Producer gas applications

The producer gas obtained can be used either to produce heat or to generate electricity.

5.2.1 Thermal applications

Producer gas can also be burnt directly in open air, much like Liquid Petroleum Gas (LPG), and therefore can be used for cooking, boiling water, producing steam, and drying food and other materials.

- **Dryer:** The hot gas after combustion can be mixed with the right quantity of secondary air to lower its temperature to the desired level for use in dryers in the industries such as tea drying, cardamom drying etc.
- **Kilns**: Firing of tiles, pottery articles, limestone and refractories, where temperatures of 800–950 °C are required.
- **Boilers**: Producer gas can be used as fuel in boilers to produce steam or hot water.

5.2.2 Power applications

Producer gas can be used for generating motive power to run either dual-fuel engines (which run on a mixture of gas and diesel, with gas replacement of up to 85% of diesel) or engines that run on producer gas alone (100% diesel replacement). In general, the fuel-to electricity efficiency of gasification is much higher than that of direct combustion: The conversion efficiency of gasification is 35%–45% whereas that of combustion is only 10%–20%. Generated electricity can be fed into the grid or can be used for farm operations, irrigation, chilling or cold storage, and other commercial and industrial applications.

5.2.3 Conditions and requirements for implementation

Biomass gasifier needs uniform-sized and dry fuel for smooth and trouble-free operation. Most gasifier systems are designed either for woody biomass (or dense briquettes made from loose biomass) or for loose, pulverized biomass.

Woody biomass:

- Pieces smaller than 5–10 cm (2–4 inches) in any dimension, depending on design
- Bulk density of wood or briquettes: less than 250–300 kg/m^3

Loose biomass:

- Pulverized biomass, depending on design
- Moisture content up to 15%–25%, depending on gasifier design
- Ash content below 5% preferred; with a maximum limit of 20%
- Bulk density of loose biomass is less than 150 kg/m^3

Lecture No.6

Briquettes, types of briquetting, uses of briquettes, shredders

6.1 Briquetting

It is the process of compaction of residues into a product of higher density than the original raw materials. It is also known as densification. The handling characteristics of material for packaging, transportation and storage are also improved. If produced at low cost and made conveniently accessible to consumers, briquettes could serve as compliments to firewood and charcoal for domestic cooking and agro-industrial operations, thereby reducing the high demand for both. Besides, briquettes have advantages over fuel wood in terms of greater heat intensity, cleaningness, convenience in use and relatively smaller space requirement for storage. The briquettes are normally cylindrical or rectangular in shape.

6.1.1 Types of Briquetting

On the basis of compaction, the briquetting technologies can be divided into: High pressure compaction, medium pressure compaction with a heating device and low pressure compaction with a binder.

At present, there are two high-pressure technologies: Piston press and screw extrusion machines used for briquetting. The briquetting produced by a piston press are completely solid, while screw press briquettes have a concentric hole, which gives better combustion characteristics due to a larger specific area. The screw press briquettes are also homogenous and do not disintegrate easily. Having a high combustion rate, these can substitute for coal in most applications and in boilers. Briquettes can be produced with a density of 1200 Kg/m^3 from loose biomass of bulk density 100 to 200 Kg/m^3 . A higher density gives the briquette a higher heat value (KJ/Kg), and makes the briquettes burn more slowly as compared to the raw materials from which the briquettes are made.

6.1.2Process of briquetting

Briquetting is a technological method of compressing and densifying the bulky raw material, thereby reducing its volume-weight ratio and making it usable for various purposes. The vital requirement of briquette formation from woody biomass is the destruction of the elasticity of the wood, which could be done either by previous heat treatment or by a high pressure or by a combination of both. There are two processes of briquetting biomass, namely direct compaction and compaction after pyrolysis or carbonization as mentioned below:

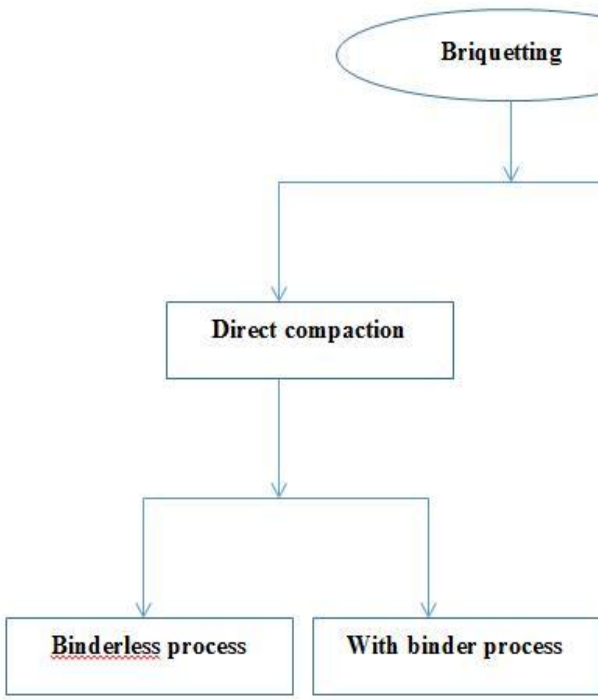


Fig. 6.1Process of briquetting

a) Direct compaction

There are two technologies for the manufacture of briquettes by directly compacting the biomass without previous heat treatment.

(i) Binderless process : The process involves two steps

- **Semi-fluidizing the biomass***:* Biomass is semi-fluidized through the application of high pressure in the range of 1200 – 2000 kg/cm^2, at which conditioned biomass gets heated to a temperature of about 182°C and the lignin present in biomass begins to flow and act as binder, provides mechanical support and repels water.

- **Extracting the densified material:** The semi-fluidized biomass is densified through electrically operated briquetting machines available in the range of 100-300 kg/h, the cost of such briquetting units depend upon its capacity and is in between Rs. 3 lakh to 20 lakhs.

(ii) With binder process: In this process, the biomass requires addition of some external binding materials like molasses, dung slurry, lignasulphonate, sodium silicate etc. The briquetting machines operate at lower pressure range of 500-1000 kg/cm^2 and are powered by electricity. Such machines are available in the capacity range of 100 to 400 kg/h.

b)Pyrolysis / carbonization and extrusion

The elasticity of biomass could be destroyed by previous heat treatment of the biomass. Pyrolysis is the process of destructive distillation of organic materials heated at slow rate at about 270°C in the absence or minimum presence of oxygen. During process of pyrolysis, solid char, liquid tar and combustible gases besides organic liquids are produced. The nature and quantum of these products depend on various factors such as composition of biomass, residence time in kiln and temperature. During the pyrolysis, the fibre content of biomass is broken, which later facilitates in briquetting of produced charcoal. The charcoal is briquetted through extrusion or compaction process.

6.2 Briquettes

Fuel briquettes are essentially a compressed block of organic waste materials used for domestic cooking and heating. The final end product of briquetting process is known as a briquette. Briquettes are made from raw materials that are compacted into a mould. Briquette could be made of different shapes and sizes depending on the mould. The appearance, burning characteristics of briquettes depend on the type of feedstock and the level of compactness and the mould used. But in general, briquettes have better physical properties and combustion rate than the initial waste. Production of briquette charcoal helps to ease the pressure on the forest reserve, there by solving the deforestation problem.

6.2.1 Applications of Briquettes

Briquettes have many numerous uses which include both domestic and small industrial cottage applications. They are often used as a development intervention to replace firewood, charcoal, or other solid fuels. This is because with the current fuel shortage and ever rising prices, consumers are looking for affordable alternative fuels and briquettes fill this gap for:

• Cooking and water heating in households

• Heating productive processes such as tobacco curing, fruits, tea drying, poultry rearing etc.

• Firing ceramics and clay wares such as improved cook stoves, pottery, bricks etc.

• Fuel for gasifiers to generate electricity

• Powering boilers to generate steam.

6.2.2 Advantages of Briquetting Process

- The process helps to solve the problem of loose waste / residues of agricultural forestry and agro-industrial processing so as to check environmental pollution.
- The process increases the net calorific value per unit volume.
- The fuel produced is uniform in size and quality. No toxic gas and sulphur emission, even no odour during combustion.
- Densified product is easy to transport and store. Bulk density of briquettes (1000 kg $/m^3$) is higher than agro-wastes (50 kg $/m^3$).
- Fire risk in loose storage of biomass is minimized.
- The process produces high quality fuel with very low ash content (2-5 %) compared to 30-40% in case of coal.
- The briquettes are easy to burn, as briquettes have lower ignition temperature compared to coal.
- It produces gas during burning which accelerates burning efficiencies and inhales Co_2 and releases oxygen to the atmosphere

6.2.3 Limitations of Briquetting Process

- Briquettes can only be used as solid fuels. They have no application as liquid fuel such as the one being used in internal combustion engines.

- The second major problem identified with the briquetting process is the life of the screw, where dies screw is used. Usually the screw wears out within 3-4 hours and becomes unusable.
- Repairing of the screw causes interruption in the work and also one screw cannot be repaired more than 10 times Therefore, the cost of screw and its repair are one of the major barriers to further dissemination of briquetting technology.
- Briquettes cannot withstand direct contact with water, so a covered storage facility is required. The maximum attainable temperature is 1000^{o}C due to their low carbon content. However, this temperature is more than adequate for cooking purpose, but may not be sufficient for industrial applications.
- The burning capacity per unit volume is low compared to coal, so a larger storage area is required.

6.3 Shredders

Shredders are used to reduce biomass volume and make it convenient for handling, transport and storage. This machine uses high speed rotating flails to shred material.

6.3.1 Types of densification processes

- **Briquetting:** Where biomass is compacted between rollers with cavities producing egg-shaped briquettes (product 1-4 cm size).
- **Pelleting:** Where biomass is forced through the holes in a die-plate by pressure rolls (product 0.5- 1 cm size).
- **Cutting:** A modified form of pelleting (product 2 -5 cm size).
- **Extruding**: Where biomass is forced through the holes using a screw (2 -10 cm dia).
- **Rolling / Compressing**: Where biomass is wrapped round a rotating shaft which produces a high density roll or log (Where biomass is forced through the holes in a die-plate by pressure rolls (product 10 -18 cm dia).

Lecture No. 7

Solar energy, solar flat plate and focussing plate collectors

7.1 Solar Energy

The Earth receives around 170,000 terawatts of solar energy continuously, which is roughly 10,000 times what is needed to power the world. Every day, the sun radiates an enormous amount of energy. This energy comes from within the sun itself. Like most stars, the sun is a big gas ball made mostly of hydrogen and helium. The sun produces energy in a process called nuclear fusion. The high pressure and temperature in the sun‟s core cause hydrogen atoms to split apart. Four hydrogen nuclei combine or fuse, to form one helium atom, producing radiant energy in the process.

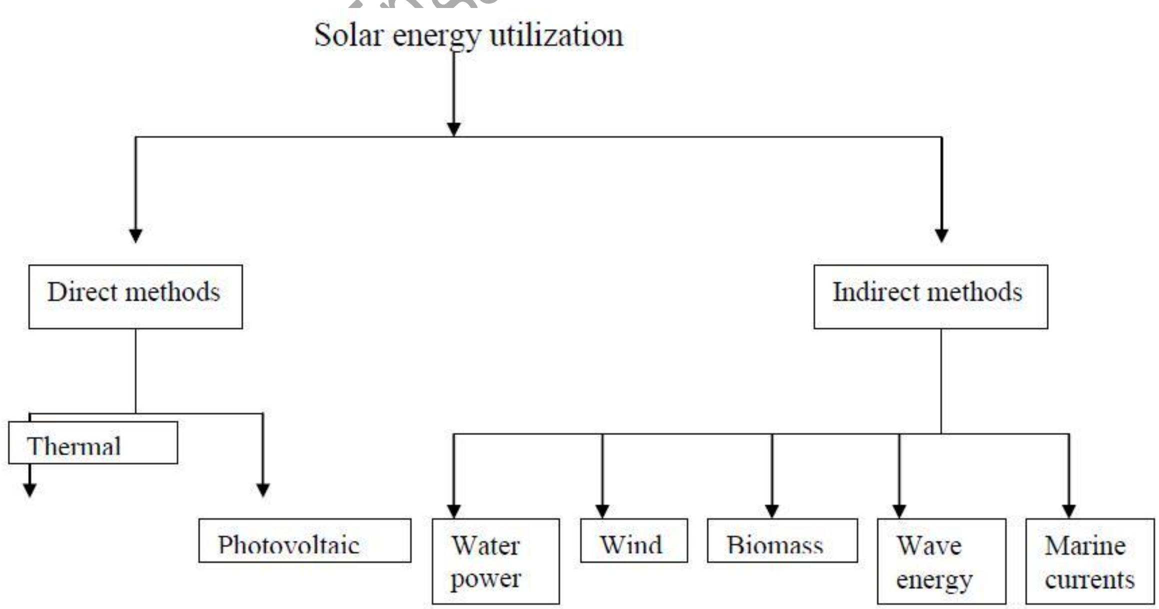
The sun radiates more energy in one second than the world has used since time began. Only a small portion of this energy strikes the earth, one part in two billion. Yet this amount of energy is enough to meet the world‟s needs, if it could be harnessed. About 15 percent of the radiant energy that reaches the earth is reflected back into space. Another 30 percent is used to evaporate water, which is lifted into the atmosphere and produces rainfall. The radiant energy is also absorbed by plants, landmasses and the oceans.

Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximtely1.8×1011 MW which is many thousand times larger than the present consumption rate on the earth of all commercial energy sources. Thus, in principle, solar energy could supply all the present and future energy needs of the world on a continuing basis. This makes it one of the most promising of the unconventional energy sources. The advantages of solar energy are (i) environmentally clean source of energy and (ii) freely available in adequate quantities in almost all parts of the world where people live. The main problems associated with solar energy are: (i) dilute source of energy and (ii) availability varies widely with time. India, being tropical country receives solar insolation in the order of 1650-2100 kwh/m^2/year for nearly 250-300 days. Solar energy can be used directly or indirectly.

7.2 Applications of solar energy

- Heating and Cooling of buildings
- Solar water and air heating
- Salt production by evaporation of seawater
- Solar distillation
- Solar drying of agricultural products
- Solar cookers
- Solar water pumping
- Solar refrigeration
- Electricity generation through Photo voltaic cells
- Solar furnaces
- Industrial process heat
- Solar thermal power generation

7.3 Classification of methods for solar energy utilization



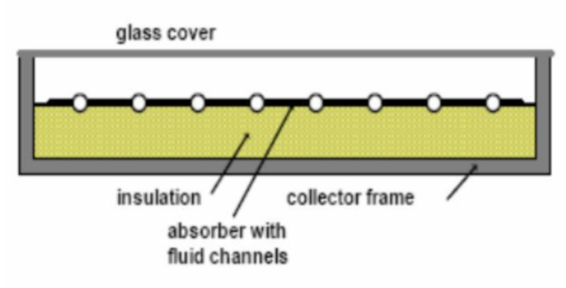
7.4 Solar energy collectors

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days. There are basically two types of solar collectors: nonconcentrating or stationary and concentrating. A nonconcentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun‟s beam radiation to a smaller receiving area, thereby increasing the radiation flux.

7.4.1 Flat plate collectors (FPC)

A typical flat-plate solar collector is shown in Fig.7.1.The flat plate collector mainly consist of a casing, absorber plate, transparent glass covers, insulating material and fluid passage tubes .When solar radiation passes through a transparent cover and impinges on the blackened absorber surface of high absorptivity, a large portion of this energy is absorbed by the plate and then transferred to the transport medium in the fluid tubes to be carried away for storage or use. The underside of the absorber plate and the side of casing are well insulated to reduce conduction losses. The liquid tubes can be welded to the absorbing plate, or they can be an integral part of the plate. The liquid tubes are connected at both ends by large diameter header tubes. The transparent cover is used to reduce convection losses from the absorber plate through the restraint of the stagnant air layer between the absorber plate and the glass. It also reduces radiation losses from the collector as the glass is transparent to the short wave radiation received by the sun but it is nearly opaque to long-wave thermal radiation emitted by the absorber plate (greenhouse effect).The absorber is usually a sheet of high-thermal conductivity metal such as copper or aluminum, with tubes either integral or attached. Its surface is coated to maximize radiant energy absorption and to minimize radiant emission. The insulated box reduces heat loss from the back or the sides of the collector.

FPC are usually permanently fixed in position and require no tracking of the sun. Flat-plate collectors are the most widely used kind of collectors in the world for domestic water-heating systems and solar space heating/cooling.



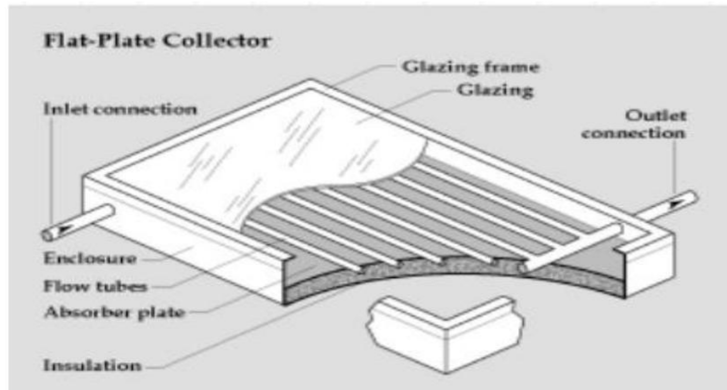


Fig.7.1. Flat plate collector

7.4.2 Centrating collectors (Focussing plate collectors)

For applications such as air conditioning, central power generation, and numerous industrial heat requirements, flat plate collectors generally cannot provide carrier fluids at temperatures sufficiently elevated to be effective. They may be used as first-stage heat input devices; the temperature of the carrier fluid is then boosted by other conventional heating means. Alternatively, more complex and expensive concentrating collectors can be used. These are devices that optically reflect and focus incident solar energy onto a small receiving area. As a result of this concentration, the intensity of the solar energy is magnified, and the temperatures that can be achieved at the receiver (called the "target") can approach several hundred or even several thousand degrees Celsius. The concentrators must move to track the sun if they are to perform effectively.

Concentrating, or focusing, collectors intercept direct radiation over a large area and focus it onto a small absorber area. These collectors can provide high temperatures more efficiently than flat-plate collectors, since the absorption surface area is much smaller. However, diffused sky radiation cannot be focused onto the absorber. Most concentrating collectors require mechanical equipment that constantly orients the collectors toward the sun and keeps the absorber at the point of focus. Therefore; there are many types of concentrating collectors.

7.4.2.1 Types of concentrating collectors

There are four basic types of concentrating collectors:

- Parabolic trough system
- Parabolic dish
- Power tower
- Stationary concentrating collectors

7.4.2.2 Parabolic trough system

Parabolic troughs are devices that are shaped like the letter "u". The troughs concentrate sunlight onto a receiver tube that is positioned along the focal line of the trough. Sometimes a transparent glass tube envelops the receiver tube to reduce heat loss.

These solar collectors use mirrored parabolic troughs to focus the sun's energy to a fluid-carrying receiver tube located at the focal point of a parabolically curved trough reflector. The energy from the sun sent to the tube heats oil flowing through the tube, and the heat energy is then used to generate electricity in a conventional steam generator. The temperature attained by the collector is **100-3000C.** Many troughs placed in parallel rows are called a "collector field." The troughs in the field are all aligned along a northsouth axis so they can track the sun from east to west during the day, ensuring that the sun is continuously focused on the receiver pipes. Individual trough systems currently can generate about 80 MW of electricity

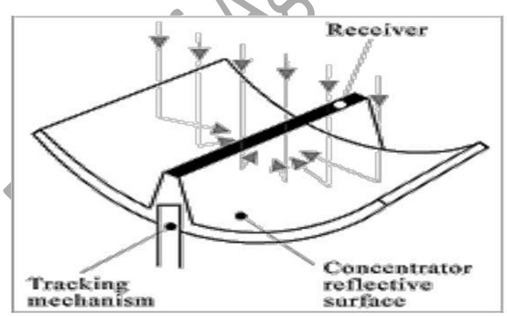


Fig.7.2.Parabolic trough system

7.4.2.2 Parabolic dish systems

A parabolic dish collector is similar in appearance to a large satellite dish, but has mirror-like reflectors and an absorber at the focal point. It uses a dual axis sun tracker.The radiation received on the collector is reflected towards the concentrator. The concentrator, which is coated with absorber coating, is heated up with concentrated radiation. The temperature attained with this type of collector is more than 300^0C.

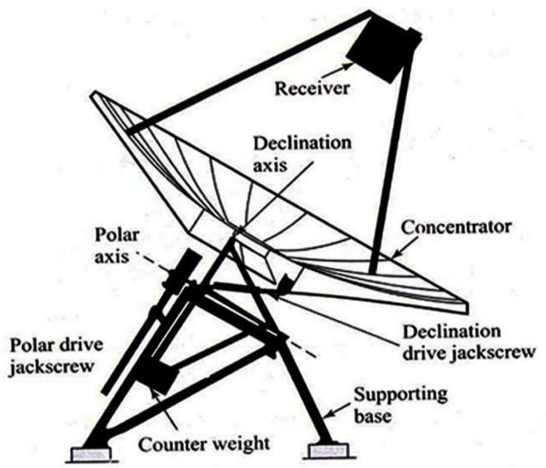


Fig.7.3. Parabolic dish systems

Fig.7.4. Parabolic dish collector with a mirror-like reflectors and an absorber at the focal point

7.4.2.4 Power tower system

A heliostat uses a field of dual axis sun trackers that direct solar energy to a large absorber located on a tower. To date the only application for the heliostat collector is power generation in a system called the power tower

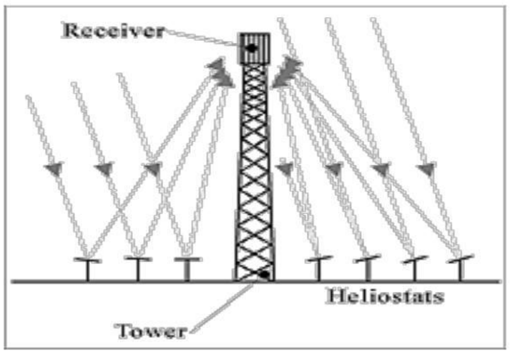


Fig.7.5.Power tower system

A power tower has a field of large mirrors that follow the sun's path across the sky. The mirrors concentrate sunlight onto a receiver on top of a high tower. A computer keeps the mirrors aligned so the reflected rays of the sun are always aimed at the receiver, where temperatures well above 1000°C can bereached.High-pressure steam is generated to produce electricity.

Lecture No. 8

Solar air heaters, solar space heating and cooling

8.1 Solar air heaters

Solar air heating is a solar thermal technology in which the energy from the sun, insolation, is captured by an absorbing medium and used to heat air. Solar air heating is a renewable energy heating technology used to heat or condition air for buildings or process heat applications. It is typically the most cost-effective out of all the solar technologies, especially in commercial and industrial applications, and it addresses the largest usage of building energy in heating climates, which is space heating and industrial process heating.

The heat absorbed by the absorber plate is transmitted to the air drawn into the collector (Fig.8.1). The hot air leaves the collector to a storage tank for further use. If the size of collector is large, a blower is used to draw air into the collector and transmit the hot air to dryer. The most favorable orientation, of a collector, for heating only, is due south at an inclination angle to the horizontal equal to the latitude plus 15°.

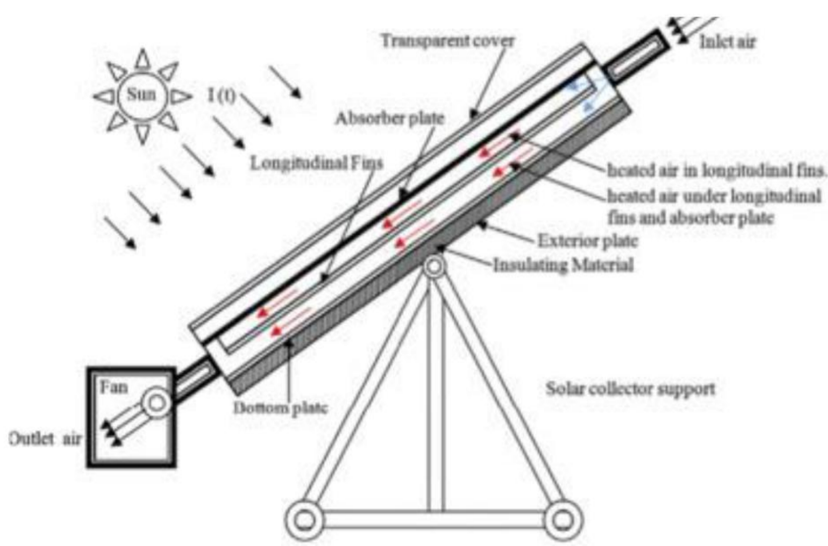


Fig.8.1. Solar air heater

8.2 Solar space heating

Space heating is of particular relevance in colder countries where a significant amount of energy is required for the heating. In India, it is of importance mainly in the northern and north eastern regions in winter. Space heating can be done by two methods:

(i) Passive methods

(ii) Active methods

8.2.1 Passive method of space heating

Space heating gives a fair degree of comfort by adopting passive method. A passive method is one in which thermal energy flows through a living space by natural means without the help of a mechanical device like a pump or blower.

Typically, passive solar heating involves:

- The collection of solar energy through properly-oriented, south-facing windows.
- The storage of this energy in "thermal mass," comprised of building materials with high heat capacity such as concrete slabs, brick walls, or tile floors.
- The natural distribution of the stored solar energy back to the living space, when required, through the mechanisms of natural convection and radiation.
- Window specifications to allow higher solar heat gain coefficient in south glazing.

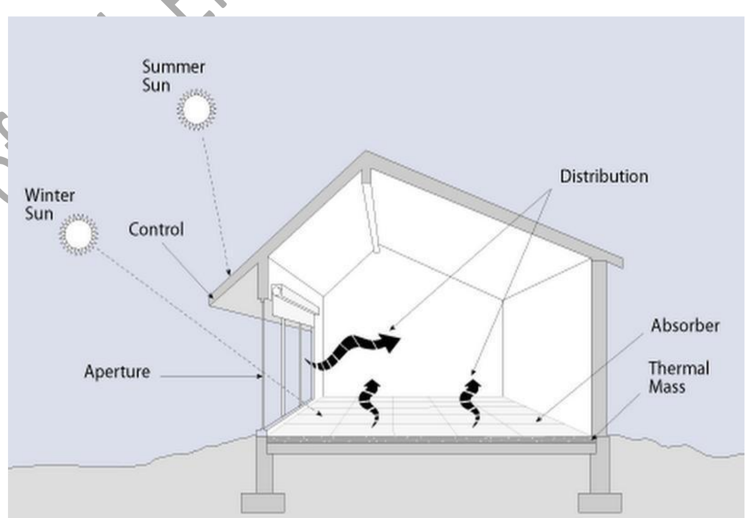


Fig.8.2. Passive method of space heating

8.2.2 Active method of space heating

Space heating system mainly consists of an array of collectors arranged on the roof of a building, insulted storage tank, auxiliary heater, pump/blower and heat exchanger. Liquid/air gets heated up in the flat plate collectors. The hot fluid passes to storage tank. The fluid from storage tank is transmitted by pump/blower to heat exchanger. The heat exchanger blows out hot air and heats up the surrounding living space in the building. Again the cool air/water passes to the storage tank, which supplied to flat plate collectors for heating. In the absence of solar energy, an auxiliary heater is used for space heating.

Lecture No. 9

Solar energy applications, solar cookers, solar water heating system

9.1 Solar Energy applications

Energy from sun can be categorised in two ways: in the form of heat and light. We use the solar energy every day in many different ways. When we hang laundry outside to dry in the sun, we are using the solar heat to dry our clothes. Plants make their food in the presence of sunlight. Animals and humans get food from plants. Fossil fuels are actually *solar energy* stored millions and millions of years ago.

There is variety of products that uses solar energy. These products are called solar devices (or appliances) or solar thermal collectors. Solar thermal technologies uses the solar heat energy to heat water or air for applications such as space heating, pool heating and water heating for homes and businesses.

Some of the major applications of solar energy are as follows

- Solar water and air heating
- Heating and cooling of buildings
- Salt production by evaporation of seawater
- Solar distillation
- Solar pumping
- Solar drying of agricultural and animal products
- Solar furnaces
- Solar cooking
- Solar refrigeration
- Solar electric power generationthrough Photo voltaic cells
- Solar thermal power production
- Industrial process heat
- Solar green houses

9.2 Solar cooker

A 'solar cooker' is a device which uses the energy of direct sunlight to heat, cook or pasteurize food or drink. Many solar cookers currently in use are relatively inexpensive, low-tech devices, although some are as powerful or as expensive as traditional stoves, and advanced, large-scale solar cookers can cook for hundreds of people. Because they use no fuel and cost nothing to operate, many nonprofit organizations are promoting their use worldwide in order to help reduce fuel costs (especially where monetary reciprocity is low) and air pollution, and to slow down the deforestation and desertification caused by gathering firewood for cooking. Solar cooking is a form of outdoor cooking and is often used in situations where minimal fuel consumption is important, or the danger of accidental fires is high, and the health and environmental consequences of alternatives are severe.

9.3 Types of solar cooker

1. For household cooking : Box type solar cooker
2. For community cooking : Concentrator type solar cookers

9.3.1. Box Type solar cooker

The solar rays penetrate through the glass covers and absorbed by blackened metal trays (Boxes) kept inside the cooker (Fig.9.1). The upper cover has two glass sheets each 3 mm thick fixed in the wooden frame with 20 mm distance between them. This prevents the loss of heat due to re radiation from blackened surface. The loss due to convection is minimized by making the box air-light by providing a rubber strap all round between the upper lid and the box. Insulating material like glass wool saw dust or any other material is filled in the space which minimizes heat loss due to conduction. When this type of cooker is placed in the sun, the blackened surface starts absorbing sunrays and temperature rises. The food in the trays is cooked. The temperature of cooking depends upon the intensity of radiation. The size of a box type cooker is 50×50×12 cm. Overall dimensions of the latest model are 60×60×20 cm. This type of cooker is termed as family solar cooker as it cooks sufficient dry food materials for a 49 family of 5 to 7 people. The temperature attained is about 100ºC. With the addition of single glass reflector, 15-20ºC more temperature is obtained and the cooking time is reduced.

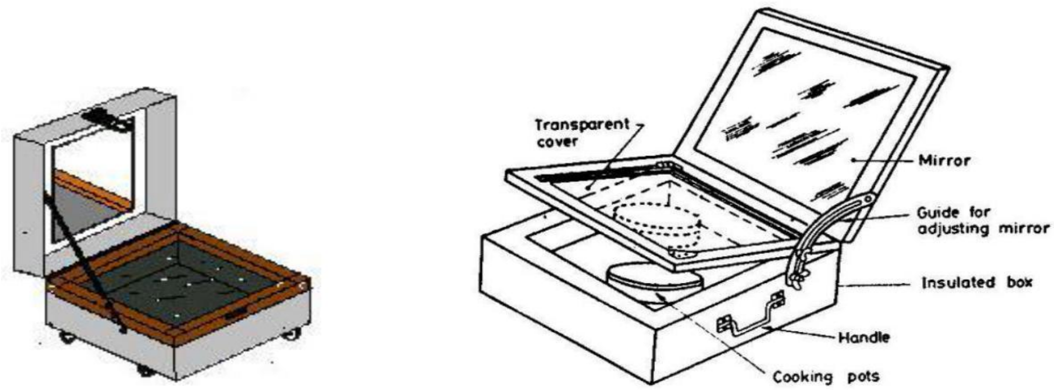


Fig.9.1.Box Type solar cooker

9.3.2 Concentrator type solar cooker for community cooking

It works on the principle of solar energy concentration using a Reflecting Parabolic Solar Concentrator. A parabolic solar concentrator is used for concentrating solar radiation on a focal area where the cooking vessel is placed.

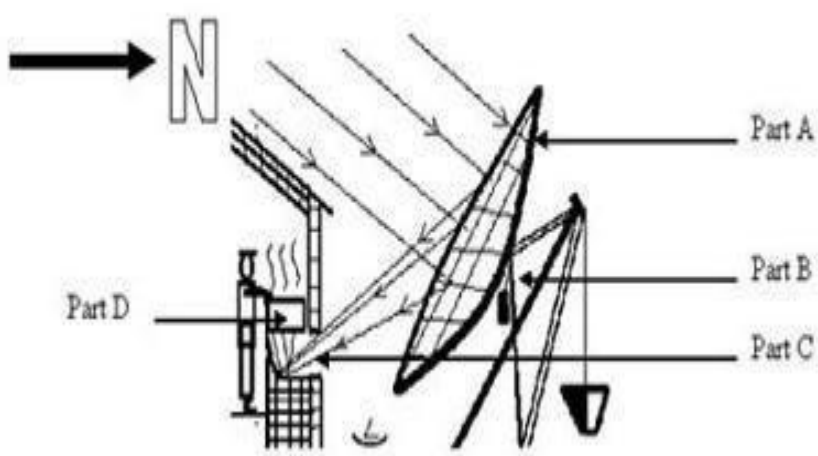


Fig.9.2. Parts of the concentrator type solar

- Part A - Solar Concentrating Disc (Primary Reflector) - The disc which helps in concentrating solar energy to a focal point

- Part B- Automatic Tracking System - With the help of a simple automatic mechanical tracking system the solar disc rotates in the direction of the movement of the Sun to give continuous and accurate solar energy concentration.
- Part C - Secondary Reflector - This is provided opening in the north-facing wall of the kitchen or the cooking place just below the cooking vessel. This reflector receives the concentrated solar radiation and reflects it on to the bottom of the cooking vessel.
- Part D- Cooking vessels

9.4 Merits of solar cooker

- No requirement of cooking gas or kerosene, electricity, coal or wood.
- No need to spend on fuel, as solar energy is available free.
- No loss of vitamins in the food: Food cooked in solar cooker is nutritious. About 10-20% of protein retention is more as compared to that in conventional cooking .Vitamin thiamine retention is about 20 to 30% more whereas vitamin A is retained 5 to 10% more when food is cooked in solar cooker.
- No orientation to sun is needed
- No attention is needed during cooking.
- No fuel, maintenance and recurring cost.
- Simple to use and fabricate.
- Solar cooking is pollution free and safe.
- Solar cookers come in various sizes. Based on the number of family members, the size of the cooker can be chosen.
- All cooking activities (like boiling, roasting) can be done using a solar cooker.
- There are government schemes which offer subsidies to purchase solar cookers.

9.5 Demerits of solar cooker

- Adequate sunshine is required for cooking: Cooking can be done only when there is sunshine.
- Takes longer time to cook food than the conventional cooking methods
- All types of foods can"t be cooked.

9.6 Solar water heater

A solar water heating unit comprises a blackened flat plate metal collector with an associated metal tubing facing the general direction of the sun. The plate collector has a transparent glass cover above and a layer of thermal insulation beneath it.The metal tubing of the collector is connected by a pipe to an insulated tank that stores hot water during cloudy days. The collector absorbs solar radiations and transfers the heat to the water circulating through the tubing either by gravity or by a pump.This hot water is supplied to the storage tank via the associated metal tubing. This system of water heating is commonly used in hotels, guest houses, tourist bungalows, hospitals, canteens as well as domestic and industrial units.

It consists mainly of:

- A thermal panel (solar collector) installed on the roof;
- A tank to store hot water;
- Accessories, such as a circulating pump to carry the solar energy from the collector to the tank, and a thermal regulator.

Small capacity domestic solar water heaters are also available in simpler design, in which the functions of the collector and storage tank are combined in one unit. The hot water is used for domestic purposes or meeting the needs of industries and commercial establishments. Solar water heating systems can be classified into two categories:

(i) Natural circulation (thermo-syphon) system

(ii) Forced circulation system

9.6.1 Natural circulation water heating system

Basic elements of a solar water heating system are: (i) flat plate collector, (ii) storage tank, (iii) circulation system (iv) auxiliary heating system and (v) control of the system is shown in Fig.9.3 natural circulation system consists of a tilted collector, with transparent cover plates, a separate, highly insulated water storage tank, and well-insulated pipes connecting the collector and storage tank. The bottom of the storage tank is at least a foot higher than the top of the collector, and 52 no auxiliary energy is required to circulate water through it. Circulation occurs through natural convection, or thermo-siphoning. When water in the collector is heated by the sun, it expands (becomes less dense) and rises up the collector, through a pipe and into the top of the storage tank. This forces cooler water at the bottom of the tank and flow out from storage tank by gravity, enter into the bottom of the collector through pipe provided at the bottom of the storage tank. This water, in turn, is heated and rises up into the tank. As long as the sun shines the water will quietly circulate, getting warmer. After sunset, a thermo-siphon system can reverse its flow direction and loss heat to the environment during the night. To avoid reverse flow, the top heater of the absorber should be at least 1 foot below the bottom of the storage tank. To provide heat during long, cloudy periods, an electrical immersion heater can be used as a back up for the solar system.

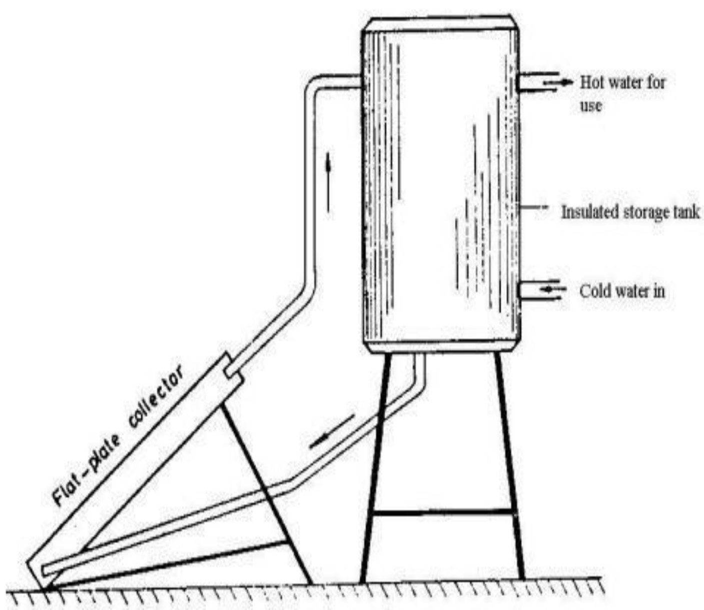
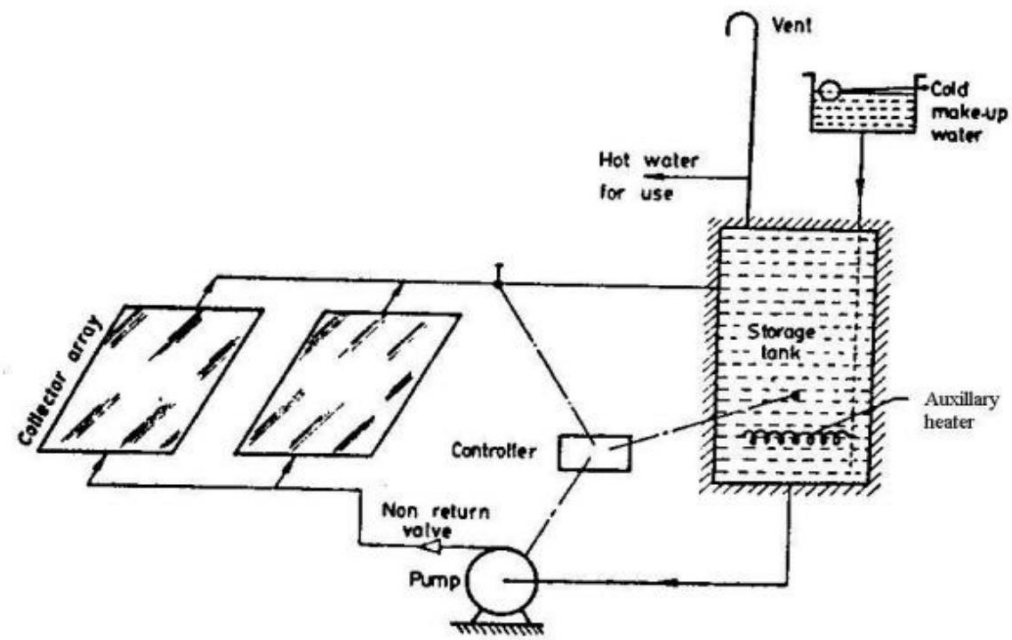


Fig.9.3.Natural circulation water heating system

9.6.2 Forced circulation water heating system

The forced circulation water heating system is suitable for supplying hot water to community centers such as hostels, hotels etc., and industries. Large array of flat-plate collectors are then used and forced circulation is maintained with a water pump. The restriction to keep storage tank at a higher level is not required, as done in the case of natural circulation water heating system. Depending on the size of storage tank, a group of flat plate collectors are selected and connected together. The storage tank is maintained with cold water fully by connecting to a make-up water tank which is provided with ball-float control mechanism. The pump for maintaining the forced circulation is operated by an on-off controller which senses the difference between the temperature of water at the exit of collectors and a suitable location inside the storage tank. When the temperature in the storage tank is reduced, the thermal controlling system operates the pump and cold water is pumped to the collectors. The cold water gets heated up in the collector and the flow to the storage tank. If the temperature of water in the storage tank reaches to a predetermined value, the pump automatically stop the pumping water from the tank to collector. If the temperature of hot water falls, the pump starts working and water flows to collector. In the absence of solar energy, the auxiliary heater operated by electrical power is used. The auxiliary heater has to be kept in the storage tank is shown in fig.9.4



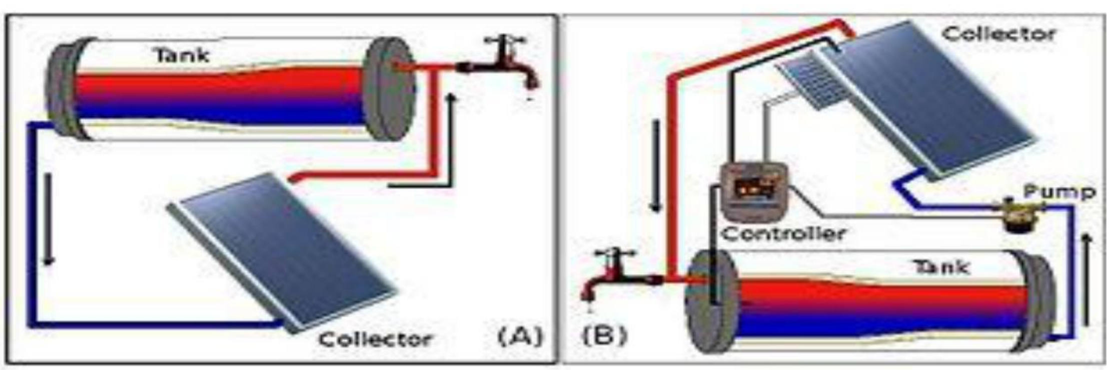


Fig.9.5. Direct systems: (A) Passive CHS system with tank above collector. (B) Active system with pump and controller driven by a photovoltaic panel.

Lecture No. 10

Solar grain dryers, solar refrigeration system, solar ponds

10.1 Solar Drying

One of the traditional uses of solar energy has been for drying of agricultural products. The drying process removes moisture and helps in preservation of the product. Traditionally drying is done on open ground. The disadvantages associated with the traditional system of drying are slow process, uncontrolled drying, quality deterioration, and losses due to birds, rodents and insects. Drying under solar cabinet or convective dryers can be done faster and in a controlled condition.

10.2 Advantages of Solar Drying System

1) Better Quality of Products are obtained

2) It reduces losses and better market price to the products.

3) Products are protected against flies, rain and dust;

4) Product can be left in the dryer overnight during rain, since dryers are waterproof.

5) Prevent fuel dependence and Reduces the environmental impact

6) It is more efficient and cheap.

10.3 Disadvantages of Solar Drying System

1) Quality of products are not obtained in some cases.

2) Adequate solar radiation is required.

3) It is more expensive

4) Require more time for drying.

10.4 Different types of solar dryer

10.4.1 Direct type solar dryer/ cabinet dryer:

A cabinet type solar dryer is suitable for small scale use**.** The figure 10.1 shows simplest type of cabinet dryer. Here moisture is removed from top; air enters into cabinet from below and leaves from top. The dryer consists of an enclosure with a transparent cover. This is open to the sun drying type of dryer only difference is food product is covered with the glass cover. The material to be dried is placed on the perforated trays. The solar radiation entering the enclosure is absorbed in the product itself and the surrounding internal surfaces of the enclosure. As a result, moisture is removed from the product and the air inside is heated. Suitable openings at the bottom and top ensure a natural circulation. Temperature from 50-80ºC is attained and drying time ranges from 2-4 days.

When sun light fall on the surface of glass then three things happens, first is some light is absorbed, some light is reflected back from the glass, and some light is transmitted. As part of radiation absorbs by surface of crop which causes increase in temperature. The glass cover reduces direct convective losses to the ambient and which plays important role in increasing temperature of agricultural product and cabinet temperature. Products like dates, apricots, grapes, chillies, turmeric etc., can be dried in a cabinet dryer. There are some disadvantages of cabinet dryer like, drying time required is large due to natural convection of air flow hence low heat and moisture transfer coefficient. Hence efficiency is low.

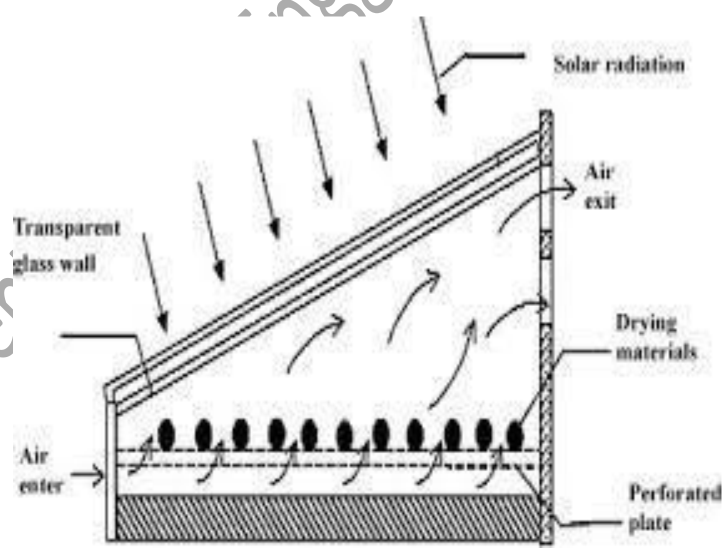


Fig.10.1 Direct type solar dryer/ cabinet dryer

10.4.2 Indirect type of solar dryer/Convective dryer:

For large scale drying, convective dryer is used (Fig.10.2). In this dryer, the solar radiation does not fall on the product to be dried. Air is heated separately in a solar air heater and then forced into the chamber in which the product to be dried is placed. A blower circulates the air from the heater to the grain hopper.

This type of dryer differs from direct dryer by heat transfer and vapour removal. In this method atmospheric air heated in flat plate collector. Then this hot air from flat plate collector is flow in the cabin where products are placed. The moisture from this type of dryer is removed by convection as well as by diffusion. These dryers are suitable for food grains, tea, tobacco, spices etc. In India about 10,000m^2 of collector area for drying various kinds of crops and food products and for drying timber has been installed in about 50 industries.

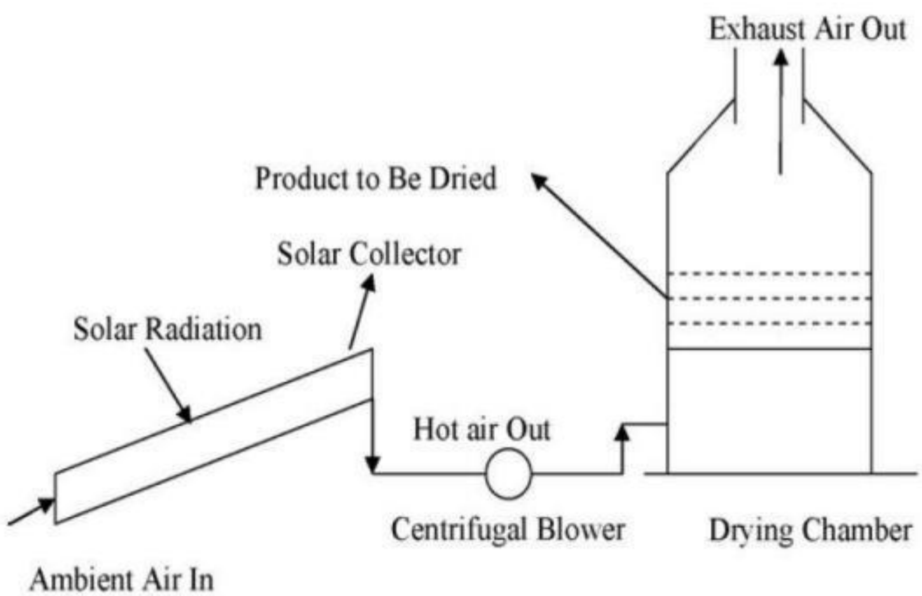


Fig.10.2 Convective dryer

10.5. Space cooling and refrigeration system

Space cooling is one of the promising applications of solar energy to provide comfortable living conditions (air-conditioning) or of keeping a food product at low temperature to increase its shelf life. Since the energy of the sun is being received as heat, the obvious choice is absorption refrigeration system, which requires most of its energy input as heat.

A diagram of a simple solar operated absorption refrigeration system is shown in fig.10.3. The water heated in a flat plate collector array, is passed through a heat exchanger called the generator where transfer of heat takes place to a solution (absorbent + Refrigerant), which is rich in refrigerant. Refrigerant vapour boiled off at a high pressure and goes to the condenser where it is condensed into a high pressure liquid. The high pressure liquid is throttled to a low pressure and temperature in an expansion value and passes through an evaporator coil. Hence, the refrigerant vapour absorbs heat and cooling is obtained in the space surrounding this coil. The refrigerant vapour is now absorbed back into a solution mixture withdrawn from the generator. The refrigerant concentration is weak in this solution and pumped back into the generator, there by completing the cycle. The common refrigerant absorbent liquids are ammonia-water, water-lithium bromide. The later is used in air conditioning.

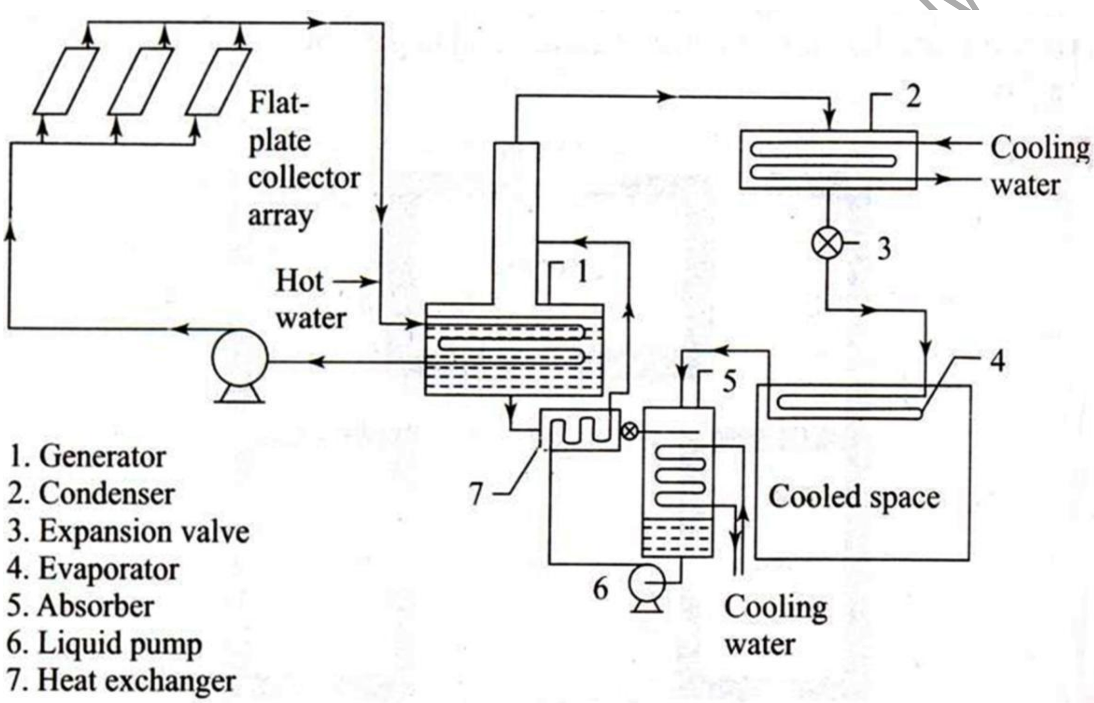


Fig.10.3 Schematic diagram of solar absorption refrigeration system

10.6 Solar Pond

The solar pond is a simple device for collecting and storing solar heat. The solar pond combines solar energy collection and sensible heat storage. Solar ponds are also called solar salt ponds. The solar pond works on a very simple principle. It is well-known that water or air is heated they become lighter and rise upward e.g. a hot air balloon. Similarly, in an ordinary pond, the sun‟s rays heat the water and the heated water from within the pond rises and reaches the top but loses the heat into the atmosphere. The net result is that the pond water remains at the atmospheric temperature. A solar pond, on the other hand, is designed to reduce convective and evaporative heat losses .The solar pond restricts this tendency by dissolving salt in the bottom layer of the pond making it too heavy to rise.so that useful amounts of heat can be collected and stored. A greater salt concentration at the bottom than at top causes bottom water to have greater density and remains at the bottom and is also hotter. The solar energy is absorbed in deep layers and is usually trapped.

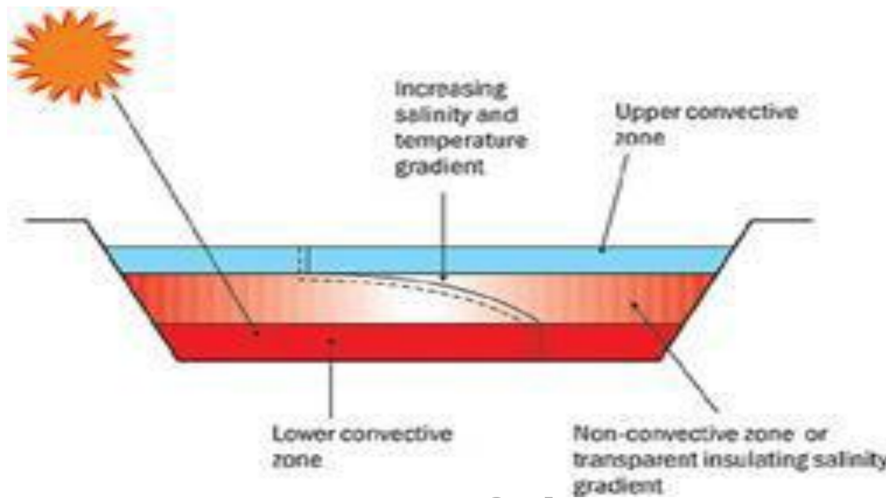


Fig.10.4 Solar Pond

10.6.1 Applications of solar ponds

- Heating and cooling of buildings
- Power generation
- Agricultural crop drying
- Desalination
- Industrial process heat
- Production of renewable liquid fuels

10.6.2 Limitations of solar ponds

- Need for large land area
- Require sunny climate
- Availability of brackish water

10.7 Types of Solar Ponds

There are two main categories of solar ponds: nonconvecting ponds, which reduce heat loss by preventing convection from occurring within the pond; and convecting ponds, which reduce heat loss by hindering evaporation with a cover over the surface of the pond.

10.7.1 Convecting Solar Ponds

Convecting solar ponds trap heat by stopping evaporation rather than by stopping convection. The structure consists of a large bag of water with a blackened bottom, foam insulation below the bag, and two layers of plastic or glass glazing on top of the bag; the design allows convection but prevents evaporation. The Sun heats the water during the day. Then, at night, hot water is pumped into heat-storage tanks

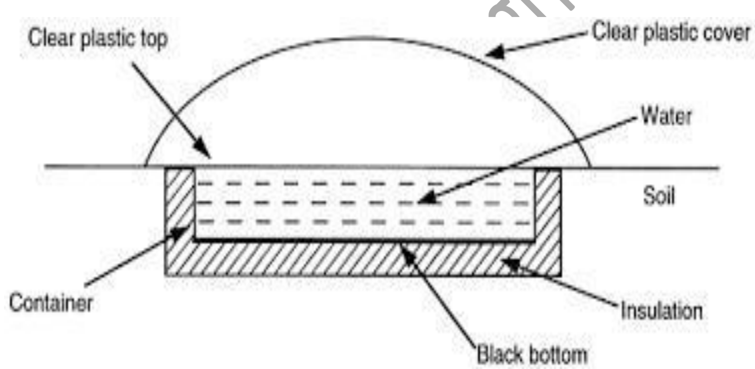


Fig.10.5Convecting Solar Ponds

10.7.2 Non-convecting Solar Ponds

Solar ponds are of two types: non-convecting and convecting. The more common non-convecting solar pond reduces heat loss by preventing convection (the transfer of heat from one place to another by the movement of fluids) with the addition of a concentration of 20–30 percent salt to the bottom level (lower convective zone) of the pond. When saturated with high amounts of salt in the form of concentrated brine, the temperature of the bottom level rises to about 100 °C (212 °F) as heat from the Sun is trapped. The middle level (non-convective zone) receives a lower amount of salt than the bottom level. Because it is lighter than the bottom level but heavier than the top level, the water in the middle level is unable to rise or sink. The middle level, therefore, halts convection currents and acts as an insulator, trapping sunlight in the bottom level. In the top level (upper convective zone), where there is little salt, the water remains cold. Fresh water is added to that level, and saline water is drained. Finally, heat from the bottom level is transferred to pipes circulating through the pond to extract thermal energy.The salt gradient pond is the most common type of non-convective solar pond.

10.7.3 Salinity Gradient Solar Pond (SGSP)

A solar pond is mass of shallow water about 1 – 1.5 m deep with a large collection area, which acts as a heat trap. It contains dissolved salts to generate a stable density gradient. Salts have been dissolved in high concentrations near the bottom, with decreasing concentration towards the surface. The salts most commonly used for salt gradient ponds are sodium chloride and magnesium chloride. Part of the incident solar radiation entering the pond surface is absorbed throughout the depth and the remainder which penetrates the pond is absorbed at the black bottom. Convective losses can be eliminated by initially creating a sufficient strong salt concentration gradient with convection suppressed, the heat is lost from the lower layers only by conduction. Because of its relatively low thermal conductivity, the water acts as an insulator and permits high temperatures (over 90°C) to develop in the bottom layers.The solar gradient pond consists of three layers as shown in fig.10.6

In the top layer, vertical convection takes place due to effects of wind evaporation. There is no membrane or glazing covering this pond. The next layer, which may be as much as about one meter thick, contains an increasing concentration of salt with increasing depth. This layer is nonconvective. The bottom layer is a convective layer of essentially salt concentration, which provides thermal storage. Non-convective pond of this type have been known to heat water to the boiling point.

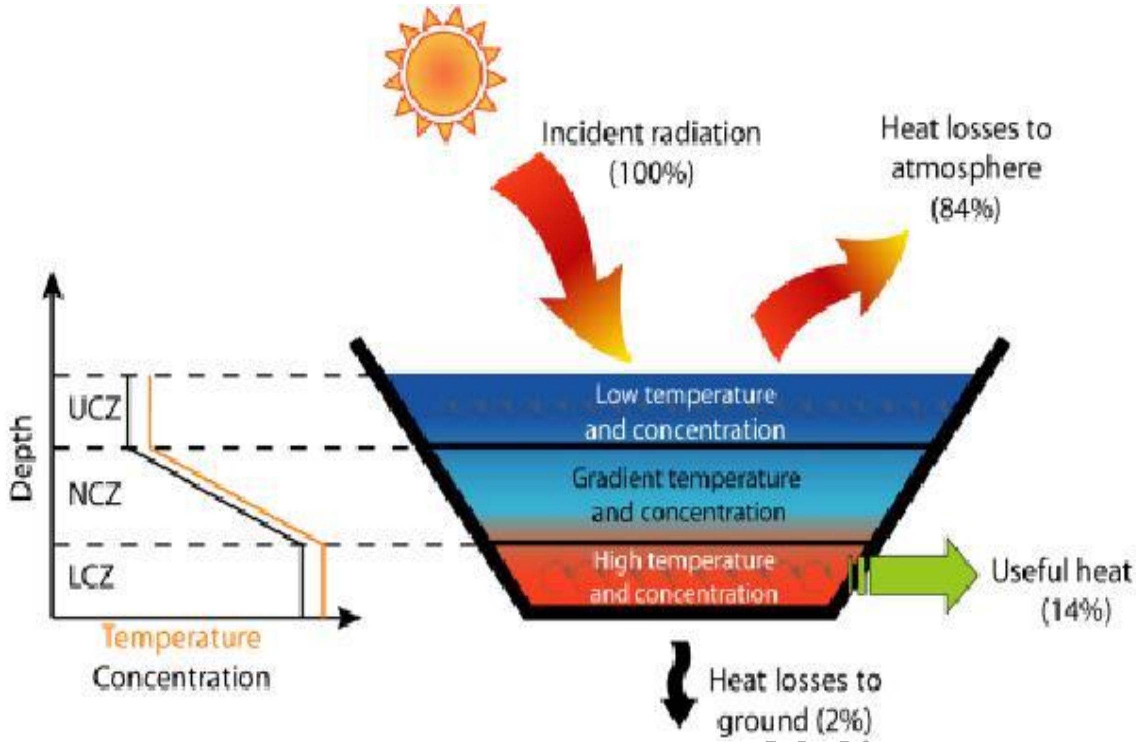


Fig.10.6 Salinity Gradient Solar Pond (SGSP)

Lecture No. 11

Solar photovoltaic systems, solar latern, Solar street lights, solar fencing

11.1 Solar Photovoltaic systems

The most useful way of harnessing solar energy is by directly converting it into DC electricity by means of solar photo-voltaic cells. Energy conversion devices which are used to convert sun light to electricity by the use of photo-voltaic effect are called solar cells. A typical photovoltaic cell consists of semiconductor material (usually silicon) having a pn junction as shown in Figure 11.1. Sunlight striking the cell raises the energy level of electrons and frees them from their atomic shells. The electric field at the pn junction drives the electrons into the n region while positive charges are driven to the p region. A metal grid on the surface of the cell collects the electrons while a metal back-plate collects the positive charges.

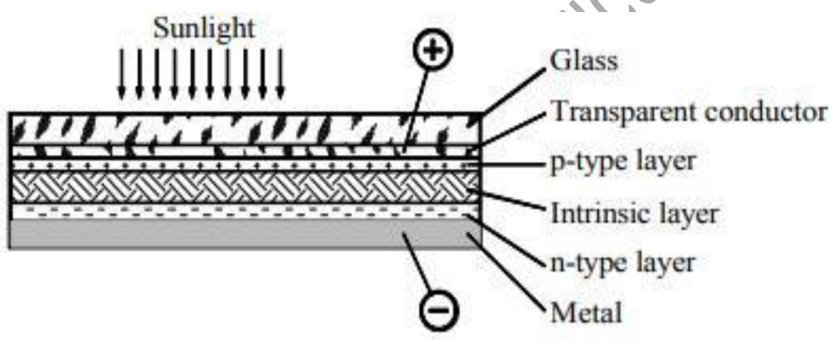


Fig.11.1 solar photo-voltaic cells

Photovoltaic is a well-established, proven technology with a substantial international industry network. And PV is increasingly more cost-effective compared with either extending the electrical grid or using generators in remote locations. The cost per peak watt of today‟s PV power is about $7. Local supply conditions, including shipping costs and import duties, vary and may add to the cost. PV systems are very economical in providing electricity at remote locations on farms, ranches, orchards and other agricultural operations. A "remote" location can be as little as 15 meters from an existing power source. PV systems can be much cheaper than installing power lines and step-down transformers in applications such as electric fencing, area or building lighting, and water pumping – either for livestock watering or crop irrigation.

Solar cells can be manufactured from different semiconductor materials and their combinations. The voltage generated by a solar cell depends on the intensity of solar radiation and the cell surface area receiving the radiations. The maximum achievable power is about 100 W/m^2 of solar cell surface area. The main types of solar cells aremonocrystalline silicon cells, poly crystalline silicon cells,amorphous silicon cells, gallium arsenide (GaAs), andCopper indium diselenide (CID) cells.

At present, silicon solar cells occupy 60% of the world market. Basic types of silicon solar cells are: (i) Mono crystalline silicon solar cells, (ii) poly crystalline silicon solar cells,and (iii) thin film or Amorphous silicon solar cells.

11.2 Mono crystalline silicon solar cells

A silicon solar cell of size 10cm×10cm produces a voltage of 0.5V and power output of 1 W at a solar radiation intensity of 1000 W/m2. The solar cells are formed into modulus by enclosing in an air tight casing with a transparent cover of synthetic glass. These modulus posses high efficiency between 15 and 18% and are used in medium and large size plants.

11.3 Poly crystalline silicon solar cells: The higher efficiency of solar module is 12 to 14%.

11.4 Thin-film solar cells: The crystalline solar cells are labour and energy intensive in manufacturing. The thin film cells are produced from amorphous silicon. It has the capacity to absorb more solar radiation due to irregular atom arrangement. The efficiency is 5 to 8%. These are very cheap to manufacture. Cell efficiency is defined as the ratio of electric power output of the cell, module, or array to the power content of sunlight over its total exposed area. The maximum theoretical efficiency of solar cells is around 47 percent.

11.5 Advantages of photovoltaic solar energy conversion

- Absence of moving parts.
- Direct conversion of light to electricity at room temperature.
- Can function unattended for long time. Low maintenance cost.
- No environmental pollution.
- Very long life. Highly reliable.
- Solar energy is free and no fuel required.
- Can be started easily as no starting time is involved.

- Easy to fabricate. These have high power-to-weight ratio, therefore very useful for space application.
- Decentralized or dispersed power generation at the point of power consumption can save power transmission and distribution costs.
- These can be used with or without sun tracking.

11.6 Limitations of photovoltaic solar energy conversion

- Manufacture of silicon crystals is labour and energy intensive.
- High cost.
- The insolation is unreliable and therefore storage batteries are needed.
- Solar power plants require very large land areas.
- Electrical generation cost is very high.
- The energy spent in the manufacture of solar cells is very high.
- The initial cost of the plant is very high and still requires a long gasification period.

11.7 Solar lantern

A solar lamp also known as solar light or solar lantern, is a lighting system composed of an LED lamp, solar panels, battery, charge controller and there may also be an inverter. The lamp operates on electricity from batteries, charged through the use of solar photovoltaic panel.

It is a simple application of solar photovoltaic technology, which has found good acceptance in rural regions where the power supply is irregular and scarce. Even in the urban areas people prefer a solar lantern as an alternative during power cuts because of its simple mechanism. Solar Lantern (Fig.11.2) is made of three main components - the solar PV panel, the storage battery and the lamp. The lamp, battery and electronics all placed in a suitable housing made of metal, plastic or fiber glass. The operation is very simple. The solar energy is converted to electrical energy by the SPV panel and stored in a sealed maintenance-free battery for later use during the night hours. A single charge can operate the lamp for about 4-5 hours. The lantern is basically a portable lighting device suitable for either indoor or outdoor lighting, covering a full range of 360 degrees.

Solar-powered household lighting can replace other light sources like candles or kerosene lamps. Solar lamps have a lower operating costthan kerosene lamps because renewable energy from the sun is free, unlike fuel. In addition, solar lamps produce no indoor air pollution unlike kerosene lamps. However, solar lamps generally have a higher initial cost, and are weather dependent.

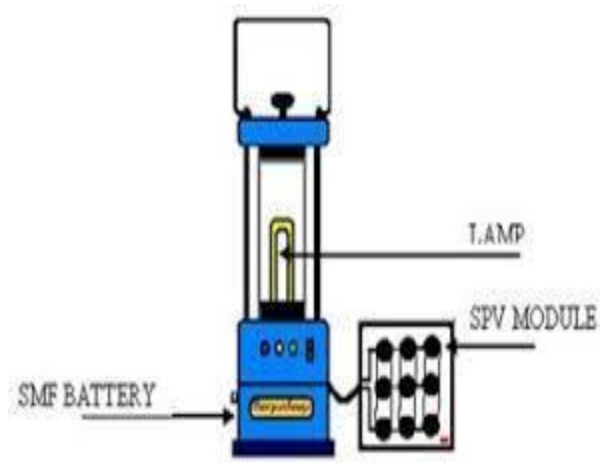


Fig.11.2 Solar lantern

11.7.1 Applications and uses

Emergency and/or house lighting, table lamp, camping, patrolling (streets, farms), Hawker / Vendor Stalls, non-electrified remote places: Adult education, mass communication. Easy and convenient alternative to kerosene / petromax / gas.

11.8 Solar Street Light

Solar street lights are raised light sources which are powered by solar panels generally mounted on the lighting structure or integrated in the pole itself. The solar panels charge a rechargeable battery, which powers a fluorescent or LED lamp during the night. The system is provided with battery storage backup sufficient to operate the light for 10-11 hours daily. Solar street lights are designed for outdoor application in un-electrified remote rural areas (Fig.11.3). This system is an ideal application for campus and village street lighting.

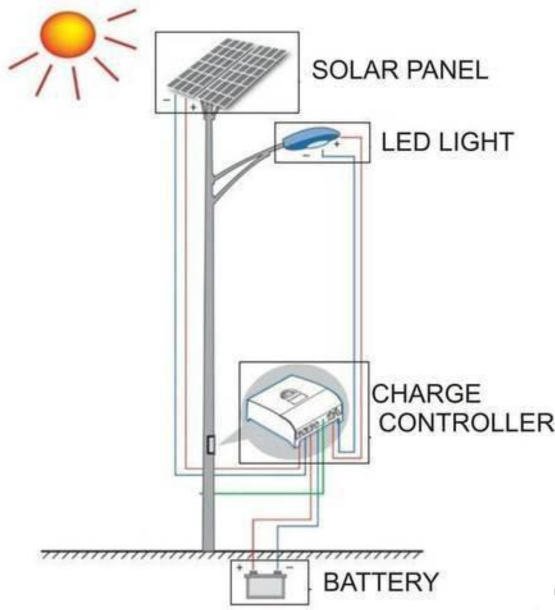


Fig.11.3 solar street light

11.8.1 Advantages of solar street lights

- Solar street lights are independent of the utility grid. Hence, the operation costs are minimized.
- Solar street lights require much less maintenance compared to conventional street lights.
- Since external wires are eliminated, risk of accidents are minimized.
- This is a non polluting source of electricity
- Separate parts of solar system can be easily carried to the remote areas
- It allows the saving of energy and also cost.

11.8.2 Disadvantagesof solar street lights

- Initial investment is higher compared to conventional street lights.
- Risk of theft is higher as equipment costs are comparatively higher.
- Snow or dust, combined with moisture can accumulate on horizontal PV-panels and reduce or even stop energy production.
- Rechargeable batteries will need to be replaced several times over the lifetime of the fixtures adding to the total lifetime cost of the light.

11.9 Solar Fencing

Like a normal electric fence, a solar-powered electric fence can be used to protect livestock, pets, or land from wildlife and pests. However, unlike normal electric lines or battery-powered fences, a solar electric fence charger use a small solar photovoltaic (PV) panel to collect and convert sunlight into energy, which is then stored in the battery so that it can charge the fence.

The Solar module generates the DC energy and charges the Battery. The output of the battery is connected to Energizer or Controller or Charger or Fencer. The energizer will produce a short, high voltage pulse at regular rate of one pulse per second. The live wire of the energizer is connected to the fence wire and the earth terminal to the Earth system. Animal / Intruder touching the live wire creates a path for the current through its body to the ground and back to the energizer via the earth system and completes the circuit.

The Energizer has to be set up with its earth terminal coupled to an adequate earthing or grounding system. The live terminal is coupled to the live insulated wires of the fence. Energizer will send an electric current along an insulated steel wire The shock felt is a combination of fence voltage and pulses time or energy.

The basic building blocks of a power fence are: Energizer, Earthing (Grounding System) and 3. Fence system

1. Energizer: Most important part of the system. The energizer is selected depending on the animals to be controls, length of the fence and number of strands. Takes input from DC battery. Main function of the energizer is to produce short and sharp pulses of about 8000 volts at regular intervals. The power input is from the DC energy from battery.

2. Earthing (Grounding System): The earth or ground system must be perfect to enable the pulse to complete its circuit and give the animal an effective shock. Soil is not a good conductor so the electrons spread out and travel over a wide area, inclining towards moist mineral soils.

11.10Features of Solar Power Fencing:

- Easy Construction.
- Power fence can be erected to target species only.
- Low maintenance.
- Long lasting because of minimal physical pressure.
- All domestic and wild animals can be controlled economically.
- Makes strip grazing and back fencing easy.
- Encourages additional subdivision, giving increased production.
- Modification of system to control a variety of animals is very easy.
- Aesthetically pleasing.
- Discourages trespassers and predators.
- Not harmful. It gives a short, sharp but safe shock to the intruder.
- Perimeter protection

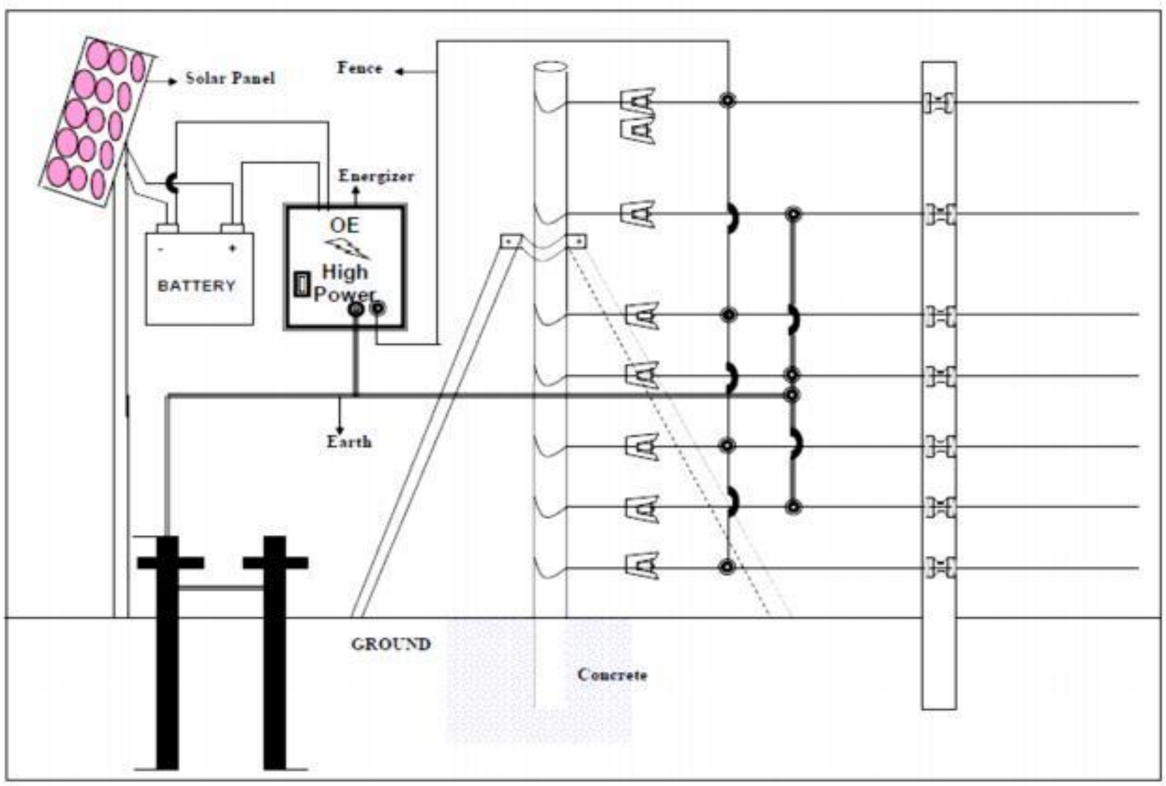


Fig.11.4 Solar fencing

Lecture No. 12

Lecture No.12

Solar pumping system

12.1 Solar Pumping System

Water pumping is one of the simplest and most appropriate uses for photovoltaic. From crop irrigation to stock watering to domestic uses, photovoltaic-powered pumping systems meet a broad range of water needs.

The solar water pumping system (Fig.12.1) is a stand-alone system operating on power generated using solar PV (photovoltaic) system.The solar cells in a PV module are made from semiconductor materials. When light energy strikes the cell, electrons are knocked loose from the material"s atoms. Electrical conductors attached to the positive and negative sides of the material allow the electrons to be captured in the form of a D.C. current. The power generated by solar cells is used for operating DC surface centrifugal mono-block pumpset for lifting water from bore / open well or water reservoir for minor irrigation and drinking water purpose.

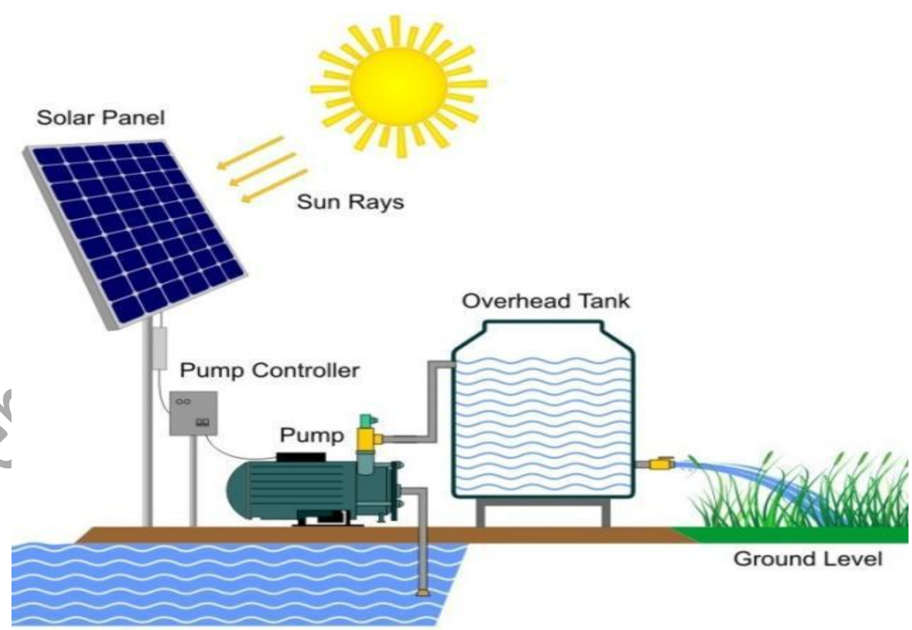


Fig.12.1Solar pumping system

12.2 Performance of Solar pumping system

The Solar PV Water Pumping System should provide a minimum of 85 liters of water per watt peak of PV array used per day under average daily solar radiation conditions of 5.5 KWh/sq.m. on a horizontal surface, from a total head of 10 metres (Suction head up to a maximum of 7 metres). For Deep Well Pumps, the water discharge should be a minimum of 28 liters of water per watt peak of PV array capacity used per day from a total head of 30 metres. In case of High Head, Deep Well Pumps, the water discharge should be a minimum of 17 liters of water per watt peak of PV array capacity used per day from a total head of 50 metres. Use of a tracking system to enhance the availability of solar radiation to lift desired quantity of water is desirable. It should be specified whether the minimum water output is achieved directly or through tracking of PV Array. The actual duration of pumping of water on a particular day and the quantity of water pumped could vary depending on the location, season, etc.

12.3 Advantages of solar pump sets

a) No fuel cost-uses abundantly available free sun light

b) No conventional grid electricity required

c) Long operating life

d) Highly reliable and durable- free performance

e) Easy to operate and maintain

f) Eco-friendly

g) Saving of conventional diesel fuel

Lecture No.13

Wind energy, types of wind mills

13.1 Wind Energy

Wind is simple air in motion. It is caused by the uneven heating of the earth‟s surface by the sun. Since the earth‟s surface is made of very different types of land and water, it absorbs the sun‟s heat at different rates. Energy derived from wind velocity is wind energy. It is a non-conventional type of energy, which is renewable with suitable devices. This energy can be used as a perennial source of energy. Wind energy is obtained with the help of wind mill. The minimum wind speed of 10kmph is considered to be useful for working wind mills for agricultural purpose. Along the sea coast and hilly areas, wind mills are likely to be most successful in Karnataka, Maharastra and Gujarat.

The wind energy over earth is estimated to be 1.6×10^7 M.W, which is equivalent to the energy consumed. But, the wind energy is available in dilute form. The conversion machines are large. The wind energy varies from time to time and place to place. Due to this reason some storage facility is required. The kinetic energy of wind is converted into useful shaft power by wind mills. General applications of wind mills are pumping water, fodder cutting, grain grinding, generation of power etc. In India, wind speed lies between 5 kmph-20 kmph. The high wind velocity is seasonal. The wind energy, if used for power generation, it will be uncertain to generate power. In India, wind power can be used for lifting water in rural areas for drinking and for irrigation purpose.

13.1.1 Factors affecting the wind

- Latitude of the place
- Altitude of the place.
- Topography of the place 4. Scale of the hour, month or year

13.1.2 Suitable places for the erection of wind mills

- Off-shore and on the sea coast: An average value is 2400 kWH/m^2/year

- Mountains: An average value is 1600 KWH/m^2/year
- Plains: An average value is 750 KWH/m^2/year

13.1.3 Places unsuitable for wind mills

- Humid equatorial region- there is virtually no wind energy
- Warm, windy countries, wind energy may not be usual because of the frequency of cyclones

13.2 Advantages and disadvantages of wind mills

Advantages	Disadvantages
• It is a renewable source of energy • It is non-polluting and no adverse influence on the environment • No fuel and transportation is required • The cost of electricity under low production is comparatively low	• The available wind energy is dilute and fluctuating in nature • Unlike water energy, wind energy requires storage capacity because of its irregularity • Wind energy operating machines are noisy in operation • Large areas are required for wind mill • The present wind mills are neither maintenance free nor practically reliable

13.3 Types of wind mills

There are two types of wind machines (turbines) used today based on the direction of the rotating shaft (axis): horizontal–axis wind machines and vertical-axis wind machines. The size of wind machines varies widely. Small turbines used to power a single home or business may have a capacity of less than 100 kilowatts. Some large commercial sized turbines may have a capacity of 5 million watts, or 5 megawatts. Larger turbines are often grouped together into wind farms that provide power to the electrical grid.

13.3.1 Vertical axis wind mills

a) Savonius or S type wind mill (low wind velocity)

b) Darrius wind mill (high wind velocity)

13.3.2 Horizontal axis wind mills

a) Single blade wind mills
b) Double blade wind mills
c) Multi blade wind mills
d) Bicycle multiblade type i.e., Sail type

13.3.1 Vertical axis wind mills

Vertical axis machines are of simple design as compared to the horizontal axis. The axis of rotation of vertical axis wind turbine is vertical to the ground and almost perpendicular to the wind direction. These turbines can receive wind from any direction. Hence complicated yaw devices can be eliminated. The generator and the gearbox of such systems can be housed at the ground level, which makes the tower design simple and more economical. Moreover, the maintenance of these turbines can be done at the ground level. The major disadvantage of vertical axis machines are that, these turbines usually not self-starting. Additional mechanism may be required to push and start the turbine, once it is stopped.

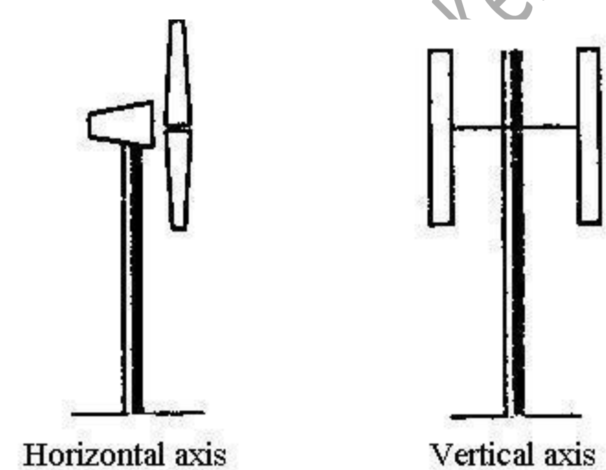


Fig 13.1 Vertical axis wind mill

a) Savonius wind mill

It works on the principle of cup anemometer. This machine has become popular, since it requires low wind velocity for operation. It consists of two half cylinders, which are mounted on a vertical axis perpendicular to the direction of wind, with a gap at the axis between the two cylinders. Two half cylinders facing each other forming an „s" shaped cross-section. Irrespective of the wind direction, the rotor rotates such as to make the convex sides of the buckets head into the wind. From the rotor shaft, we can tap power for our use like water pumping, battery charging, grain winnowing etc.

The main action of the wind is very simple, the force of the wind is greater on the cupped face than on rounded face. A low pressure is created on the convex sides of drums. Torque is produced by the pressure difference between the two sides of the half cylinders facing the wind. This design is efficient but requires a large surface area. A savonius wind energy conversion system has a vertical axis which eliminate the expensive power transmission system from the rotor to the axis. Since it is a vertical axis machine it does not matters much about the wind direction. The machine performs even at lower wind velocity ranges (i.e., 8 kmph).

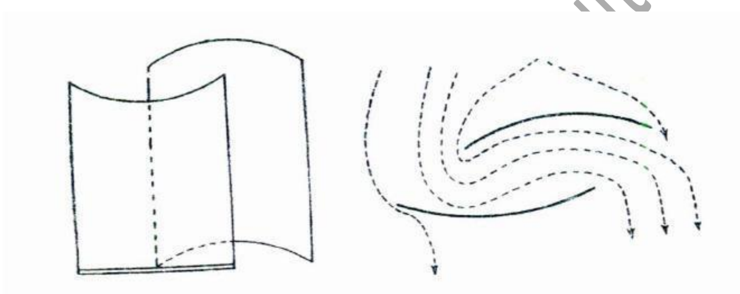


Fig 13.2 Schematic diagram of savonius wind mill

b) Darrieus wind mill

Added advantage with this mill is that it supports its blades in such a way that minimizes bending stresses in normal operation. It requires less surface area as compared to Savonius type. In this machine, the blades are curved and attached to the hubs on the vertical shaft at both ends to form a cage-like structure. The blades look like an egg beater. Darrieus rotors have three symmetrical aerofoil blades, both ends of which are attached to a vertical shaft. Thus, the force in the blade due to rotation is pure tension. This provides a stiffness to withstand the wind forces it experiences.

The blades are made lighter than in the propeller type. When rotating, these aerofoil blades provide a torque about the central shaft in response to a wind direction. This shaft torque is transmitted to a generator at the base of the central shaft for power generation. Both Savonius and darrieus type rotors run independently of the direction of wind because they rotate about a vertical axis. Major advantage of darrieus wind mill is that the rotor blades can accept the wind from any point of the compass. The machine can be mounted on the ground eliminating the tower structures. Disadvantage is that, it may experience lower velocity wind when compared to tower mounted conventional wind energy conversion system.

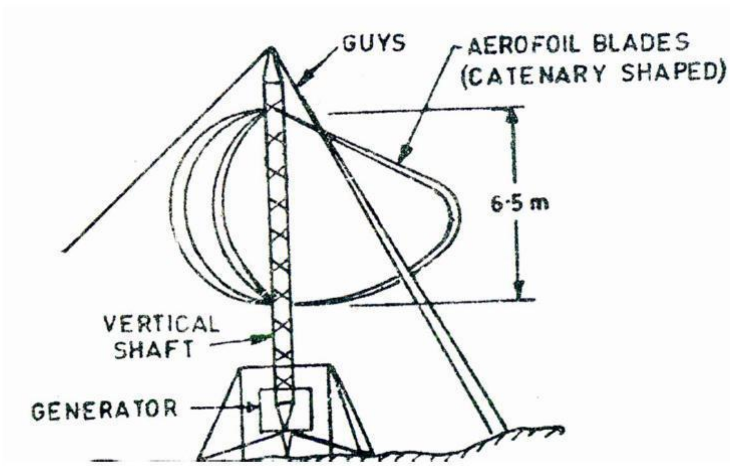


Fig. 13.3. Schematic diagram of darrieus wind mill

13.3.2 Horizontal axis type wind mills

Horizontal axis wind turbines have their axis of rotation horizontal to the ground and almost parallel to the wind stream. Most of the commercial wind turbines fall under this category. Horizontal axis machines have some distinct disadvantages such as low cut-in speed and easy furling. In general, they show relatively high power coefficient. However, the generator and gearbox of these machines are to be placed over the tower which makes its design more complex and expensive. Depending on the number of blades, horizontal axis wind turbines are further classified as single bladed, two bladed, three bladed and multi bladed.

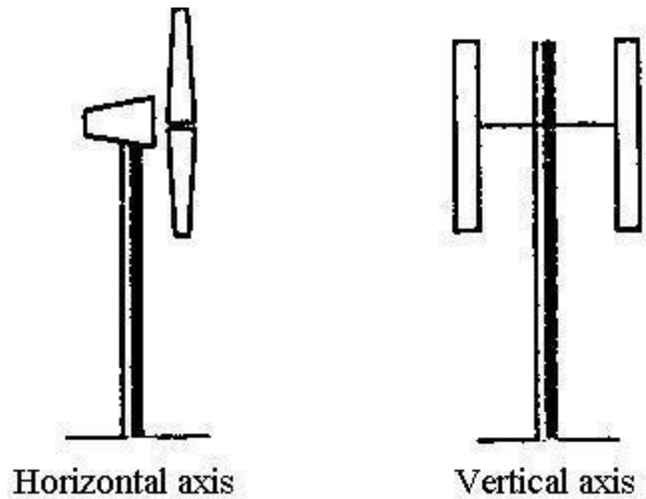


Fig 13.4Horizontal axis wind mill

The horizontal type wind mills have thin cross-section or more efficient thick cross-section of aerofoil blade. The blade is designed such that the tip of the blades makes a small angle with the plane of rotation and almost at right angles to the direction of wind. In a modern wind turbine, the velocity of blades is six times the wind velocity. Ideally, the blade should be twisted, but because of construction difficulties this is not always achieved. The horizontal axis wind mills generally have better performance. These are mainly used for electric power generation and pumping water.

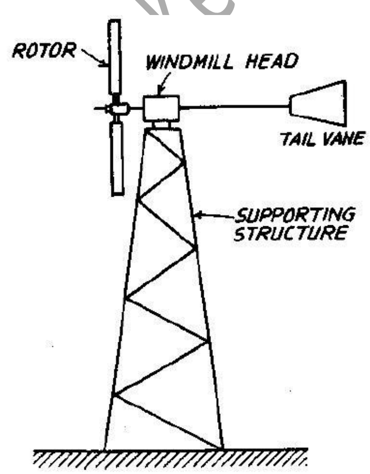


Fig. 13.5 Schematic diagram of horizontal axis wind mill

a) Horizontal axis propeller type wind mill with single blade

In this type of machine, a long blade is mounted on a rigid hub. Induction generator and gear box are arranged as shown in Fig.13.6. If extremely long blades (60 m) are mounted on the hub, large blade root bending moments may occur due to tower shadow, gravity and sudden shifts in the wind directions. To reduce rotor cost, use of low cost counter weight is recommended for balancing long blade centrifugally.

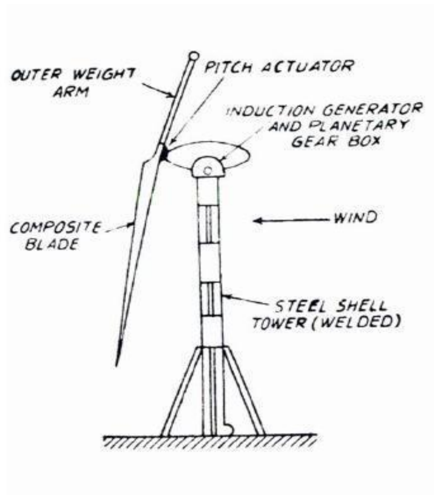


Fig. 13.6. Schematic diagram of horizontal axis single blade wind mill

b) Horizontal axis - two blade wind mill

In this type of design, rotor drives a generator through a step-up gear box. The blade rotor is designed to be oriented downwind of the tower. The components are mounted on a bedplate, which is attached on a pintle at the top of the tower. The arrangement is shown in Fig 13.7. The rotor blades are continuously flexed by unsteady aerodynamic, gravitational and inertial loads, when the machine is in operation. If the blades are made of metal, flexing reduces their life due to fatigue loading. With rotor, the tower is also subjected to above loads, which may cause serious damage. If the vibrational modes of the rotor happen to coincide with one of the natural mode of vibration of the tower, then the mill may get damaged. Due to high cost of blades, the rotor with more than two blades is not recommended. Rotors more than two, say 3 or 4 blades would have slightly higher coefficient.

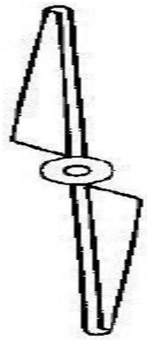


Fig. 13.7 Schematic diagram of horizontal axis two blade wind mill

c) Horizontal axis-multi blade type wind mill

This type of design for multi blades (Fig. 13.8)made from sheet metal or aluminum. The rotors have high strength to weight ratios and are strong enough to with stand a wind speed of 60 Kmph. This type of wind mills have good power coefficient, high starting torque, simple and are low in cost.

d) Sail type wind mill

It is recent development in wind mills. The blades are made by stretching out triangular pieces of canvas cloth or nylon or plastics (Fig.13.9). There is also variation in the number of sails used. It runs at 60 to 80 rpm.

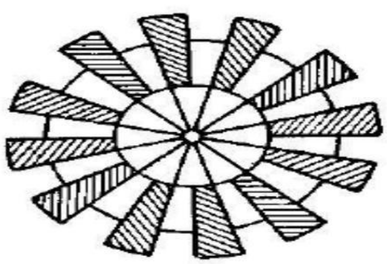


Fig.13.8. Schematicdiagram of horizontal axis multi blade wind mill

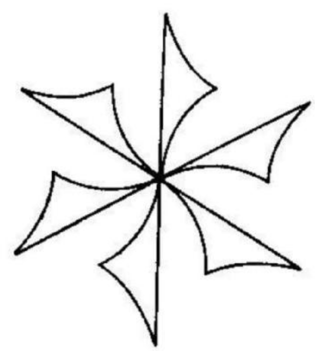


Fig. 13.9. Schematic diagram of horizontal axis sail type wind mill

Lecture No.14

Construction details and application of wind mills

14.1 Construction details

There are two classes of windmill, horizontal axis and vertical axis. The vertical axis design was popular during the early development of the windmill. However, its inefficiency of operation led to the development of the numerous horizontal axis designs.

Of the horizontal axes versions, there are a variety of these including the post mill, smock mill, tower mill, and the fan mill. The earliest design is the post mill. It is named for the large, upright post to which the body of the mill is balanced. This design gives flexibility to the mill operator because the windmill can be turned to catch the most wind depending on the direction it is blowing. To keep the post stable a support structure is built around it. Typically, this structure is elevated off the ground with brick or stone to prevent rotting.

The post mill has four blades mounted on a central post. The horizontal shaft of the blades is connected to a large break wheel. The break wheel interacts with a gear system, called the wallower, which rotates a central, vertical shaft. This motion can then be used to power water pumping or grain grinding activities.

The smock mill is similar to the post mill but has included some significant improvements. The name is derived from the fact that the body looks vaguely like a dress or smock as they were called. One advantage is the fact that only the top of the mill is moveable. This allows the main body structure to be more permanent while the rest could be adjusted to collect wind no matter what direction it is blowing. Since it does not move, the main body can be made larger and taller. This means that more equipment can be housed in the mill, and that taller sails can be used to collect even more wind. Most smock mills are eight sided although this can vary from 6 to 12.

Tower mills are further improvements on smock mills. They have a rotating cap and permanent body, but this body is made of brick or stone. This fact makes it possible for the towers to be rounded. A round structure allows for even larger and taller towers. Additionally, brick and stone make the tower windmills the most weather resistant design.

While the previous windmill designs are for larger structures that could service entire towns, the fan-type windmill is made specifically for individuals. It is much smaller and used primarily for pumping water. It consists of a fixed tower (mast), a wheel and tail assembly (fan), a head assembly, and a pump. The masts can be 10-15 ft (3-15 m) high. The number of blades can range from four to 20 and have a diameter between 6 and 16 ft (1.8-4.9 m).

14.2 Raw Materials

Windmills can be made with a variety of materials. Post mills are made almost entirely of wood. A lightweight wood, like balsa wood, is used for the fan blades and a stronger, heavier wood is used for the rest of the structure. The wood is coated with paint or a resin to protect it from the outside environment. The smock and tower mills, built by the Dutch and British prior to the twentieth century, use many of the same materials used for the construction of houses including wood, bricks and stones.

The main body of the fan-type mills is made with galvanized steel. This process of treating steel makes it weather resistant and strong. The blades of the fan are made with a lightweight, galvanized steel or aluminum. The pump is made of bronze and brass that inhibits freezing. Leather or synthetic polymers are used for washers and o-rings.

14.3 Application of wind energy:

a)Mechanical application: mainly (water pumping) Multi-blade windmill used for water pumping shown below:

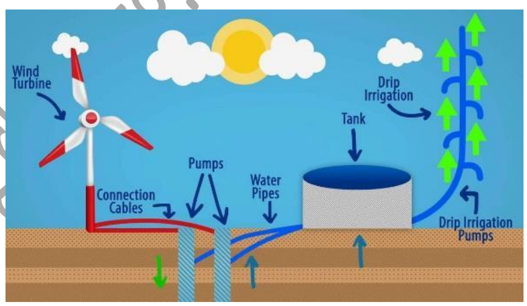


Fig. 14.1 water pumping system using wind mill

b) Electricity generation: Wind turbines vary in size and type. They are commercially available for electricity generation. Size of wind turbines (400 Watt-5 MW)

c) Industrial Applications

The number of dedicated industrial applications for wind power continues to grow. Small wind power systems are ideal for applications where storing and shipping fuel is uneconomical or impossible. Wind power is currently being used for the following applications:

- Telecommunications
- Radar
- Pipeline control
- Navigational aids
- Cathodic protection
- Weather stations/seismic monitoring
- Air-traffic control

Wind machines in industrial applications typically encounter more extreme weather than home power systems and must be designed to be robust with very minimal maintenance.

Lecture No. 15

Liquid bio fuels, types

15.1 Biofuel

Itis a generic description given to all type of fuel produced from biomass, that is, material derived from recently living organisms. This is the scientific name given to any plant or animal substance that is combustible, thus releasing off energy which can be then used for a number of purposes, including for producing motion (such as the movement of a piston in an internal combustion engine) and heating liquids (such as water in a boiler).

15.2 Types of biofuels

Biofuels can range from solid, liquid and gaseous products, and their application is as varied as that of the petroleum products they replace. Biofuels can be used in almost all applications where petroleum products are used. Only in the aviation industry is their used still very limited, almost inexistent, however recent studies and experimental flights might in the future lead to a breakthrough and a wider use similar to that experienced in the road transport sector. The following is a list of the main biofuels available and a brief description of their use.

15.2.1 Solid biofuels

Examples of solid biofuels are probably the most common to understand as their use has been present for as long as man has discovered fire. The main examples are wood and charcoalwhich are used for everyday use in heating and cooking.

15.2.2 Liquid biofuels

Liquid biofuels Liquid biofuels, as their name suggests, are fuels derived from biomass and processed to produce a combustible liquid fuel.

There are two main categories:

- **Alcohol fuels** - these include ethanol and methanol
- **Vegetable oils** - derived from plant seeds, such as sunflower, sesame, linseed

15.2.2.1 Bioethanol

Ethanol fuels basically an alcohol fuel produced by the use of enzymes and micro-organisms through the process of fermentation of starches and sugar. It can be used as a fuel, mainly as a biofuel alternative to petrol, and is widely used in cars in Brazil, where sugar cane is used as the base material. Ethanol with less than 1% water called anhydrous ethanolcan be blended with petrol in varying quantities. Currently, all sparkignited petrol engines can operate with mixtures of up to 5% bioethanol (E5), however certain engine manufacturers do not discourage and actually suggest higher blends of bioethanol to be used.

The substitution of ethanol for gasoline in passenger cars and light vehicles in Brazil is one of the largest biomass-to-energy programmes in existence today. Engines that run strictly on gasoline are no longer available in the country, having been replaced by neat ethanol engines and by gasohol engines that burn a mixture of 78 per cent gasoline and 22 per cent ethanol by volume. Technological advances, including more efficient production and processing of sugarcane, are responsible for the availability and low price of ethanol. The transition to ethanol fuel has reduced Brazil‟s dependence on foreign oil (thus lowering its import export ratio), created significant employment opportunities and greatly enhanced urban air quality. In addition, because sugarcane-derived ethanol is a renewable resource (the cane is replanted at the same rate it is harvested), the combustion of ethanol adds virtually no net carbon dioxide to the atmosphere and so helps reduce the threat of global warming.

15.2.2.2Methanol

Itis produced by a process of chemical conversion. It can be produced from any biomass with moisture content of less than 60%; potential feed stocks include forest and agricultural residues, wood and various energy crops. As with ethanol it can either be blended with gasoline to improve the octane rating of the fuel or used in its neat form. Both ethanol and methanol are often preferred fuels for racing cars.

15.2.3 Vegetable oils

A further method of extracting energy from biomass is the production of vegetable oils as a fuel known as biodiesel. The process of oil extraction is carried out the same way as for extraction of edible oil from plants. There are many crops grown in rural areas of the developing world which are suitable for oil production – sunflower, coconut, cotton seed, palm, rapeseed, soy bean, peanut, hemp and more. Sunflower oil, for example, has an energy content about 85% that of diesel fuel.

There are two well-established technologies for oil extraction:

- The simple screw press, which is a device for physically extracting the oil from the plant - this technology is well suited to small-scale production of oil as fuel or as foodstuff in rural areas. The press can be motorised or hand-operated.
- Solvent extraction is a chemical process which requires large, sophisticated equipment. This method is more efficient - that is, it extracts a greater percentage of the oil from the plant - but is less suited to rural applications.

The oil, as well as being used for lighting and heating, can be used as a fuel in internal combustion engines.

Biodiesel production is not complex and can be done on a small scale. The vegetable oil is converted to a useable fuel by adding ethanol or methanol alcohol along with a catalyst to improve the reaction. Small amounts of potassium hydroxide or sodium hydroxide (commonly called lye or caustic soda, which is used in soap making) are used as the catalyst material. Glycerine separates out as the reaction takes place and sinks to the bottom of the container. This removes the component that gums up the engine so that a standard diesel engine can be used. The glycerine can be used as a degreasing soap or refined to make other products.

15.2.4 Gaseous biofuels

Biogas is a renewable fuel, which is produced by the breaking down of organic matter by a process of microbiological activity. Basically this means that rotting municipal waste, food waste or sewage (both human and animal) is turned into gas by means of „anaerobic conversion" in a digester.Biogas contains methane, which in itself is a fuel and can be recovered from industrial anaerobic digesters, mechanical biological treatment systems and engineered landfills. In engineered landfills, the collected landfill gas can be used to produce electricity and heat.

Lecture No. 16

Bio diesel and ethanol from agricultural produce

16.1 Biodiesel

It is an alternative fuel similar to conventional or „fossil" diesel. Its primary advantages are that it is one of the most renewable fuels currently available and it is also non-toxic and biodegradable. It can also be used directly in most diesel engines without requiring extensive engine modifications. Biodiesel can be produced from straight vegetable oil, animal oil/fats, tallow and waste cooking oil. The largest possible source of suitable oil comes from oil crops such as rapeseed, palm or soybean. Most biodiesel produced at present is produced from waste vegetable oil sourced from restaurants, chip shops, industrial food producers such as Birdseye etc. Though oil straight from the agricultural industry represents the greatest potential source it is not being produced commercially simply because the raw oil is too expensive. After the cost of converting it to biodiesel has been added on it is simply too expensive to compete with fossil diesel. Waste vegetable oil can often be sourced for free or sourced already treated for a small price. (The waste oil must be treated before conversion to biodiesel to remove impurities). The result is Biodiesel produced from waste vegetable oil can compete with fossil diesel.

16.2 Significance of biodiesel

- It is a processed fuel resulting from the biological sources and it is equivalent to petro-diesel
- Biodiesel acts as a safe alternative fuel for substituting traditional petroleum diesel. It is a clean burning fuel with high lubricity
- It is produced from renewable sources acts like petroleum diesel but produces significantly less air pollution
- It is bio-degradable and very safe for the environment
- Biodiesel production can be achieved in different methods. Biodiesel is a mono alkyl ester of fatty acids produced from both edible and non edible vegetable oils or animal fat and various other bio fuels such as methanol, ethanol etc.

16.3 Advantages of biodiesel

- Biodiesel can be produced from renewable, domestic resources
- It is energy efficient (The total fossil fuel energy efficiency of biodiesel is 320% vs. 83% for petroleum diesel)
- Can be used directly in most diesel engine applications
- Can reduce global warming and tailpipe emissions (-41%)
- It is nontoxic and biodegradable
- It is a good solvent and may clean out fuel line and tank sediments (this may result in fuel filter clogging during initial use.

16.5 Limitations of biodiesel

- Biodiesel contains approximately 8% less energy per gallon
- It has a higher cloud and pour point (will freeze at a higher temp) than conventional diesel
- It is not compatible with some hose and gasket materials, which may cause them to soften, degrade, and rupture.
- Biodiesel is not compatible with some metals and plastics
- It may increase nitrogen oxide emissions

Lecture No.17

Production of biodiesel and ethanol from agricultural produce

17.1 Method of biodiesel production

There are so many investigations on biodiesel production of nonconventional feedstock of oils and have reached a faster pace in the last few years. An adaptation of the vegetable oil as a CI engine fuel can be done by four methods

a) Pyrolysis
b) Micro-emulsification
c) Dilution
d) Transesterification

a) Pyrolysis

The pyrolysis refers to a chemical change caused by the application of thermal energy in the absence of air or nitrogen. The liquid fractions of the thermally decomposed vegetable oils are likely to approach diesel fuels. The pyrolyzate has a lower viscosity, flash point, and pour point than diesel fuel and equivalent calorific values. The cetane number of the pyrolyzate is lower. The pyrolyzed vegetable oils contain acceptable amounts of sulfur, water and sediments and give acceptable copper corrosion values but unacceptable ash, carbon residual and pour point. Depending on the operating conditions, the pyrolysis process can be divided into three subclasses: conventional pyrolysis, fast pyrolysis and flash pyrolysis

b) Micro-emulsification

The formation of micro emulsion is one of the potential solutions for solving the problem of vegetable oil viscosity. Micro-emulsions are defined as transparent, thermodynamically stable colloidal dispersion. The droplet diameters in micro-emulsions range from 100 to 1000 Å. Microemulsion can be made of vegetable oils with an ester and dispersant (co solvent), or of vegetable oils, and alcohol and a surfactant and a cetane improver, with or without diesel fuels. All micro-emulsions with butanol, hexanol and octanol met the maximum viscosity requirement for diesel fuel. The 2-octanol was found to be an effective amphiphile in the micellarsolubilization of methanol in triolein and soybean oil.

c) Dilution

The dilution of vegetable oils can be accomplished with such material as diesel fuels, solvent or ethanol. Dilution results in the reduction of viscosity and density of vegetable oils. The addition of 4% ethanol to diesel fuel increases the brake thermal efficiency, brake torque and brake power, while decreasing the brake specific fuel consumption. Since the boiling point of ethanol is less than that of diesel fuel, it could assist the development of the combustion process through an unburned blend spray.

d) Transesterification

Transesterification is the method of biodiesel production from oils and fats and can be carried out by two ways.

i)Catalytic Transesterification

The "Catalytic Transesterification" process is the reaction of a triglyceride (fat/oil) with an alcohol in the presence of some catalyst to form esters and glycerol. A triglyceride has a glycerin molecule as its base with three long chain fatty acids attached. The characteristics of the oil/fat are determined by the nature of the fatty acids attached to the glycerin. The nature of the fatty acids can in turn affect the characteristics of the biodiesel.

ii) Super Critical Transesterification

The simple transesterification processes discussed above are confronted with two problems, i.e. the processes are relatively time consuming and needs separations of the catalyst and saponified impurities from the biodiesel. The first problem is due to the phase separations of the vegetable oil/ alcohol mixture, which may be dealt with by vigorous stirring. These problems are not faced in the supercritical method of transesterification. This is perhaps due to the fact that the tendency of two phase formation of vegetable oil/alcohol mixture is not encountered and a single phase is found due to decrease in the dielectric constant of alcohol in the supercritical state (at 340°C and 43 MPa). As a result, the reaction was found to be complete in a very short time within 2-4 mins. Further, since no catalyst is used, the purification of biodiesel is much easier, trouble free and environment friendly.

17.2Ethanol from agricultural produce (Sugar cane and corn)

Non-petroleum fuels liquid fuels find use when petroleum fuels are scarce or costly. Among all the fuels, alcohols, which can be produced from sugarcane waste and many other agricultural products, are considered the most promising fuels for the future. There are two types of alcohols: methanol (CH_3OH) and ethanol (C_2H_5OH). Ethanol has attracted a lot of attention as a transport fuel because it is relatively cheap non-petroleum-based fuel. Also, the emissions from the combustion of ethanol are much less than for fossile fuels. Ethanol, being a pure compound, has a fixed set of physical as well as chemical properties. This is in contrast to petrol and diesel, which are mixtures of hydrocarbons. Earlier, this fuel was not used in automobiles due to low energy density, high production cost and corrosion. The current shortage of gasoline has made it necessary to substitute ethanol as fuel in SI engines.

At present, Brazil is the only country that produces fuel alcohol on a large scale from agricultural products (mainly sugarcane). Brazil was the first and biggest producer of cheapest bio-ethanol in the world. Second cheapest bio-ethanol is made from corn in the USA. Properties of ethanol and methanol are similar, with difference of only 5 -10%. Ethanol is superior to methanol as it has wider ignition limit (3.5 -17) than methanol (2.15 -12.8). Ethanol calorific value (26,880 kJ/kg) is considerably higher than methanol (19,740 kJ/kg). Ethanol is a much more superior fuel for diesel engines as its cetane number is 8 compared to the cetane number of 3 for methanol. Ethanol is used in racing cars due to its very high heat of vaporization.

17.3Production of ethanol

Three different feed stocks are available for ethanol production such as, sugar feed stock i.e., sugarcane and sugar beet; starch feed stock i.e., cereal grains and potato and cellulose feed stock i.e., forest products and agricultural residues.

a) Ethanol from starchy feed stock (grains)

Ethanol production from cereal grains such as barley, wheat and corn is a much easier process than from cellulose material. The process includes several steps, as listed below:

a) Milling of grains

b) Hydrolysis of starch to sugar units

c) Fermentation by yeast

d) Distillation

e) Removal of water from ethanol

After grinding the raw material, it is mixed with water and enzymes to break down the starch to sugar units. The free sugar can be used by yeast or bacteria and converted to ethanol and carbon dioxide. As the concentration of ethanol increases to about 15%, fermentation is reduced, since high alcohol concentration kills the yeast or bacteria. It is then necessary to separate the ethanol from the other material in the fermentation tanks by distillation. Distillation increases the ethanol concentration up to about 95%. In order to remove the rest of the water from the ethanol solution, it must be dried by different drying agents to a concentration of 99.5% ethanol or absolute ethanol. Extractive distillation with benzene also yields anhydrous ethanol. It is possible to produce 1 litre of absolute ethanol from about 3 kg of wheat.

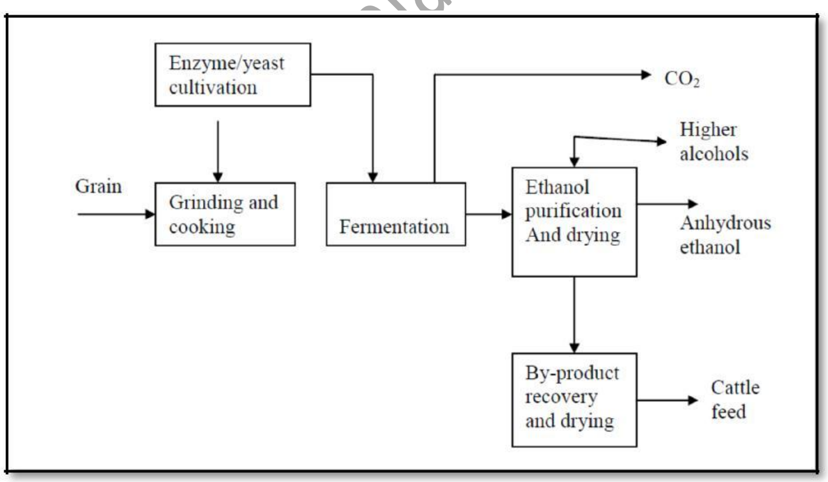


Fig. 17.1 The process flow chart for production of ethanol from grains

b) Ethanol from sugarcane

Ethanol production from sugarcane is one of the easiest and most efficient processes since sugarcane contains about 15% sucrose. The glycosidic bond in the disaccharide can be broken down into two sugar units, which are free and readily available for fermentation. The cane is cut and the juice is extracted by maceration. After clarification, the juice is concentrated by boiling. The concentrated juice is fermented with yeast to produce raw ethanol. A series of distillation steps including a final extractive distillation with benzene are used to obtain anhydrous ethanol. The normal yield of ethanol is about 8.73 litres of alcohol per tonne of cane. The potential of ethanol production in India is about 475 litres per year. The process flow chart for production of ethanol from sugarcane is shown in Fig. 17.1.

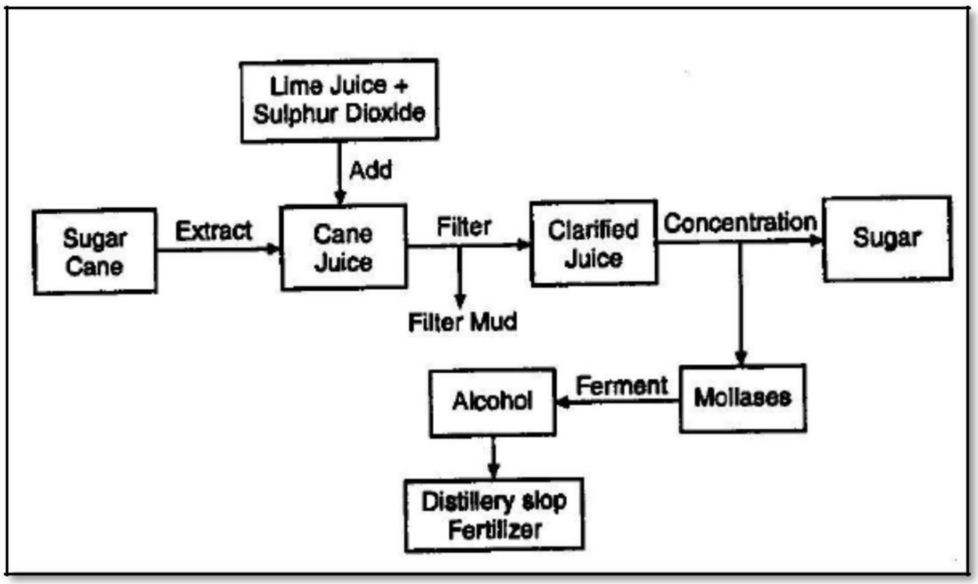


Fig. 17.2. Process flow chart for production of ethanol from sugarcane

Lecture No.18

***Applied use of different types of renewable energy sources from the practical stand* point**

18.1 Applications of renewable energy

Applications of renewable energy are broadly classified as "on-grid" and "off-grid".

A grid is basically an integration of generation, transmission and distribution system which supplies energy to several consumers. On-grid and off-grid are the terms which describe the way electricity is delivered. On grid deals with power stations which are directly connected to grids such as wind farm and solar panels.

Off grid applications, in general, serve only one load, such as a small home or a village house. Off-grid applications can take many forms, from photovoltaic (PV) modules for an individual village home to centralized windmills to power a village water pump or a commercial battery charging facility. These off-grid applications are most generally used in remote or rural settings. A major on-grid application is to generate electricity in mass amounts.

The most important application of wind energy is the wind turbine. The wind turbine can convert the energy in the wind to mechanical power which, in turn, can be fed into a generator to generate large amounts of electricity. This electricity may be used to charge batteries or pump water. Wind energy can also be used in wind-powered vehicles. This can save a lot of fuel and can provide increased performance and efficiency.

Similarly, solar energy can be used to power photovoltaic panels which are an excellent way of producing electricity at small scales, especially for rural and remote areas, where transmission lines cannot reach. Due to their little maintenance and high reliability, they are ideal to use in isolated and far-flung places. Offices can employ glass PV modules for reliable supply of electricity. Solar energy is also widely utilized in solar water heaters, solar calculators and solar lights. They work on the principle of storing energy from the sun during the day and utilizing it at night time.

Geothermal energy is most common amongst farmers. They use this energy to heat their greenhouses which enable them to grow various fruits and vegetables all around the year. In some countries, the heat produced from this energy is also utilized to heat pedestrian walkways and bicycle lanes in order to prevent them from freezing in extreme winters. Solid biomass can be burnt in incinerators to produce heat that can be used to produce steam for electricity generation.

Biomass can also be converted to biofuels like ethanol for transportation needs. A widely used application of hydropower is in a compressor. Specially designed compressors can be used for adjusting turbine blades and governor valves. They can also be used to blow out the water to eliminate the load during starting .