Lecture Outlines
Course No: AENG-351 (NS) 2 (1+1)
Renewable Energy Sources

Lecture No.1

Introduction-Renewable energy sources, classification, advantages and disadvantages

Energy has been an important component to meet the day to day need of human beings. The degree of civilization is measured by the energy utilization for human advancement or needs. Energy has been defined as the capacity to do work or capability to produce an effort. It is expressed in N-m or Joules. The energy density is expressed as J\kg. Before the industrial revolution of the 18^{th} century, most energy used relied on two important sources i.e., human and animal muscles, and the energy of wind and water available in nature. The chemical energy in fire wood was the main source of heat and light.

1.0 Different forms of energy

Broadly speaking two main types of energy are heat and work. However, other forms of energy are 1) electrical energy, 2) mechanical energy, 3) chemical energy, 4) heat energy and 5) nuclear energy. Electrical energy is the most convenient form of energy because it can be easily transported, easily controlled and easily converted into other forms of energy at about 100% efficiency. The only short coming of electrical energy is that it can't be stored in large quantities.

1.1 Classification of energy resources: The various sources of energy can be conveniently grouped as

1.1.1 Commercial primary energy resources: Non-renewable sources of energy or conventional sources of energy are being accumulated in nature for a very long time and can't be replaced if exhausted. Nature gifted resources which are consumed can't be replaced.

Eg: coal, petroleum, natural gas, thermal power, hydro power and nuclear power are the main conventional sources of energy.

1.1.2 Renewable sources of energy: Energy sources which are continuously and freely produced in the nature and are not exhaustible are known as the renewable sources of energy. Eg: solar energy, biomass and wood energy, geo thermal energy, wind energy, tidal energy and ocean energy. But main attention has to be directed to the following sources of renewable namely, a) solar photovoltaic, b) wind, and c) hydrogen fuel cell.

1.2 Advantages of renewable energy

a) These sources of energy are renewable and there is no danger of depletion. These recur in nature and are in-exhaustible.

b) The power plants based on renewable sources of energy don't have any fuel cost and hence negligible running cost.

c) Renewable are more site specific and are used for local processing and application. There is no need for transmission and distribution of power.

d) Renewables have low energy density and more or less there is no pollution or ecological balance problem.

e) 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.

f) 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.

1.3 Disadvantages of renewable energy

a) Low energy density of renewable sources of energy need large sizes of plant resulting in increased cost of delivered energy.

b) Intermittency and lack of dependability are the main disadvantages of renewable energy sources.

c) Low energy density also results in lower operating temperatures and hence low efficiencies.

d) Although renewables are essentially free, there is definite cost effectiveness associated with its conversion and utilization.

e) Much of the construction materials used for renewable energy devices are themselves very energy intensive.

f) The low efficiency of these plants can result in large heat rejections and hence thermal pollution.

g) The renewable energy plants use larger land masses.

1.4 New sources of energy: The new sources of energy is available for local exploitation. In many cases, autonomous and small power plants can be built to avoid transmission losses. Most prominent new sources of energy are tidal energy, ocean waves, OTEC, peat, tar sand, oil shales, coal tar, geo thermal energy, draught animals, agricultural residues etc.,

The total energy production in India is 14559×10^{15} joules. 93% of India's requirement of commercial energy is being met by fossil fuels, with coal contributing 56%, and oil and natural gas contributing 37%. Water power and nuclear power contributing only 7% of total energy production. Comparing the total energy production in India from commercial sources with that of world, it is only 3.5% of total world production.

Lecture No.2

Biomass-Importance of biomass, classification of energy production- principles of combustion, pyrolysis and gasification

2.0 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. Photosynthesis is a naturally occurring process which derives its energy requirement from solar radiation. The plants may be grown on land (terrestrial plants) or grown on water (aquatic plants). Biomass also includes forest crops and residues after processing. The residues include crop residues (such as straw, stalks, leaves, roots etc.,) and agro-processing residues (such as oilseed shells, groundnut shells, husk, bagasse, molasses, coconut shells, saw dust, wood chips etc.,). 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.

2.1 Availability of biomass

The total terrestrial crop alone is about 2×10^{12} metric tones. These include sugar crops, herbaceous crops and silviculture plants. The terrestrial crops have an energy potential of 3×10^{22} joules. At present only 1% of world biomass is used for energy conversion. The estimated production of agricultural residue in India is 200 million tones per year and that of wood is 130 million tones. At an average heating value of 18 MJ / kg db, a total potential of energy from agricultural residue is 6×10^{12} MJ/ Year. At a power conversion rate of 35%, total useful potential is about 75,000 MW. This can supply all our villages with power at a rate of 30,000 kWh per day per village against the present meager consumption of only 150 kWh per day per village.

The cattle production in India is nearly 237 million. Assuming the average wet dung obtained per animal per day to be 10 kg and a collection rate of 66%, the total availability of wet dung in the country would be 575 million tones per annum. This itself would enable to produce 22,425 million m^3 of biogas, which can replace kerosene oil to an extent of 13, 904 million litres per year. In a biogas plant, apart from the gas that is produced, enriched manure is also obtained as a by-product. It is estimated that, 206 million tones of organic manure per annum would be produced in biogas plants, which would replace 1.4 million tones of nitrogen, 1.3 million tones of phosphate and 0.9 million tones of potash.

2.3 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 groups, viz. (i) thermo-chemical conversion, (ii) bio-chemical conversion and (iii) oil extraction.

These alternative technologies for biomass conversion offer sound and alternative options for meeting the future fuels, chemicals, food and feed requirements. Three main approaches can be adopted for generation and utilization of biomass:

(i) Collection of urban and industrial wastes as supplementary fuel in boilers and as a feed stock for producing methane and some liquid fuels.

(ii) Collection of agricultural and forest residues to produce fuels, organic manures and chemical feed stock.

(iii) Growth of some specific energy plants for use as energy feedstock and cultivation of commercial forestry, aquatic and marine plants for different products.

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.

Biochemical conversion includes anaerobic digestion to produce biogas and fermentation to obtain alcohol fuels, The third approach is oil extraction. Edible and non-edible oils can be extracted from a variety of grains and seeds. They can be directly used as fuels by transesterification process to produce bio-diesel, which is a good substitute for conventional diesel oil.

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

Pyrolysis: Biomass +heat $\longrightarrow$ charcoal , gas and oil

Gasification: Biomass +limited oxygen $\rightarrow$ fuel gas

Combustion: Biomass +stoichiometric O_2 $\longrightarrow$ hot combustion products

2.4 Principles of combustion

In general, the term combustion refers to the process of release of heat by the exothermic heat of reaction for the oxidation of the combustible constituents of the fuel. Practically the combustion process is an interaction amongst fuel, energy and the environment.

Fuel may be defined as a combustible substance available in bulk, which on burning in presence of atmospheric air generates heat that can be economically utilized for domestic and industrial purposes. The common fuels are compounds of carbon and hydrogen; in addition variable percentages of oxygen and small percentages of sulphur and nitrogen are also present. Biomass fuels are normally thermally degradable solids. Combustion of organic materials not only generates natural components of air such as carbon dioxide and water but also produces carbonaceous residues, smoke and tar and gases of carbonyl derivatives, and carbon monoxide. The important parameters affecting combustion are moisture, organic compounds and minerals (ash).

2.4.1 Combustion Process

The pyrolysis and subsequent combustion of biomass fuels proceed by two alternative pathways. In the first pathway, which operates at higher temperatures, pyrolysis or thermal decomposition of the biomass provides a mixture of combustible gases. These gases mix with air to fuel the flaming combustion that could rapidly spread in the gas phase. In the second pathway, which dominates at lower temperatures, pyrolysis produces mainly carbonaceous char and a gas mixture containing water and carbon dioxide. That is not flammable. Oxidation of the resulting active char then provides glowing or smouldering combustion. This type of combustion proceeds as a front in the solid phase at a lower rate.

2.4.2 Principles of pyrolysis

The pyrolysis of solid wastes strictly refers to the thermal decomposition of the wastes in an inert atmosphere. In this process, a mixture of gaseous products, tars, water insoluble oils, and an aqueous solution of acetic acid, methanol and other organic compounds is evolved and a solid residue composed of the inert content of the waste and a char is produced. The amounts of the various products generated are dependent upon the rate of heating and the final temperature to which the wastes are subjected. In general, the higher the heating rate, and higher the final temperature, greater the fraction of the initial wastes that is converted into the gaseous and liquid products. The yield of gaseous products is highly variable but is about 25% of the refuse on dry ash-free basis. The yield of char is about 15 to 25% by weight of the refuse.

Pyrolysis or charring of a biomass fuel has three main objectives: (i) production of a less smoky, clean burning fuel without generation of any tar; (ii) production of a fuel with a high calorific value than that of the initial feed material; (iii) production of a more reactive fuel.

As the biomass is subjected to thermal treatment, it decomposes and volatilizes some of the volatile matters, leaving a carbonaceous residue containing the mineral components. The volatile products consists of a gaseous fraction containing CO, CO_2, some hydrocarbons and H_2; a considerable fraction containing water and organic compounds of lower molecular weights such as acids, alcohols, aldehydes, and ketones, and a tar fraction. Fine airborne particles of tar and charred materials constitute smoke. The amounts of volatiles matters formed, the residue left, and the weight loss occurred can be determined by the thermogravimetric analysis (TGA) and its derivative is called differential thermogravimetry (DTG).The change in enthalpy, ΔH canbe measured by differential thermal analysis (DTA). All these analysis are called thermal analysis. The energy released during pyrolysis and combustion can be measured as a function of time or temperature by thermal evolution analysis (TEA).

2.4.3 Principles of gasification

The equivalence ratio, φ is defined as the ratio of the actual air supplied to the theoretical air required.

The efficiency, η of a gasifier is defined as the ratio of chemical energy output in the dry producer gas at 15^0C to the energy input from the biomass.The total energy in the gaseous phase increases with the increase of equivalence ratio, Ø. The important parameters affecting the fixed bed gasification are:

(a) Shape and size of the biomass fuel and fuel bed structure,

(b) Moisture content

(c) Volatile matter content

(d) Ash content

(e) Ash composition, its moisture content and

(f) Energy content.

In the course of gasification, a number of thermochemical reactions take place. The quality of the fuel gas is dependent upon the equilibrium constants of the reactions. In gasification, the quantity of air that is supplied to the gasifier is always sub-stoichiometric. A gasification process that produces pyrolytic oil and char can achieve an overall thermal efficiency in excess of 70%. It may be noted that the products of combustion are generally CO_2, H_2O, N_2 and excess O_2 and those of gasification are CO_2, CO, H_2, CH_4, C_2H_4, C_3H_6, NH_3, H_2S, N_2, H_2O and tar vapours and low molecular weight organic liquids.

Lecture No.3

Biogas-principles of biogas production, advantages, disadvantages, utilization

3.0 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). The biogas can be upgraded to synthetic natural gas (SNG) by removing CO_2 and H_2S. The production of biogas is of particular significance in India because of its large scale cattle production. The biogas is used for cooking, domestic lighting and heating, run I.C. Engines and generation of electricity for use in agriculture and rural industry. Family biogas plants usually of 2-3 m^3 capacity.

3.1 Advantages

a) The initial investment is low for the construction of biogas plant.
b) The technology is very suitable for rural areas.
c) Biogas is locally generated and can be easily distributed for domestic use.
d) Biogas reduces the rural poor from dependence on traditional fuel sources, which lead to deforestation.
e) The use of biogas in village helps in improving the sanitary condition and checks environmental pollution.

f) The by-products like nitrogen rich manure can be used with advantage.

g) Biogas reduces the drudgery of women and lowers incidence of eye and lung diseases.

3.2 Raw materials for biogas generation

Biogas is produced mainly from (i) cow dung, (ii) sewage, (iii) crop residues, (vi) vegetable wastes (v) water hyacinth (vi) poultry droppings and (vii) pig manure. The biogas production from various feed stocks are given in Table 1.

Table 1.Biogas production from various feed stocks

S.No.	Name of the feed stock	Characteristics			
		Total solids (TS), % of wet weight	C/N ratio	Biogas production, lt/kg	Methane in biogas, %
1	Cattle dung	20.8	19.7	32	50-55
2	Banana stem	5.2	25.3	30	65-70
3	Water hyacinth	7.0	18.3	53	75-80
4	Eucalyptus leaves	8.5	38.9	145	70-75
5	Composite agricultural waste	37.0	24.5	78	60-65
6	Grass trimmings	27.0	16.0	60	60-65

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

3.3 Anaerobic digestion

The treatment of any slurry or sludge containing a large amount of organic matter utilizing bacteria and other organisms under anaerobic condition is commonly referred as anaerobic digestion or digestion. Anaerobic digestion consists of the following three stages.

The three stages are (i) the enzymatic hydrolysis, (ii) acid formation and (iii) methane formation.

3.3.1 Enzymatic hydrolosis

In this stage, a group of facultative micro-organisms acts upon the organic matter and convert insoluble, complex, high molecular compounds of biomass into simple, soluble, low molecular compounds. The organic substances such as polysaccharide, protein and lipid are converted into mono-saccharide, peptide, amino acids, and fatty acids. Then theay are further converted into acetate, propionate and butyrate.

3.3.2 Acid formation

The micro organisms of facultative and anaerobic group collectively called as acid formers, hydrolyse and ferment the productions of first phase i.e., water soluble substances into volatile acid. The major component of the volatile acid is the acetic acid. In addition to acetate or hydrogen and carbon dioxide, some other acids like butyric acid and propionic acid are also produced.

3.3.3 Methane formation

Finally, acetate or hydrogen plus carbon dioxide are converted into gas mixture of methane (CH_4) and CO_2 by the bacteria which are strictly anaerobes. These bacteria are called methane fermentators. For efficient digestion, these acid formers and methane fermentators must remain in a state of dynamic equilibrium. The remaining indigestible matter is referred as 'slurry'.

The following are some approximate rules used for sizing biogas plants or for estimating their performance:

1. One kg of dry cattle dung produces approximately 1 m^3 of biogas.
2. One kg of fresh cattle dung contains 8% dry bio-degradable mass.
3. One kg of fresh cattle dung has a volume of about 0.9 litres.
4. One kg of fresh cattle dung requires an equal volume of water for preparing slurry.
5. Typical rention time of slurry in a biogas plant is 40 days.

The efficiency of biogas generation depends upon the following factors:

a) Acid formers and methane fermentors must remain in a state of dynamic equilibrium which can be achieved by proper design of digester.

b) Anaerobic fermentation of raw cow dung can takes place at any temperature between 8 and 55°C. The value of 35°C is taken as optimum. The rate of biogas formation is very slow at 8°C. For anaerobic digestion, temperature variation should not be more than 2 to 3°C. Methane bacteria work best in the temperature range of 35 and 38°C.

c) A pH value between 6.8 and 7.8 must be maintained for best fermentation and normal gas production. The pH above 8.5 should not be used as it is difficult for the bacteria to survive above this pH.

d) A specific ratio of carbon to nitrogen (C/N ration) must be maintained between 25:1 and 30:1 depending upon the raw material used. The ratio of 30:1 is taken as optimum.

e) The water content should be around 90% of the weight of the total contents. Anaerobic fermentation of cow dung proceeds well if the slurry contains 8 to 9% solid organic matter.

f) The slurry should be agitated to improve the gas yield.

g) Loading rate should be optimum. If digester is loaded with too much raw material, acids will accumulate and fermentation will be affected.

Lecture No.4

Biogas plants –classification, types of biogas plants, constructional details of biogas plants

4.0 Types of biogas plants:

Biogas plants basically are two types.

i) Floating dome type

Eg. KVIC-type (KVIC- Khadi Village Industries Commission)

ii) Fixed dome type

Eg. Janata type (Chinese model)

4.1 KVIC type biogas plant

This mainly consists of a digester or pit for fermentation and a floating drum for the collection of gas (Fig. 1). 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.

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 - 00.

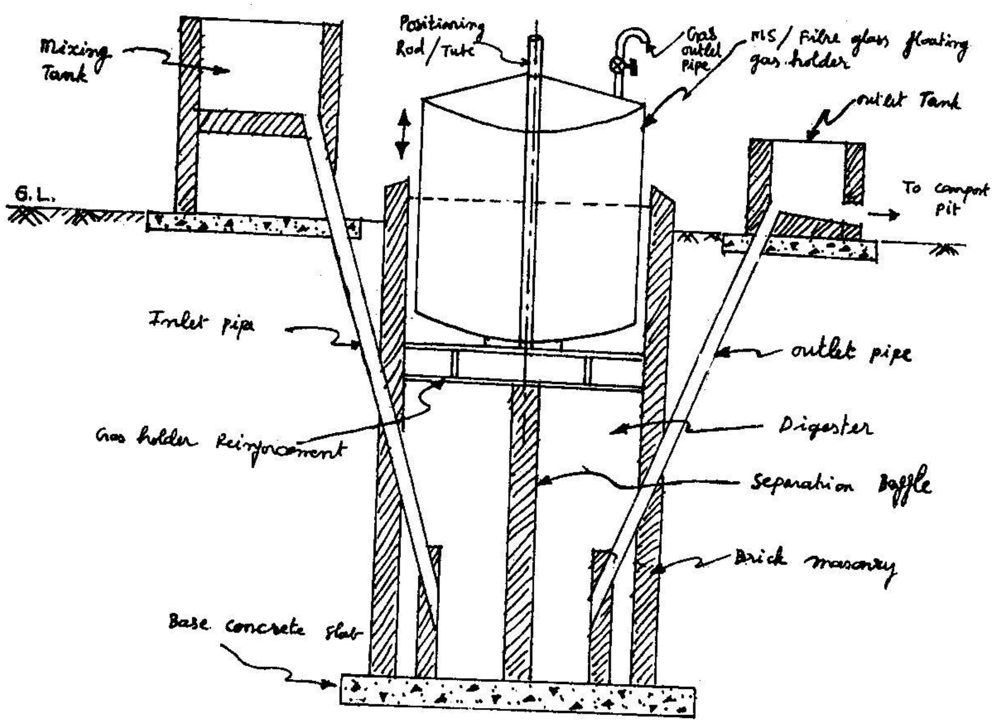


Fig. 1. Schematic diagram of a KVIC biogas plant

4.2 Janata type biogas plant

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. This model have a higher capacity when compared with KVIC model, hence it can be used as a community biogas plant. This design has longer life than KVIC models. 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.2. 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.

4.3 Deenbandhu biogas plant

Deenbandhu model was developed in 1984, by Action for Food Production (AFPRO), a voluntary organization based in New Delhi. Deenbandhu has probably been the most significant development in the

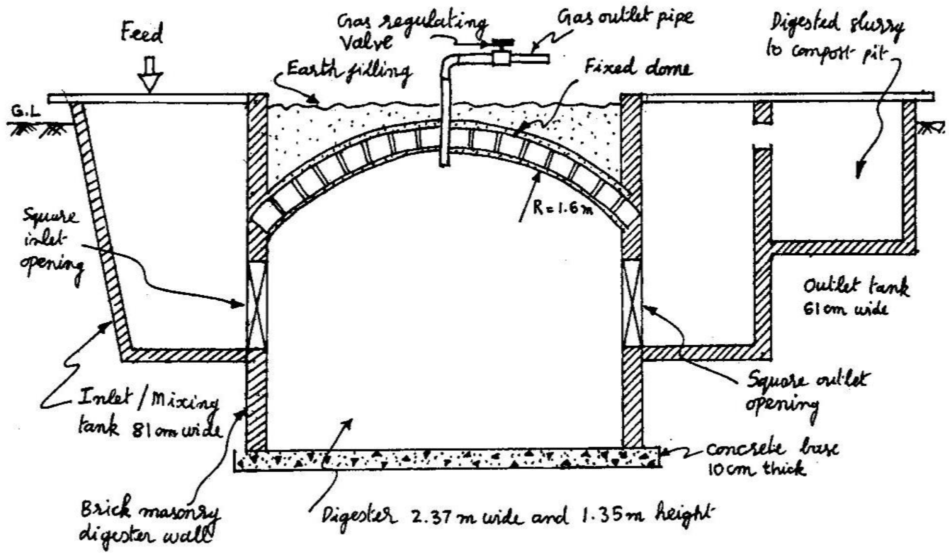


Fig. 2. Schematic diagram of a janata biogas plant

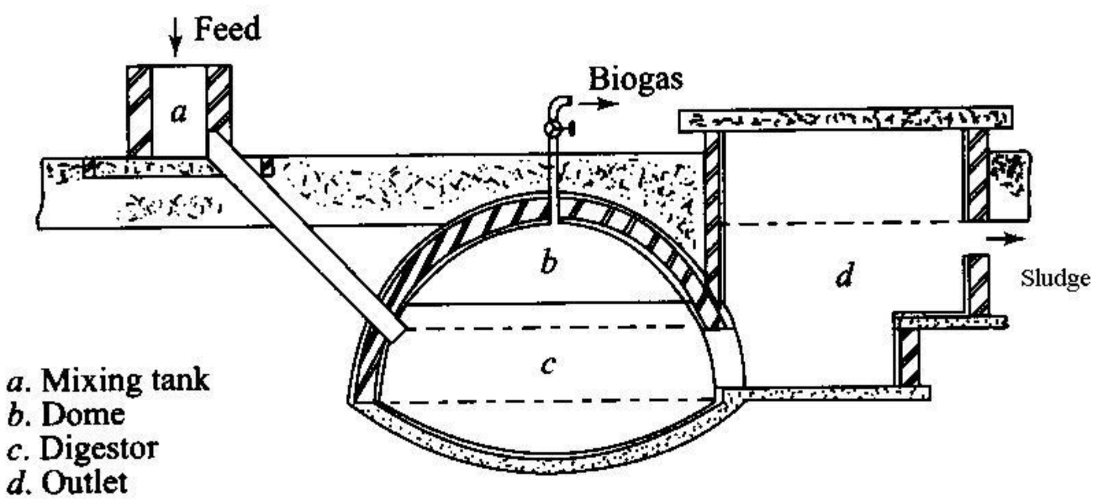


Fig. 3. Schematic diagram of a Deenabandhu biogas plant

entire biogas programme of India as it reduced the cost of the plant half of that of KVIC model and brought biogas technology within the reach of even the poorer sections of the population. The cost reduction has been achieved by minimizing the surface area through joining the segments of two spheres of different diameters at their bases. The cost of a Deenbandhu plant having a capacity of 2 m^3/day is about Rs.8000-00.

The Deenbandhu biogas plant has a hemispherical fixed-dome type of gas holder, unlike the floating dome of of the KVIC-design is shown in fig.3. The dome is made from pre-fabricated ferrocement or reinforced concrete and attached to the digester, which has a curved bottom. The slurry is fed from a mixing tank through an inlet pipe connected to the digester. After fermentation, the biogas collects in the space under the dome. It is taken out for use through a pipe connected to the top of the dome, while the sludge, which is a by-product, comes out through an opening in the side of the digester. About 90 percent of the biogas plants in India are of the Deenbandhu type.

4.4 Application of biogas

One cubic meter of biogas can do the following operations:

(i) It can illuminate a mantle lamp (60 W) for a period of 7 hours.

(ii) It can be used for cooking three meals for a family of five.

(iii) It can run 2 hp engine for one hour.

(iv) It can run 100 lt. capacity refrigerator for 9 hours.

(v) It can generate electricity of 1.25 KWH.

Comparison between KVIC type and Janata type biogas plants

S.No	KVIC- type	Janata type
1.	Capital investment is high	Capital investment is Less
2.	Cost of maintenance is high	Cost of maintenance is minimum
3.	Life span of the plant is expected to be 30 years and that of gas holder is 5-8 years.	Life span of the plant is comparatively more.
4.	Steel gas holder is essential, which require maintenance such as painting, repairing, and replacements of damaged parts due to corrosion.	Steel gas holder is not required.
5.	Locally available materials can't be used for construction of digester. Fabricated gas holder is to be transported from nearby towns.	The entire plant can be constructed with locally available materials.
6.	The space above the movable drum can't be used for other purposes.	The space above the plant can be used.
7.	Effect of temperature during winter is more.	Effect of temperature during winter is less.
8.	The gas is released at a pressure of 8-12 cm of water column.	The gas is released at a pressure of 90 cm of water column.
9.	It is suitable for processing animal dung.	It is suitable for processing other materials along with animal dung.

The following points are to be considered in the construction and maintenance of bio-gas plant:

(1) Locate the bio-gas plant nearer to kitchen to reduce the cost of pipe line.

(2) While digging the plant, the excavated soil should be kept away at least by one meter.

(3) Soil around the well should be thoroughly compacted.

(4) While laying pipe line, provide slight slope towards the kitchen.

(5) To produce more gas during winter, lay the compost around the digester well to a depth of one meter to warm the digester.

(6) Paint the gas drum at outside, every alternate year with good quality paint to prevent corrosion.

(7) Cover the gas drum with paddy straw mat to prevent the drum from cooling in winter.

(8) Mix three parts of dung and two parts of water to produce more gas.

(9) The plant should be located 15 m away from the water supply source.

(10) Avoid construction of plant under waterlogged areas.

(11) Do not allow the sand particles to enter into the digester.

(12) If possible, use PVC pipes instead of A.C. pipes for inlet and outlet.

(13) KVIC digester should be initially charged equally through inlet as well as outlet.

(14) Don't add excess molasses in winter to get more gas, which forms more non-combustible matter.

(15) Cowdung should be mixed with water prior to feeding.

(15) Banana stem and water hyacinth should be chopped in 5 - 10 cm pieces before introducing into the respective plants.

(16) Eucalyptus leaves should be soaked for five days prior to feeding into the plant.

(17) For composite waste biogas plant, chopped rice straw and banana stem should be mixed with cowdung slurry completely.

(18) Feeding should preferably be done at mid-day.

(19) Daily rotate the gas holder and stirrers for 50 times in the morning and 50 times in the evening to break the scum.

Lecture No.5

Types of gasifiers - producer gas and its utilization

Gasification is the process of converting solid biomass with a limited quantity of air into producer gas.

5.0 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:

1) A gasifier itself is of little use. It is used either (a) to generate a combustible gas to provide heat or (b) to generate a fuel gas which can be used in an internal combustion engine as a petroleum oil substitute.
2) 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.
3) 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.

4) 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 Raw materials

The biomass including agricultural residues and other common solid wastes used for gasification.

5.2 Preprocessing of raw materials

Preprocessing of some agricultural and forestry products and other solid wastes is essentially required for making them acceptable for gasification. Some of the common preprocessing operations are as follows:

1) For agricultural products and residues, chipping, drying and densifying operations are carried out.

2) For forestry products, hogging, chipping, drying and densifying operations are being followed.

3) For municipal solid wastes (MSW), size reduction of the MSW is done by one or two stage shredding only. The ferromagnetic and non ferrous metals are separated by magnetic separation and by eddy current or by any other equivalent device. The glass pieces are removed by air classification, trammeling and screening.

The advantages of preprocessing are: (i) storage and handling of feedstocks are made easier, (ii) uniform distribution of the preprocessed feedstock in the gasifier, (iii) channeling action in the flow paths is prevented, (iv) the gasifier top sealing device can be operated without any accident, (v) uniform gas quality is obtained, and (vi) steady rate of production of ash or char is possible. The disadvantages are: (i) additional capital investment for the preprocessing equipments is necessary, (ii) both operational and maintenance costs are involved, and (iii) total preprocessing costs may be high.

5.3 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:

1) Fixed bed gasifiers
2) Fluidized bed gasifiers.

5.3.1 Fixed Bed Gasifier

A fixed bed gasifier is generally a vertical reactor (furnace). The gasifier is fed either from the top or from the side at a certain height. Inside the gasifier the feedstock is supported either on a fixed grate or on a sand bottom. The fixed bed gasifiers may further be divided into updraft, downdraft and cross draft or cross flow units.

5.3.2 Updraft Gasifier

In an updraft gasifier, the feed materials descend from the top to the bottom and the air ascends from the bottom to the top, while air is being blown upward through the grate (Fig.4). The oxidation zone lies at its bottom and gasification occurs through zones of decreasing temperatures as the gas rises through the reactor-fuel bed.

As the reaction gases flow counter to the path of the incoming cool feedstock and exit at a relatively low temperature, the fuel gas produced by an updraft gasifier has high tar content. The height to diameter ratio is usually kept at 3:1.

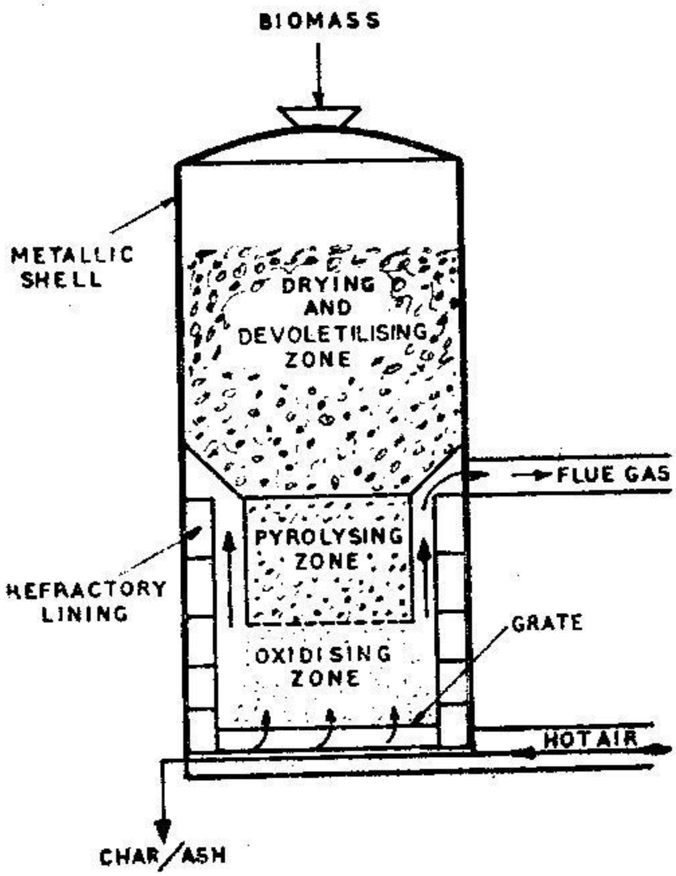


Fig.4. Schematic diagram of updraft gasifier

5.3.3 Downdraft Gasifier

A schematic diagram of down-draft gasifier is shown in Fig. 5. It is a vertical cylindrical vessel of varying cross section. The biomass is fed at the top at regular intervals of time and is converted through a series of processes into producer gas and ash as it moves down. The **first zone** is the **drying zone**, in which the moisture content in the upper layers of the biomass is removed by evaporation. The temperature in this zone is about 120°C. This temperature is acquired by heat transfer from the lower zones which are at much higher temperatures. The dried biomass moves down to the **second zone called the pyrolysis zone**, which is at temperatures ranging from 200 to 600°C from top to bottom. Throughout this zone, the biomass loses its volatiles. In addition, in the lower part of this zone, when the temperature reaches 400°C, an exothermic reaction takes place in which the structure of biomass breaks down. As a result, water vapour, methanol, acetic acid and significant amounts of hydrocarbon tar evolved. The remaining solid is called char (carbon). The third zone is called the oxidation (or combustion) zone. A predetermined quantity of air is drawn into this zone through nozzles and temperatures ranging from 900 to 1200°C are attained. In this zone, a portion of char and pyrolysed gases coming from the second zone are burnt. The principal reactions are exothermic and oxidizing in nature, and the resultant products are carbon dioxide and water vapour. These products pass on to the fourth and last zone called the reduction zone, along with un-burnt pyrolysis gases and char. This zone is at temperatures ranging from 900 to 600°C, the highest temperature being near the oxidation zone. These reactions are endothermic and consequently the temperatures of the zone progressively decrease. At the end, the char is fully consumed and the final products are producer gas and ash**.** The volumetric composition of biomass based producer gas is follows: **CO** 20-22%, **H_2** 15-18%, **CH_4** 2-4%, **CO_2** 9-11%,and **N_2** 50 -54%. The gas also contains measurable amounts of particulate material and tar. The heating value of the producer gas ranges from 4000 to 5000 kJ/m^3.

In a downdraft gasifier, the air is blown through a single duct or a number of equally spaced nozzles around the furnace. The air is blown towards the bottom of the gasifier. As a reaction gases also pass through the higher temperature zones at the bottom, the downdraft gasifier produces cleaner gas with relatively less amount of tars, compared to the updraft or cross-draft gasifiers. Usually larger amounts of tar and volatile matters are thermally cracked, while passing through the higher temperature zones of the bottom. As the gas also passes through the solid char bed, the carrying fly ash and dirt are trapped and the gas is cleaned.

5.3.4 Cross-Draft Gasifier

In a cross-draft gasifier, air is fed into the gasifier through a horizontal nozzle (Fig.6). The resulting fuel gas is discharged through a vertical grate on the opposite side of the air injection location. The biomass can be fed to the gasifier either from the top or from the side. The reactions in the cross-draft gasifier are similar to the downdraft gasifier.

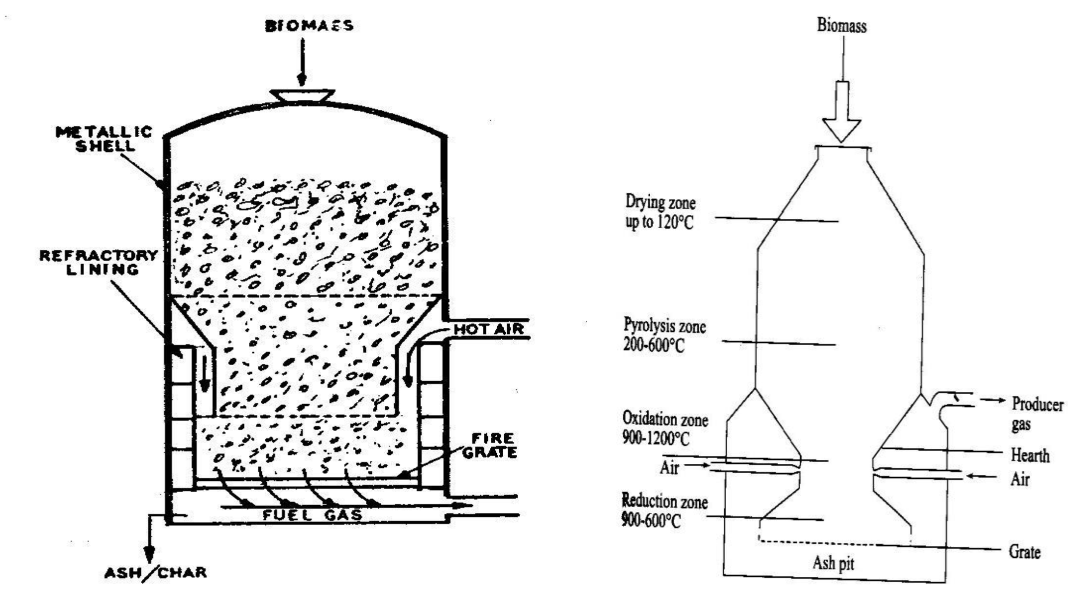


Fig. 5. Schematic diagram of downdraft gasifier

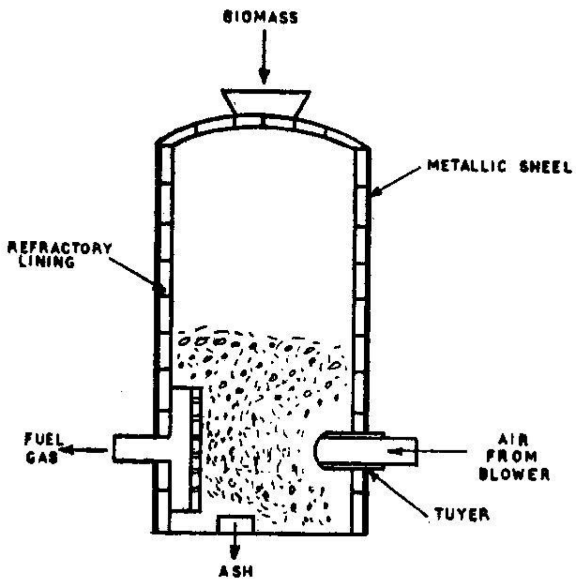


Fig.6. Schematic diagram of cross draft gasifier

5.3.5 Fluidised bed gasifier

In general, the fluidized bed gasifier is a tall refractory lined unit. The inert materials like sand or ash may be used as a fluidizing medium. At the bottom of the reactor, sand or other inert material is supported on a perforated plate with a grid network, which ensures uniform distribution of the fluidizing medium (Fig.7). Fluidization of the sand is achieved by supplying a controlled flow of air or oxygen at a fluidization velocity through the perforated supporting plate. As a result the whole bed including sand will be kept in suspension and separated. In a fluidized bed reactor, the temperature is typically uniform throughout the bed.

Simultaneous oxidation and gasification occur rapidly at constant fluidized bed medium. Because of the high turbulence and thorough mixing of the fluidized bed, its capacity is generally dependent upon the volume of the fluid bed. Generally the height to diameter ratio of a fluidized bed reactor is 10:1.

The bed temperature should be lower than 1100-1150ºC, in order to prevent slagging of the residues, but it should be higher than 850ºC to promote partial oxidation of the feed material.

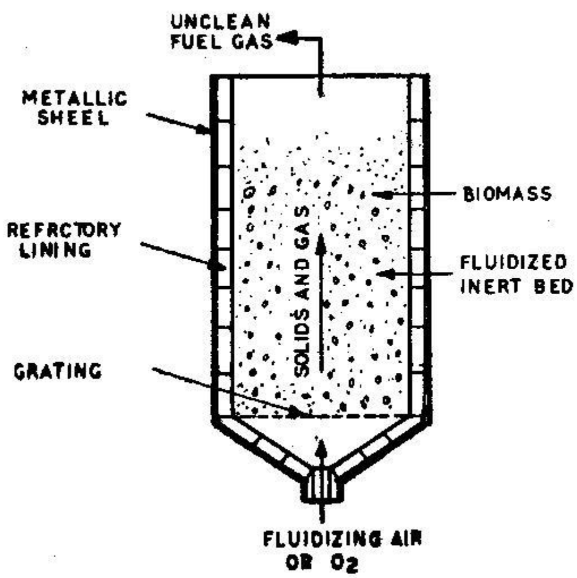


Fig.7. Schematic diagram of fluidised bed gasifier

The output of a biomass gasifier can be used for a variety of direct thermal applications such as cooking, drying, heating water, and generating steam. It can also be used as a fuel for I.C. Engines to obtain mechanical shaft power or electrical power. If the producer gas is used in IC engines, it has to be cleaned for complete removal of particulate material and tar.

The conversion efficiency of a gasifier is defined as the ratio of the heat content in the producer gas to the heat content in the biomass supplied and is usually around 75%.

Lecture No.6

Briquetts, briquetting machinery – types and uses of briquetts. Shredders.

6.0 Briquetting - The concept and background:

Briquetting of biomass is an age old technology and one of the several techniques which are broadly classified as densification technology. This process, specially in India, is as old as time. Cowdung cakes, fuel balls made from coal-dust as well as hand compressed special ‘chulhas’ using wood shavings are some of the prime examples of this process being used in India for centuries. Even development of insulation and architectural boards or wafers and cubes formation from forage materials are techniques of densification, though with a purpose other than utilizing biomass for energy production.

The process of briquetting consists of applying pressure to a mass of particles with or without binder and converting it into a compact aggromate. The products obtained could be in a solid geometrical form or in the form of hollow cylinders.

Briquetting, as a technology was invented in early 19^{th} century. In 1923, the Pacific Coal and Wood Co. Los Angeles, California, USA was already marketing wood waste briquettes.

Utilization of biomass in the form of leaves, bark, wood, cakes etc., for cooking food and warming the space in winter is known to human civilization for many centuries. The easiest and simplest way of utilizing the heat content of these biomass resources has been practiced till recent past, is to burn them ‘as it is’. However, now it has been realized that such burning of biomass has certain disadvantages as mentioned below:

1) Most of the agro-forestry biomass contains high moisture (18-20%). The heat generated by burning of high moisture biomass is consumed in drying the biomass itself, thus depriving the quality.

2) Most of the biomass are bulky and many of them are available in powder form, creating dust and polluting the environment. Also it is very difficult to handle and transport, and storage expensive.

3) Biomass has poor combustion properties.

4) It produces plenty of smoke.

5) Expensive and sophisticated furnace is needed.

6) Complete draft and exhaust system gets blocked due to ash carry over and the emission pollutes the environment.

7) Ash may insulate the heating area, thereby reducing the energy efficiency of the system.

8) Most of the biomass is not successfully used in simple gasifiers and small boilers.

10) Some of the biomass need an expensive and sophisticated equipment like fluidized bed boilers to achieve maximum efficiency.

The simplest solution of all above problems (low bulk density, high volume and expensive handling, transportation and storage) lies in briquetting of biomass. The process of compaction of biomass into a product of higher density than the original raw material is known as densification or briquetting. It has compression ratio of approximately **7:1**, the loose biomass to form briquettes. The compacted fuels, known as briquettes is more or less similar to coal and has potential to replace conventional solid fuels and even diesel to meet the local needs of various sectors.

6.1 Advantages in briquetting of biomass

1) The process helps to solve the problem of loose waste / residues of agricultural forestry and agro-industrial processing so as to check environmental pollution.

2) The process increases the net calorific value per unit volume.

3) The fuel produced is uniform in size and quality.

4) No toxic gas and sulphur emission, even no odour during combustion.

5) 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).

6) Fire risk in loose storage of biomass is minimized.

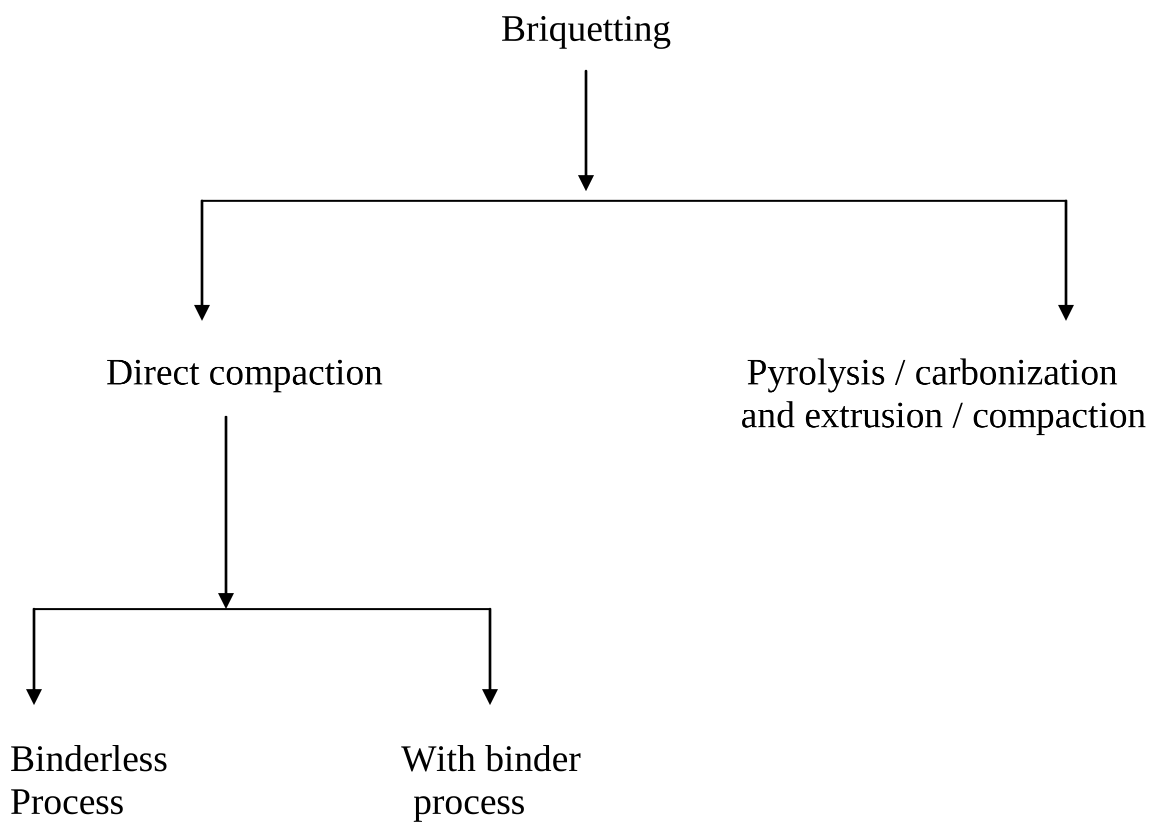
7) The process produces high quality fuel with very low ash content (2-5 %) compared to 30-40% in case of coal.

8) The briquettes are easy to burn, as briquettes have lower ignition temperature compared to coal.

9) It produces gas during burning which accelerates burning efficiencies and inhales Co_2 and releases oxygen to the atmosphere.

6.2 Process 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:



6.2.1 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

(a) **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.

(b) **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.

6.2.2 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 / compaction process.

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.

6.4 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 (product 2 -10 cm dia log).

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 –application of solar energy, methods of heat transfer, conduction, convection and radiation.

The fossil fuels in the world are depleting very fast by the turn of this century, man will have to depend upon renewable resources of energy which are free from pollution, low in cost of transmission and distribution. Sun is the primary source of energy and all forms of energy on the earth are derived from it.

Our solar system consists of the sun, 9 planets orbiting around the sun. Satellites (or moons) orbiting around the planets, asteroids, comets and meteors. The sun is at the centre of solar system and all these bodies revolve around it, and are held by its great gravitational pull, which governs their motion.

Sun is heaviest body of the solar system around which all the planets revolve. The mass of the sun is 1.98×10^{30}kg and its diameter is 1.392×10^{9}m. It is about 109 times the diameter of the earth. The average distance of the sun from the earth is about $1.496*10^{11}$m.,which is called one astronomical unit (AU).The sun rotates around its axis and completes one rotation in 25 days. The temperature and pressure in the interior of the sun are extremely high, and the temperature on the surface is 6000K.The sun continuously emits radiations in visible region and in the radio wave region in all the directions and the small fraction of it reaches the earth. The light emitted from the sun reaches the earth in 8.3 minutes, and it is the main source of heat and light energy for all the members of solar system including the earth.

Energy in the form of heat is one of the main energy requirements in the domestic, agricultural, industrial and economical sectors of our economy.

Pyranometer: It is used to measure total radiation (direct and diffuse) in terms of energy per unit time per unit area on a horizontal surface.

Pyrheliometer: It is used for measuring beam radiation.

Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximtely1.8×10^{11} 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.

7.0 Applications of solar energy

1.Heating and Cooling of buildings

2. Solar water and air heating
3. Salt production by evaporation of seawater
4. Solar distillation
5. Solar drying of agricultural products

6. Solar cookers

7. Solar water pumping

8. Solar refrigeration

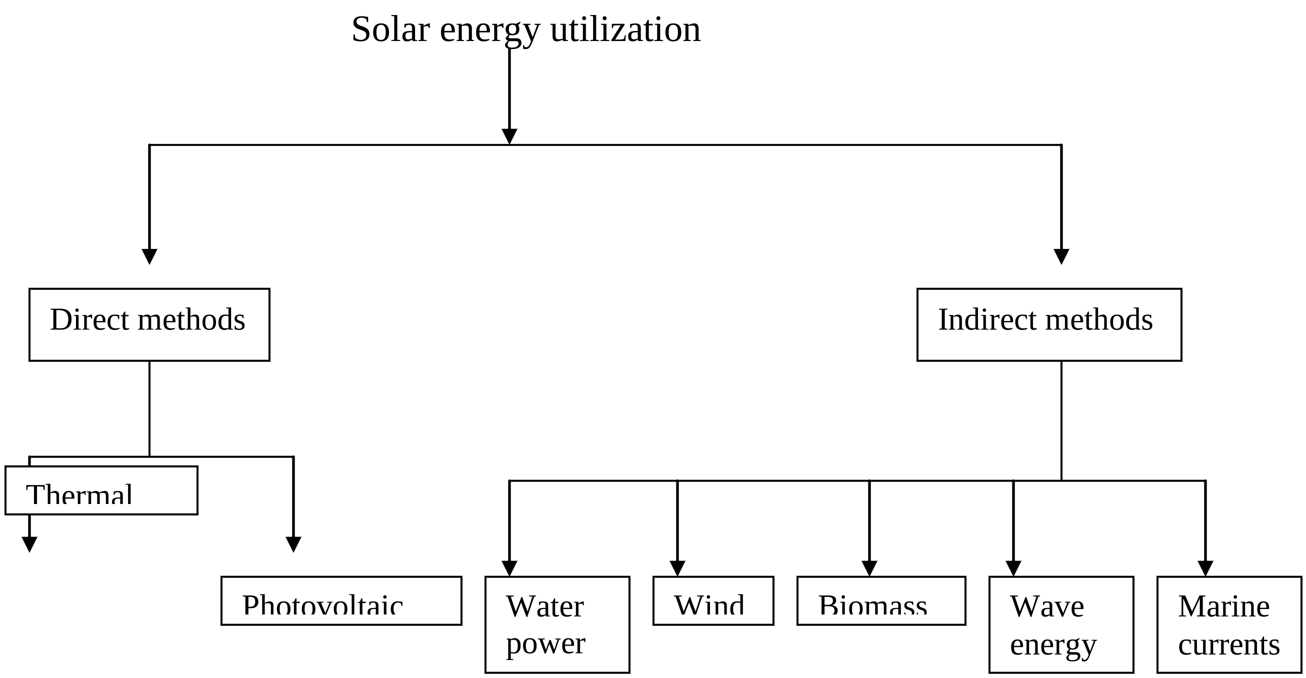
9. Electricity generation through Photo voltaic cells

10. Solar furnaces

11. Industrial process heat

12. Solar thermal power generation

7.1 Classification of methods for solar energy utilization



7.2 Heat transfer for solar energy utilization

Heat transfer occurs mainly by 3 mechanisms. The first is by conduction through solid materials in the presence of a temperature difference. The second mechanism is by radiation in which energy moves in space by electromagnetic waves in a moving fluid. The moving molecules gain heat or lose it by conduction or radiation and carry it by their movement from one place to another. In this process, the third mechanism is convection.

Lecture No.8

Solar appliances- flat plate collectors, focusing type collectors, solar air heater.

8.0 Basic principle in solar thermal energy systems

In any collection device, the principle usually followed is to expose a dark surface to solar radiation so that the radiation is absorbed. A part of the adsorbed radiation is then transferred to a fluid like air or water. When no optical concentration is done, the device in which the collection is achieved is called a flat-plate collector. When higher temperatures are required, it becomes necessary to concentrate the radiation. This is achieved using focusing or concentrating collectors. For low temperature applications i.e., below 100^0C, flat plate collector is used, while for higher temperatures, concentrating collectors are used.

8.1 Flat plate collector

The flat plate collector mainly consist of a casing, absorber plate, transparent glass covers, insulating material and fluid passage tubes (Fig.8).

When the collector is exposed to sun, the radiation (**Beam, diffuse radiation**) pass through transparent glass covers. The radiation is absorbed by absorber plate, which is coated with black absorber paint. The fluid tubes, which are connected to absorber plate, absorb the heat and transferred to the water passing through the tubes and gets heated. The hot water collected from all the tubes flow into a storage tank. Insulation (paddy husk, saw dust, glass wool.) provided to the absorber plate to avoid loss of heat by conduction. Loss of heat by re-radiation is avoided by having good absorber coating. The convective loss is reduced by minimizing the air gap between the glass covers. The temperature attained is in the range of 40 – 100^{O}C depending upon the intensity of solar radiation. A liquid flat-plate collector is usually held tilted in a fixed position on a supporting structure, facing north if located in the northern hemisphere.

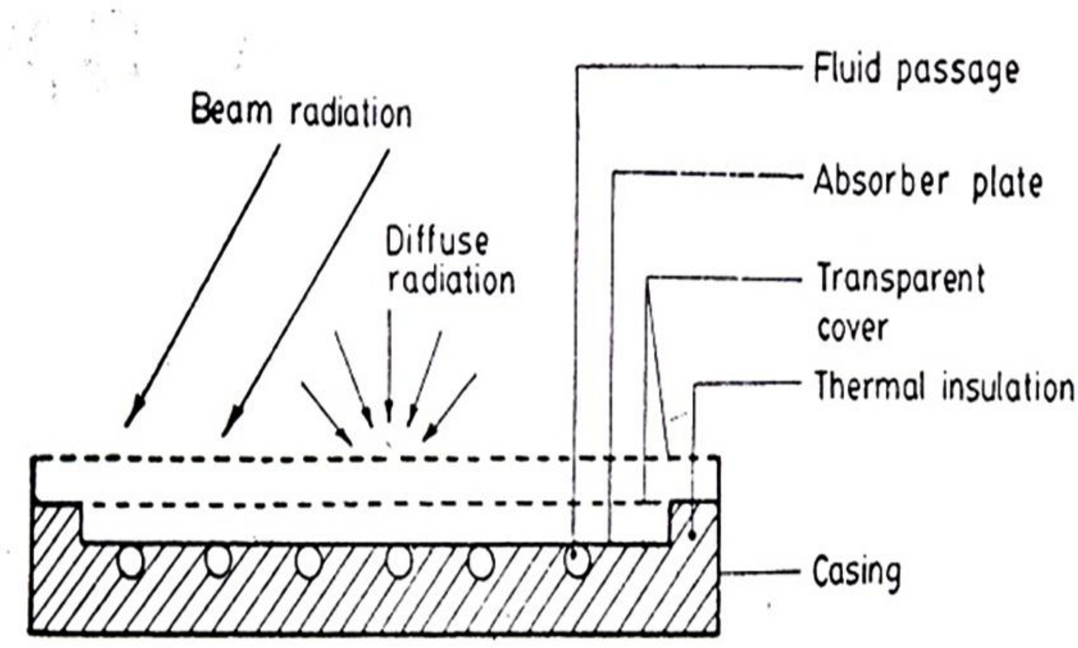


Fig. 8. Schematic diagram of liquid flat-plate collector

8.2 Cylindrical parabolic concentrating collector

In this type of collector (Fig.9), the radiation coming on concentrator is diverted to absorber tube, which is covered with glass tube to avoid re-radiation loss. The heat from the absorber tube is transmitted to the fluid passing and gets heated up. The hot liquid flows out to a storage tank for further application. The direction of concentration is changed with the sun movement by providing single axis tracking. The temperature attained by the collector is **100-300^{0}C.**

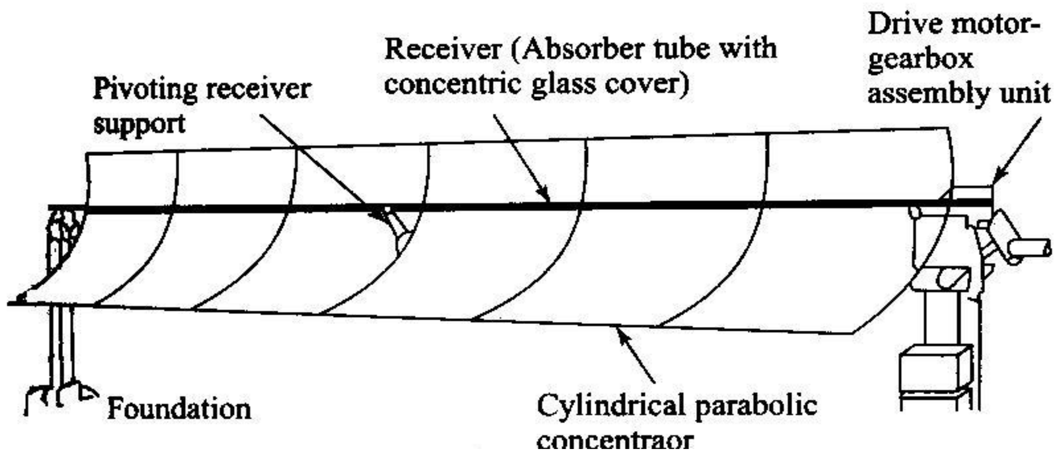


Fig. 9. Schematic diagram of cylindrical parabolic concentrating collector

8.3 Paraboloid concentrating collector

This type of collector (Fig.10) is provided with two axis tracking and is free to move both on vertical and horizontal axis. 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.

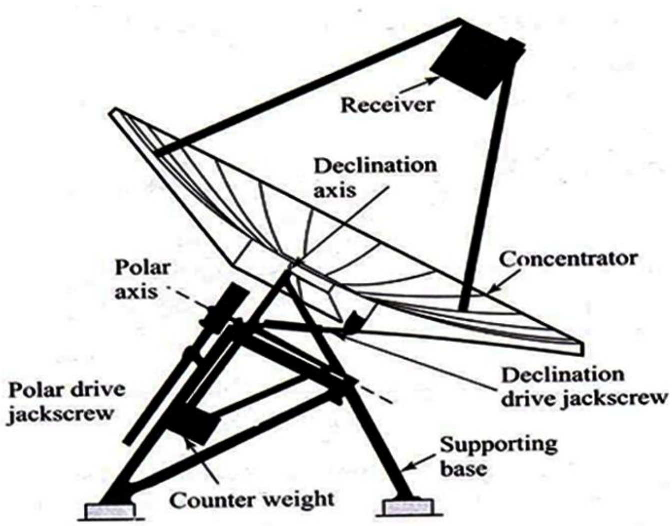


Fig. 10 . Schematic diagram of paraboloid concentrating collector

8.4 Solar air heater

The heat absorbed by the absorber plate is transmitted to the air drawn into the collector (Fig.11). 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 15^0**.

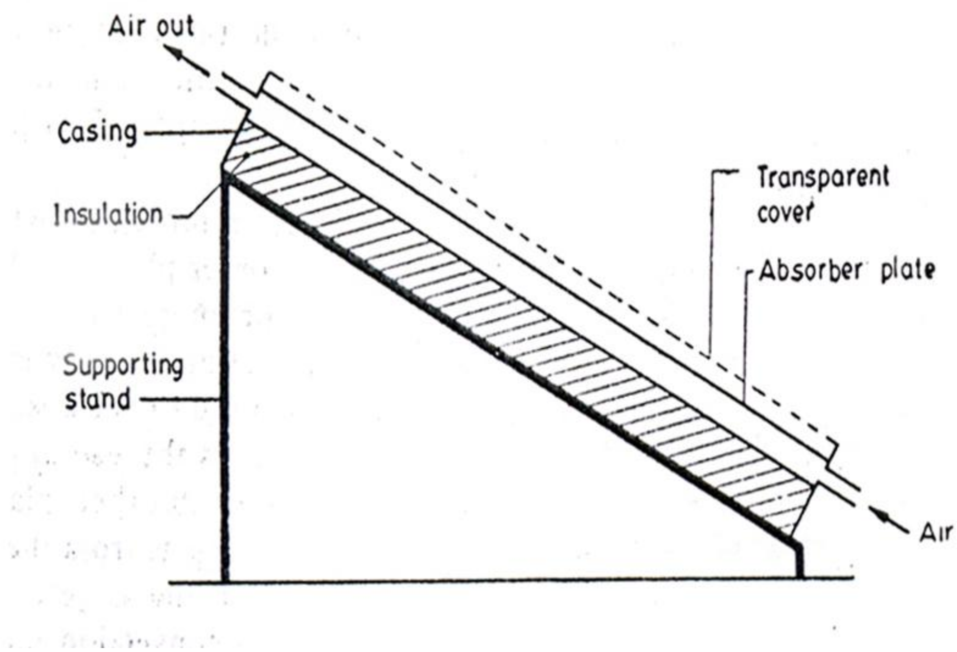


Fig. 11. Schematic diagram of solar air heater

Lecture No.9

Solar space heating and cooling- solar energy gadgets, solar cookers, solar water heating systems.

9.0 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 and (ii) Active methods.

9.1 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. A schematic diagram is shown in fig.12. It was designed by Prof.Trombe. The south face of the house is to be heated by proving a single or double glazing. Behind it is a thick, black concrete wall absorbs the solar radiation and serves as a thermal storage. Vents (A and B) are to be provided near the top and bottom of the storage wall. The whole unit consisting of the storage wall with vents and the glazing is referred to as a “Trombe wall”. During the day, both vents A and B are kept open. The air between the inner glazing and the wall gets heated and flows into the living space through the top vent. Simultaneously, the cooler air from the room is pulled out of the living space through the bottom vent. Thus, a natural circulation path is set up. Some energy transfer to the living space also takes place by convection and radiation from the inner surface of the storage wall. During the night, both vents are closed and energy transfer takes place only by convection and radiation from the inner surface.

The Trombe wall design can also provide summer ventilation by using vents C and D near the top of the glazing and on the south and north facing wall respectively. On a hot summer day, vents B, C and D have to be kept open, while vent A has to be kept closed. The heated air between the glazing and the wall would then flow out through vent C, drawing air from the living space to replace it. This in turn would cause air to be pulled in from outside through vent D. Vent D should be located in a such away that the air pulled in through it comes from a shaded and cool area, for which the presence of overhang on the roof of the house is required. This prevents falling of direct radiation on the glazing during summer and makes ventilation more effective.

9.2 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 (Fig. 12). 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.

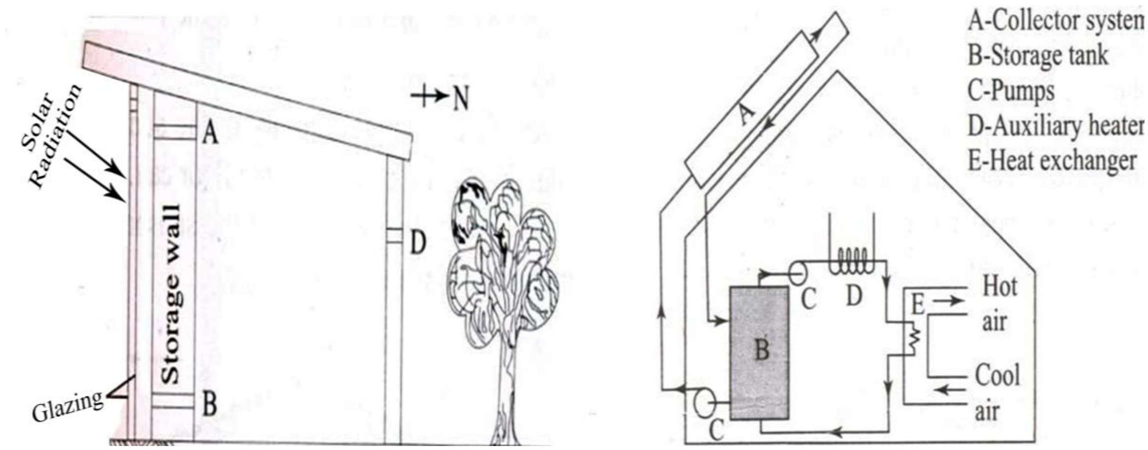


Fig. 12. Schematic diagram of a space heating system

(Passive and Active method)

9.3 Solar cooker

The solar rays penetrate through the glass covers and absorbed by blackened metal trays (Boxes) kept inside the cooker(Fig.13). 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 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.

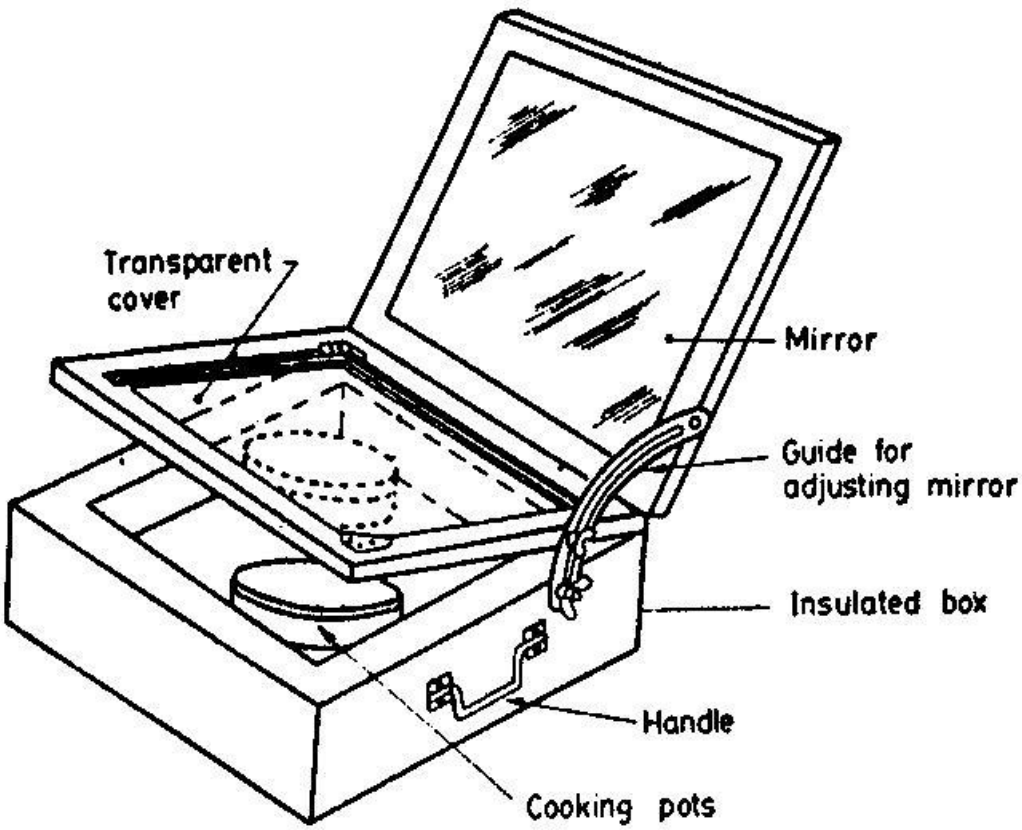


Fig. 13. Schematic diagram of box type solar cooker

Merits of solar cooker

1. No orientation to sun is needed.
2. No attention is needed during cooking.
3. No fuel, maintenance and recurring cost.
4. Simple to use and fabricate.
5. No pollution.

6. No loss of vitamins in the food.

Demerits of solar cooker

1. Cooking can be done only when there is sunshine.
2. Quick cooking is not possible.
3. Comparatively it takes more time.
4. All types of foods can’t be cooked.

9.4 Solar water heating

Solar water heating is one of the most attractive solar thermal applications from an economic standpoint. In India, a large number of systems have been installed. Most of the systems use flat-plate collectors. It is cumulatively estimated that the total area of the flat-plate collectors in the systems installed in India till june 2006 is about 1.5×10^6 m^2. In India, the market for domestic solar water heating systems has been growing steadily. Most of the systems have capacities in the range of 100 to 200 litres per day, use one or two flat-plate collectors having a face area of about 2 m^2 each, and deliver hot water in the temperature range of 50 to 70°C. The installed cost in 2006 was about Rs. 180 per liter/ day capacity The hot water is used for domestic purposes or for meeting the needs of industries and commercial establishments.

9.5 Solar water heater

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 (Fig.14).

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 and (ii) Forced circulation system.

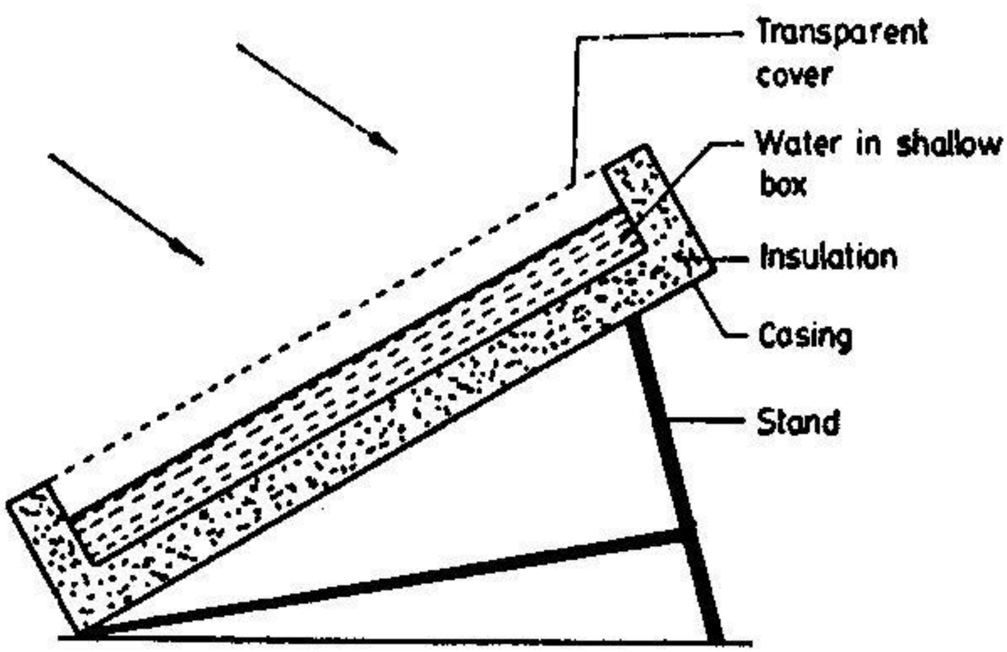


Fig. 14. Schematic diagram of solar water heater

9.6 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.15.

A 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 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.

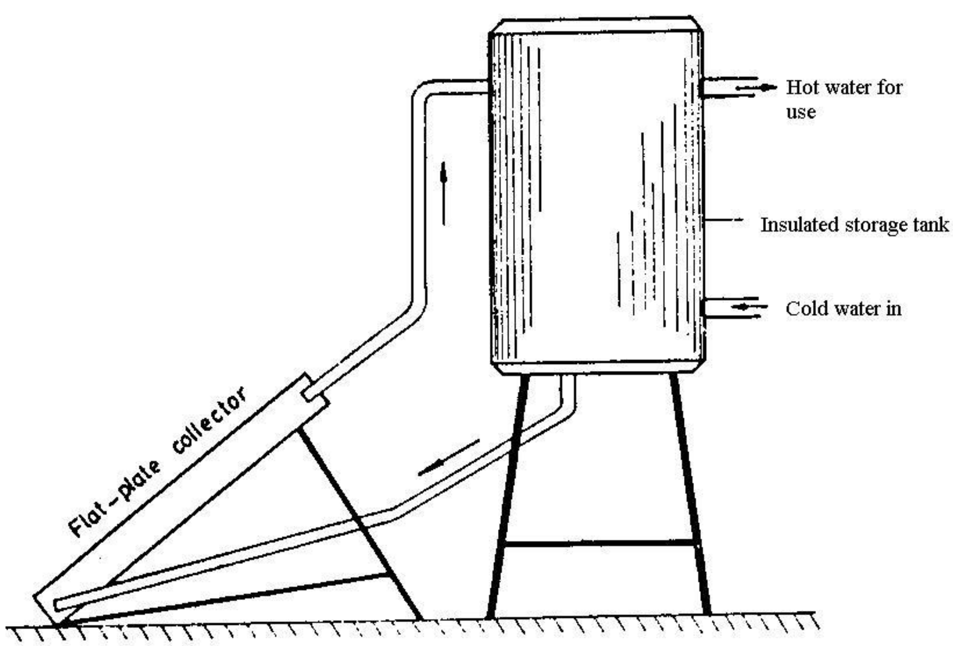


Fig. 15. Schematic diagram of natural circulation water heating system

9.7 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.16.

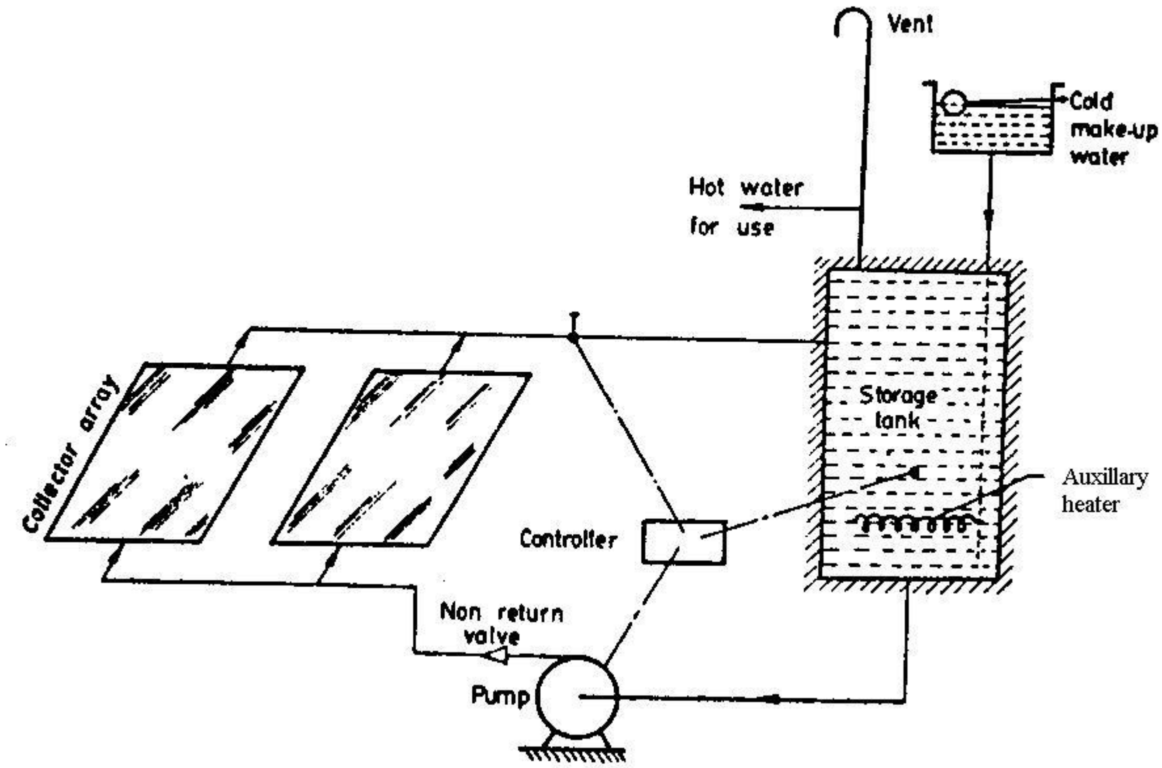


Fig. 16. Schematic diagram of forced circulation water heating system.

Lecture No.10

Solar grain dryers, solar refrigeration system, solar ponds.

10.0 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.

10.1 Cabinet dryer

A cabinet type solar dryer is suitable for **small scale** use (Fig.17). The dryer consists of an enclosure with a transparent 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**. Products like dates, apricots, grapes, chillies, turmeric etc., can be dried in a cabinet dryer.

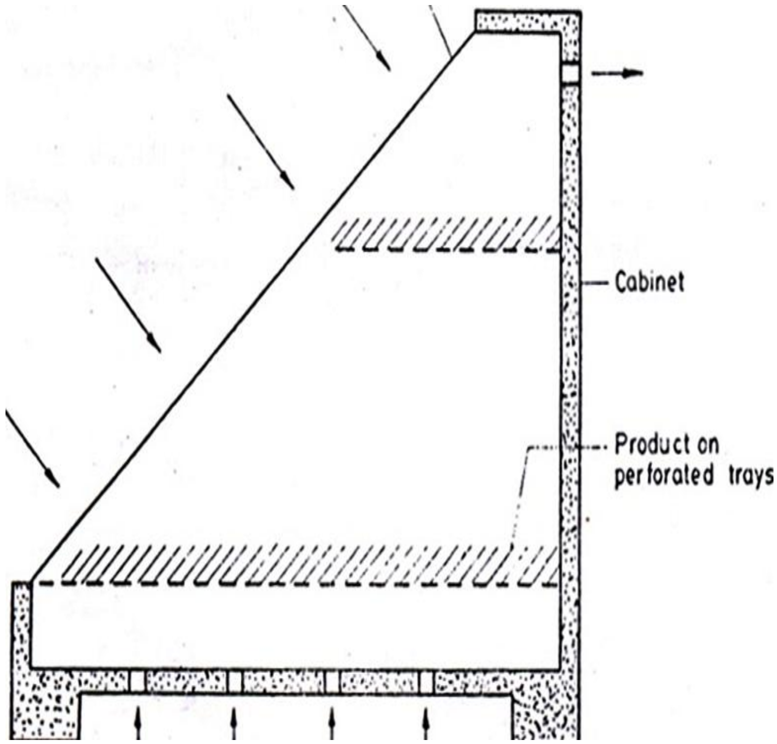


Fig. 17. Schematic diagram of cabinet dryer.

10.2 Convective dryer

For large scale drying, convective dryer is used (Fig.18). 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. 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.

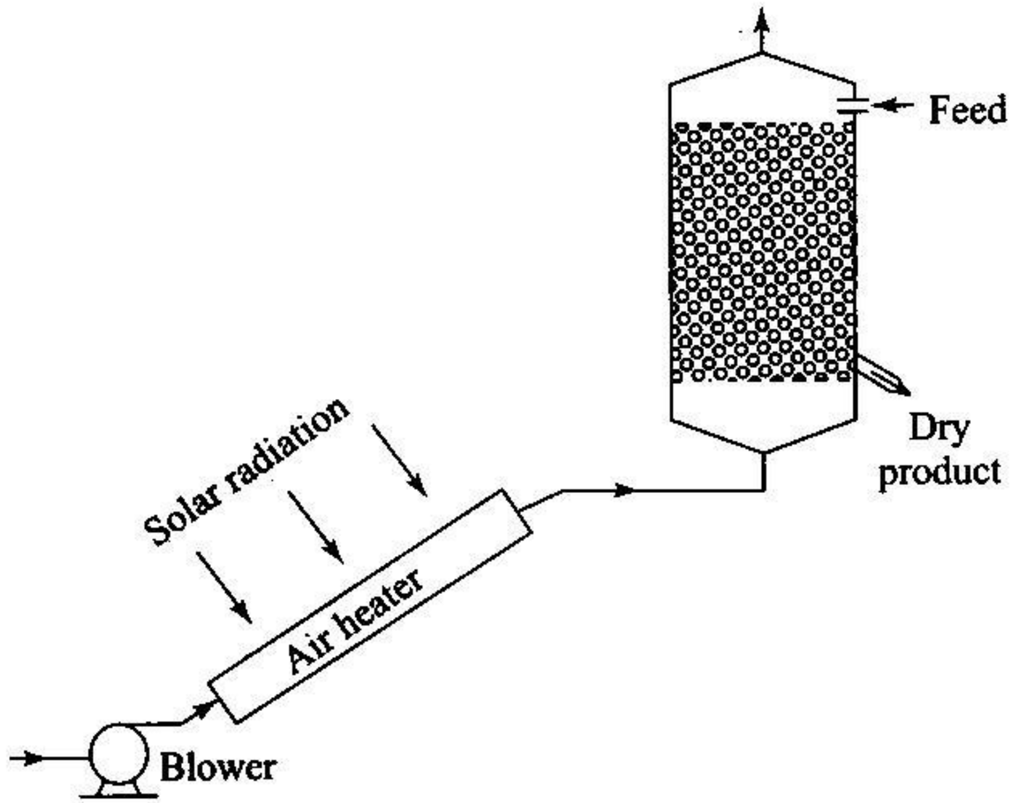


Fig. 18. Schematic diagram of convective dryer

10.3 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.19. 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.

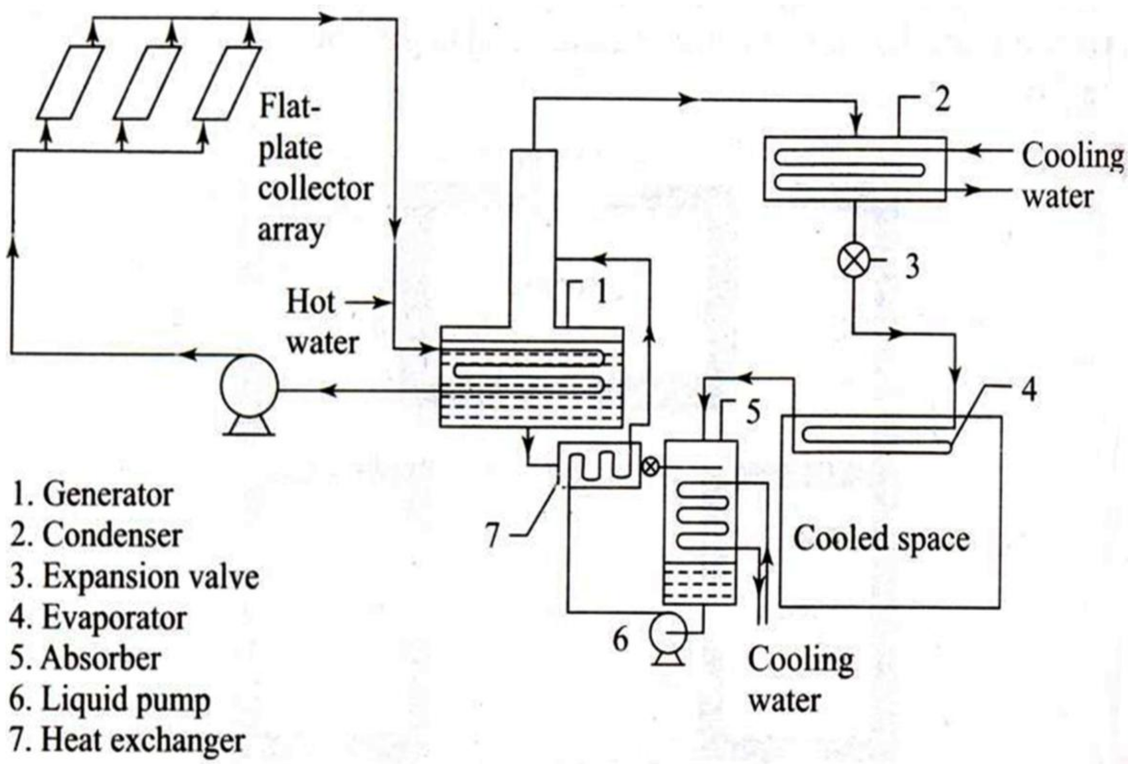


Fig. 19. Schematic diagram of solar absorption refrigeration system

10.4 Distillation of water

In many small communities, the natural supply of fresh water is inadequate in comparison to the availability of brackish or saline water. Solar distillation can prove to be an effective way of supplying drinking water to such communities.

Basin type solar stills are adopted for distillation of water. A solar still of basin type is shown in fig.20., essentially consists of a basin coated with black paint. The basin stores brackish water, which is used for distillation. The basin is closed with transparent cover. In the top of basin walls, condensate channels are provided. When the still is exposed to solar radiation, the absorber plate absorbs radiation and water inside is heated up. After sometime, evaporation starts and evaporated water gets condensed below the transparent cover and water condensate travel to the channel. The channels are provided gradient to one side where the condensed water is collected. A well designed still capacity is 3 lit/m^2 on a good sunny day.

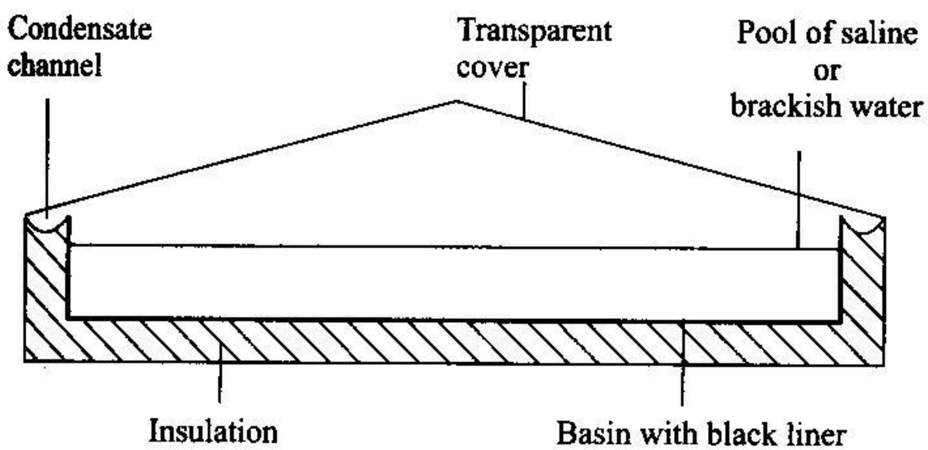


Fig. 20 . Schematic diagram of a solar still

10.5 Solar ponds

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**. Natural ponds convert solar radiation into heat, but the heat is quickly lost through convection in the pond and evaporation from its surface. A solar pond, on the other hand, is designed to reduce convective and evaporative heat losses 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.

The solar ponds are useful in two ways:

(i) The conversion of solar energy to useful work as a result of the temperature difference between bottom and top layers of the pond.

(ii) The use of pond as a thermal storage medium.

10.5.1 The main applications solar ponds are

(a) heating and cooling of buildings
(b) power generation
(c) agricultural crop drying
(d) desalination
(e) industrial process heat
(f) production of renewable liquid fuels

10.5.2 The main limitations of solar ponds are

(a) Need for large land area
(b) Require sunny climate
(c) Availability of brackish water

Solar ponds may be classified as (i) convecting and (ii) non-convecting

10.6 Convective solar ponds

Convective solar pond reduces heat loss by being covered a transparent membrane or glazing as **shown in fig. 21**. Glazing materials for the solar pond are polyvinyl chloride (PVC) film and clear acrylic panels.

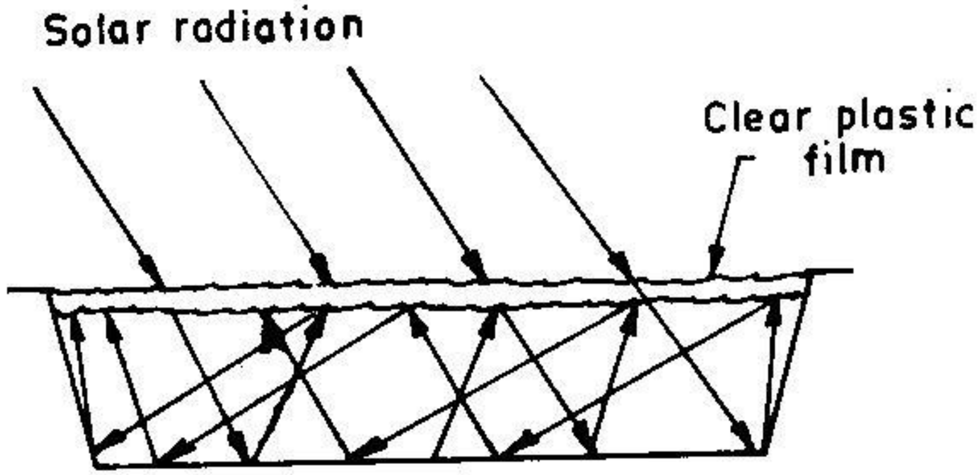


Fig. 21 . Schematic diagram of convective solar pond

One type of solar pond use a plastic tube filled with water as shown in **fig. 22.**

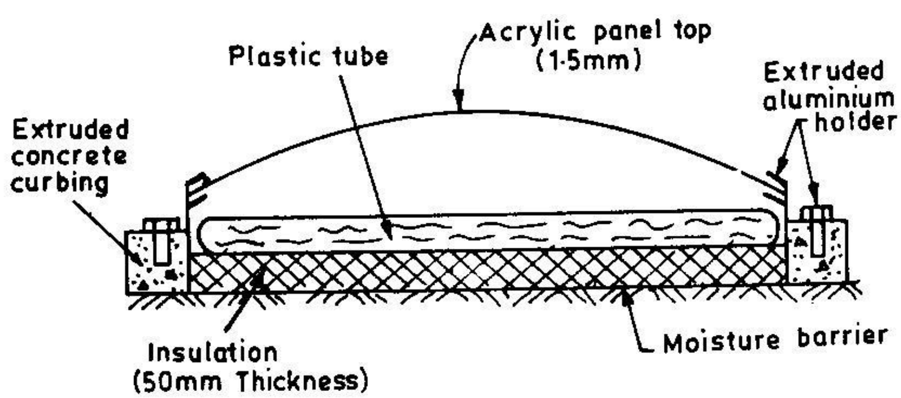


Fig. 22. Schematic diagram of shallow solar pond

Each pond module includes a long, narrow plastic bag measuring 5× 60 cm containing water 5 -10 cm deep. The bag has a transparent top to allow transmission of sunlight and to prevent evaporation losses. The bottom of the bag is black to absorb sunlight. A layer of insulation beneath the plastic bag minimizes heat losses to the ground. One or two layers may be arched over the bag of water to suppress convective and radiative losses. In this type of solar pond, the hot water is removed late in the afternoon and stored in insulated reservoirs.

10.7 Non-convective solar ponds

Non-convective solar ponds prevent heat losses by inhibiting the convective forces caused by thermal buoyancy. In convective solar ponds, solar radiation is transmitted through the water to the bottom, where it is absorbed; in turn, the water adjacent to the bottom is heated. Natural buoyancy forces cause the heated water to rise, and the heat is ultimately released to the atmosphere. In a non-convective solar ponds, the warm water is prevented from rising to he surface. Non-convective ponds may be stabilized by viscosity, a gel or a salt. The salt gradient pond is the most common type of non-convective solar pond.

10.8 Salt gradient ponds

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.23.

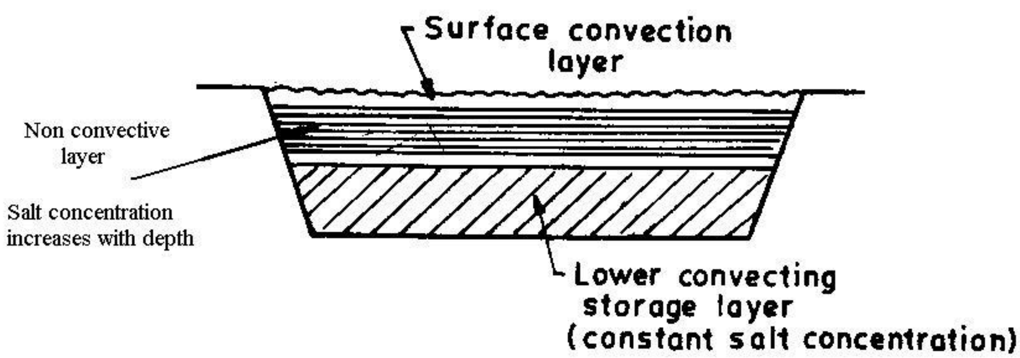


Fig. 23. Schematic diagram of salt gradient solar pond

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 non-convective. 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.

Lecture No.11

Solar photovoltaic system-solar lantern, solar street lights, solar fencing, solar water pumping system.

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. 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 are (i) monocrystalline silicon cells, (ii) Poly crystalline silicon cells, (iii) Amorphous silicon cells (iv) Gallium arsenide (GaAs), and (v) Copper 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.

11.0 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/m^2. 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.

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

11.2 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.

11.3 The advantages of photovoltaic solar energy conversion

a) Absence of moving parts.
b) Direct conversion of light to electricity at room temperature.
c) Can function unattended for long time.
d) Low maintenance cost.
e) No environmental pollution.
f) Very long life.
g) Highly reliable.
h) Solar energy is free and no fuel required.
i) Can be started easily as no starting time is involved.
j) Easy to fabricate.
k) These have high power-to-weight ratio, therefore very useful for space application.
l) Decentralized or dispersed power generation at the point of power consumption can save power transmission and distribution costs.
m) These can be used with or without sun tracking.

11.4 The limitations of photovoltaic solar energy conversion

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

11.5 Solar lantern

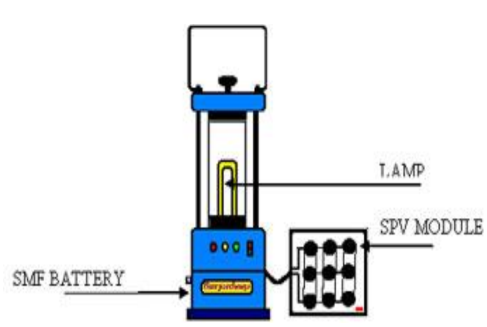


Fig.24. Schematic diagram of a solar lantern

A Solar lantern 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.24) 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.

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.

Benefits

It is easy to install, no electrical connection is required and no electricity charges.

Safety Features

System is completely shock proof due to low voltage circuitry and short circuit protection.

11.6 Solar street light

This system is designed for outdoor application in un-electrified remote rural areas (Fig.25). This system is an ideal application for campus and village street lighting. The system is provided with battery storage backup sufficient to operate the light for 10-11 hours daily. The system is provided with automatic ON/OFF time switch for dusk to down operation and overcharge /deep discharge prevention cut-off with LED indicators.

The solar street light system comprise of

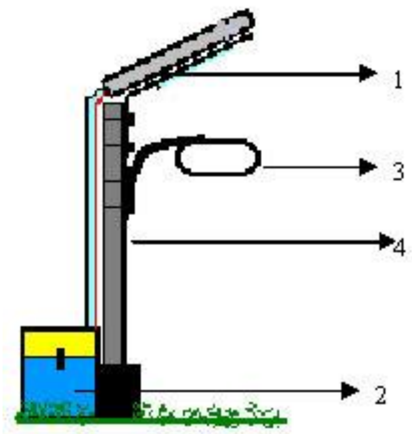
a) 74 Wp Solar PV Module

b) 12 V, 75 Ah Tubular plate battery with battery box

c) Charge Controller cum inverter (20-35 kHz)

d) 11 Watt CFL Lamp with fixtures

e) 4 metre mild steel lamp post above ground level with weather proof paint and mounting hardware.



1. SPV Module
2. Battery Box
3. Lamp with charge controller
4. Lamp Post

Fig.25. Schematic diagram of a solar street light

11.7 Solar fencing system

Solar Fencing (Fig.26) is the modern day's alternative to the conventional type of perimeter protection. These are active fences and punish the unwelcome intruder the moment they touches the fence or try to tamper the fence. The conventional types of fences are only passive fences and cannot resist the intruder if they try to forcibly intrude into the protected area. The Solar Fence gives a sharp, short but a safe shock and creates psychological fear. Against any tampering the alarm incorporated in the system gets activated and alerts the inmates of the protected area, which facilitates them to counter the unwelcome intruders. The solar fence is scientific fence and works on Solar Energy with backup facility to run uninterruptedly during the nights as well as cloudy days.

Working principle

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. Thus the intruder will receive a shock, the greater the shock the intruder receives the more lasting the memory will be avoided in future.

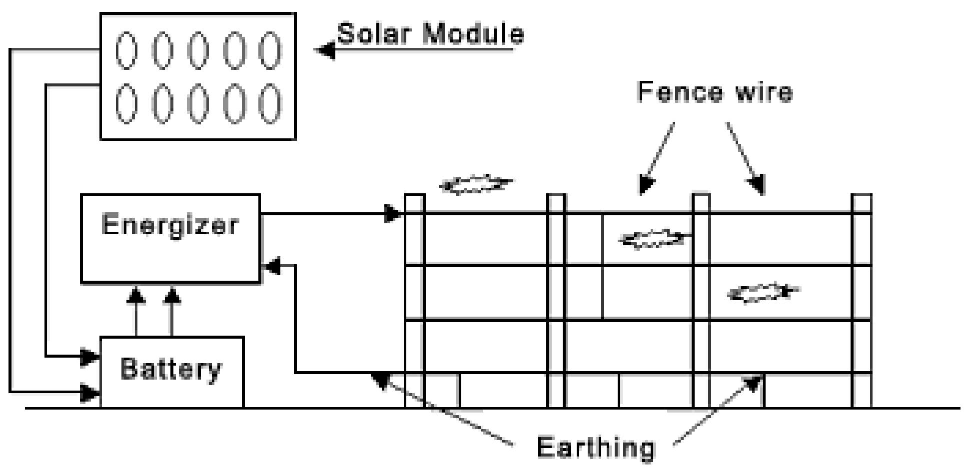


Fig. 26. Schematic diagram of a solar fence system

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. An animal or intruder touching the live wire creates a path for the electrical current through its body to the ground and back to the Energizer via the earth or ground system, thus completing the circuit. The greater the shock the animal receives the more lasting the memory will be and the more the fence will be avoided in the future. The shock felt is a combination of fence voltage and pulses time or energy. The higher the joule rating of the energizer the greater the shock and the greater the fence performance.

Features of solar fencing system

a) Easy Construction.
b) Power fence can be erected to target species only.
c) Low maintenance.
d) Long lasting because of minimal physical pressure.
e) All domestic and wild animals can be controlled economically.

f) Makes strip grazing and back fencing easy.
g) Encourages additional subdivision, giving increased production.
h) Modification of system to control a variety of animals is very easy.
i) Aesthetically pleasing.
j) Discourages trespassers and predators.
k) Not harmful. It gives a short, sharp but safe shock to the intruder.
l) Perimeter protection

The basic building blocks of a power fence are:

1. Energizer
2. Earthing (Grounding System) and
3. Fence system

Energizer

The heart of the power fence is the Energizer. The energizer is selected depending on the animals to be controls, length of the fence and number of strands. 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. The energizer should be protected from children, should be enclosed, free from mechanical damage and away from inflammable.

Earthing system

The earth or ground system of the Energizer is like the antenna or aerial of a radio. A large radio requires a large antenna to effectively collect sound waves and a high powered Energizer requires a large number of electrons from the soil. 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. If possible, select an area for the energizer earth site which is damp all the year.

Fence wire systems

They are of two types: (i) All live wire system and (ii) Earth or ground wire return system.

(i) All Live Wire System

The all live wire system should be used where there is relatively even rainfall and where there is some green vegetation most of the year, or in areas with highly conductive soils. The all live wire system should be used as much as possible.

(ii) Earth or ground wire return system

The earth or ground wires return system should be used where there is low rainfall stony and dry soil condition most of the year. The system overcomes the problem of dry, non-conductive, or frozen soils not allowing sufficient current to flow through the animal's feet back to the energizer. The fence should have both live and ground wires. By touching the live and ground wires on the fence, the animal gets the full shock..

11.8 Solar water pumping system

The solar water pumping system (Fig.27) is a stand-alone system operating on power generated using solar PV (photovoltaic) system. 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. The system schematic is shown in the figure below. The system requires a shadow-free area for installation of the Solar Panel.

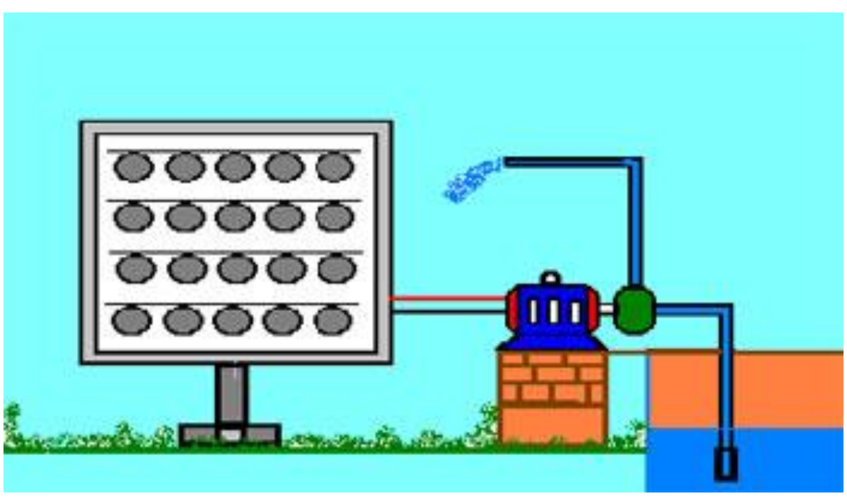


Fig. 27. Schematic diagram of a solar water pumping system

The system is provided with 1800 W solar PV panel (24 nos. X 75 Wp) and 2 HP centrifugal DC mono-block / AC submersible with inverter. The average water delivery of 2 HP solar pump will be around 1.38 to 1.40 lakh litre per day, for a suction head of 6 metres and dynamic head of 10 metres. The size of suction & delivery lines is 2.5 inches (62.5 mm).

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.12

Wind energy-advantages, disadvantages, wind mills and types.

Wind is the world's fastest growing energy source today and it has been retaining this position consecutively for the last five years. The global wind power capacity has increased by a factor of 4.2 during the last five years. The total global installed capacity is 39434 MW in 2004. Installed capacity in different regions is shown in Table 1:

Country	Installed capacity, MW
Germany	14609
United states of America	6352
Spain	6202
Denmark	3115
India	2120

Air in motion is called wind. The winds on the earth surface are caused primarily by the unequal heating of the land and water by the sun. The differences in temperature gradients induce the circulation of air from one zone to another.

Winds are caused on earth due to:

1. The absorption of solar energy on earth surface and its atmosphere. The pressure and temperature gradients causes winds or wind flow.
2. Also the rotation of earth about its axis and its movement around the sun causes the flow of wind.

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.

12.0 Factors affecting the wind

1. Latitude of the place
2. Altitude of the place.
3. Topography of the place
4. Scale of the hour, month or year.

12.1 Suitable places for the erection of wind mills

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

2.Mountains: An average value is 1600 KWH/m^2/year.

3.Plains: An average value is 750 KWH/m^2/year.

12.2 Places unsuitable for wind mills

1.Humid equatorial region- there is virtually no wind energy.

2.Warm, windy countries, wind energy may not be usual because of the frequency of cyclones.

12.3 Advantages of wind energy

1.It is a renewable source of energy.

2.It is non-polluting and no adverse influence on the environment.

3.No fuel and transportation is required.

4.The cost of electricity under low production is comparatively low.

12.4 Disadvantages

1.The available wind energy is dilute and fluctuating in nature.

2.Unlike water energy, wind energy requires storage capacity because of its irregularity.

3.Wind energy operating machines are noisy in operation.

4.Wind power systems have a relatively high overall weight. For large systems, a weight of 110 kg/kW has been estimated.

5.Large areas are required for wind mill.

6.The present wind mills are neither maintenance free nor practically reliable.

Lecture No.13

Constructional details of wind mills, applications of wind mills.

13.0 Types of wind mills

Wind mill is a machine for wind energy conversion. A wind turbine converts the kinetic energy of the wind's motion to mechanical energy transmitted by the shaft. A generator further converts it to electrical energy, thereby generating electricity.

1. Vertical axis wind mills: Ex. Savonius or S type wind mill (low wind velocity)
   Darrius wind mill (high wind velocity)
2. Horizontal axis wind mills: Ex. Single blade wind mills
   Double blade wind mills
   Multi blade wind mills
   Bicycle multiblade type i.e., Sail type.

13.1 Vertical axis type wind mills

Vertical axis machines (Fig.28) 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.

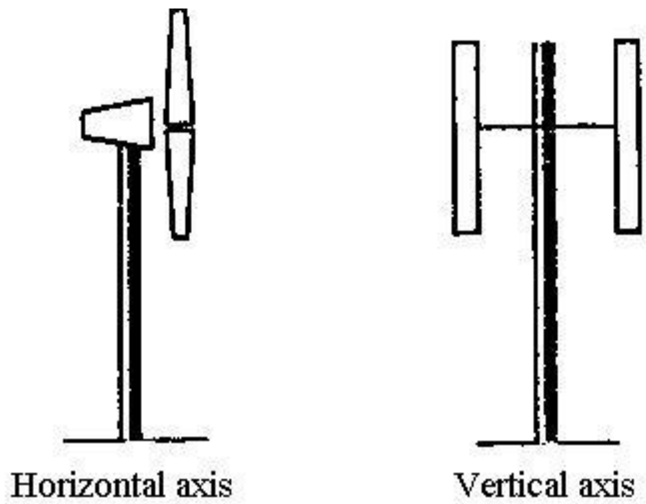


Fig. 28. Schematic diagram horizontal and vertical axis wind mill

13.1.1 Savonius wind mill

It works on the **principle of cup anemometer**. This was invented by S.J.Savonius in the year 1920. 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 (Fig.29). 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).

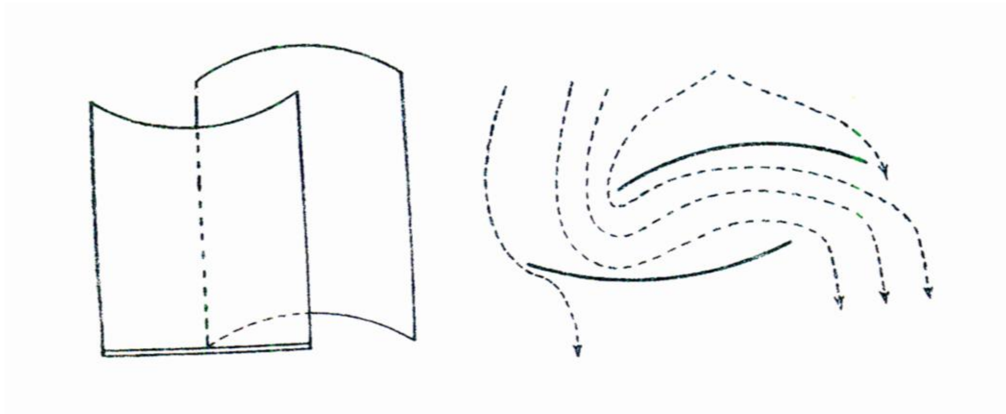


Fig. 29. Schematic diagram of savonius wind mill

13.1.2 Darrieus wind mill

This machine was invented and patented in 1925 by G.J.M. Darrieus, a French Engineer. 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** (Fig.30). 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.

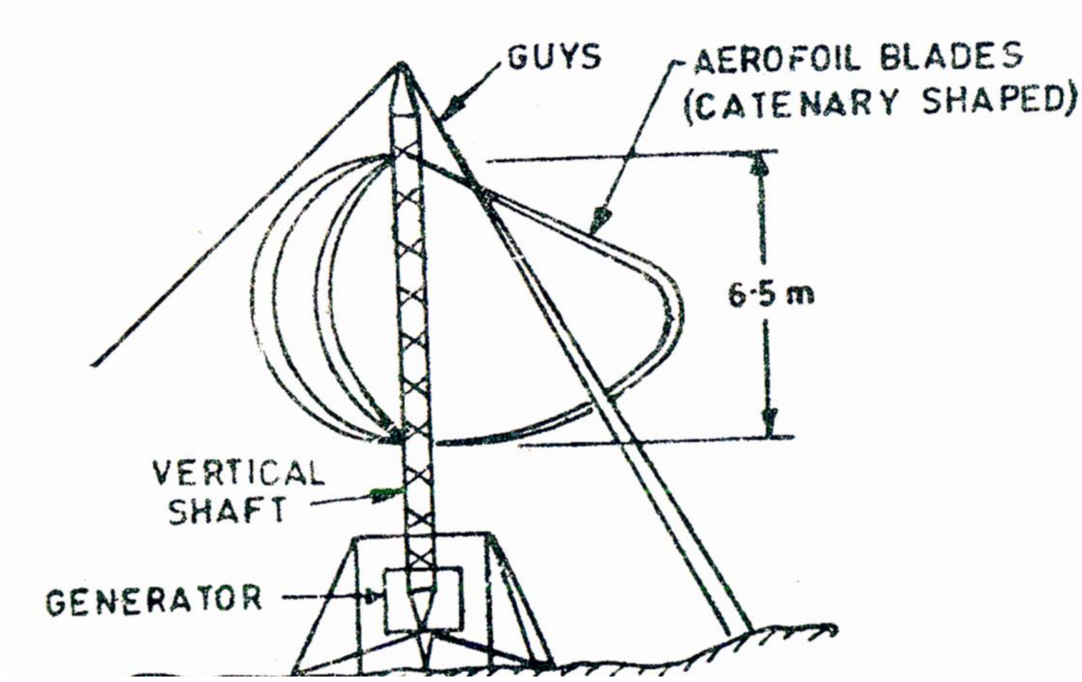


Fig.30. Schematic diagram of darrieus wind mill

13.2 Horizontal axis type wind mills

Horizontal axis wind turbines (Fig.31) 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. Single blade turbines are cheaper due to savings on blade materials. The drag losses are also minimum for these turbines. However, to balance the blade, a counter weight has to be placed opposite to the hub. Single bladed designs are not very popular due to problems in balancing and visual acceptability. Two bladed rotors also have these drawbacks, but to lesser extent. Most of the present commercial turbines used for electricity generation have three blades.

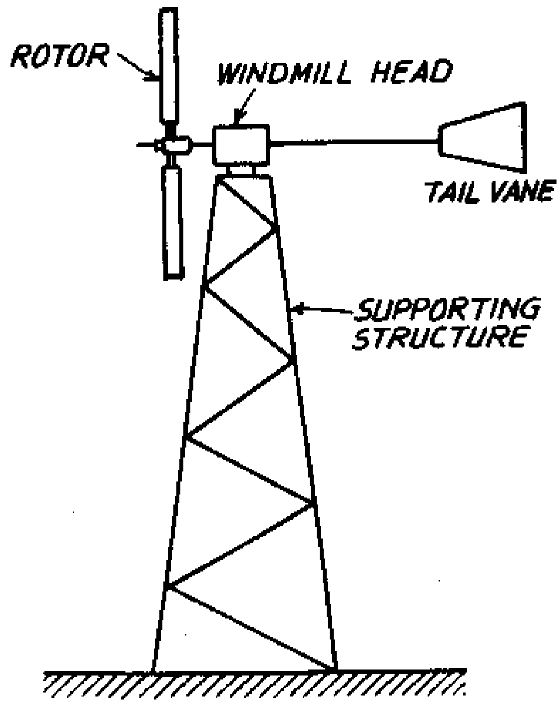


Fig. 31. Schematic diagram of horizontal axis wind mill

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.

13.2.1 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.32. 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.

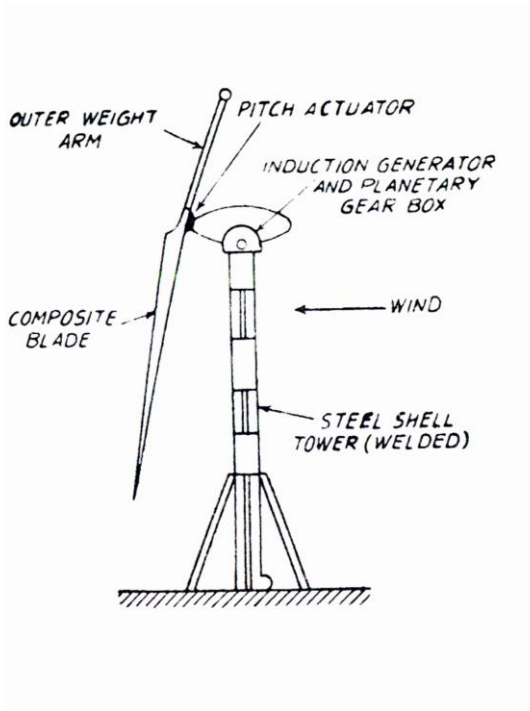


Fig. 32. Schematic diagram of horizontal axis single blade wind mill

13.2.2 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.33.

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.

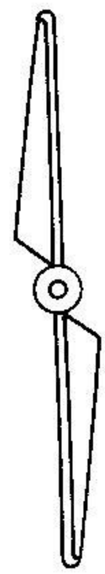


Fig. 33. Schematic diagram of horizontal axis two blade wind mill

13.2.3 Horizontal axis-multi blade type wind mill

This type of design for multi blades is shown in fig.34., 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.

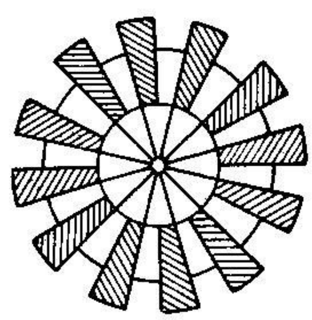


Fig. 34. Schematic diagram of horizontal axis multi blade wind mill

13.2.4 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.35). There is also variation in the number of sails used. It runs at 60 to 80 rpm.

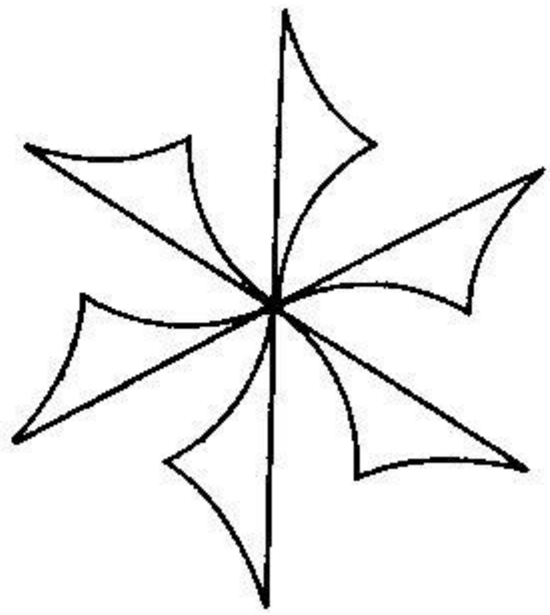


Fig.35. Schematic diagram of horizontal axis sail type wind mill

Lecture No.14

Biofuels – characteristics of various biofuels, different parameters and calorific values.

"Biofuels" are transportation fuels like ethanol and biodiesel that are made from biomass materials. These fuels are usually blended with petroleum fuels namely with gasoline and diesel fuel, but they can also be used on their own. Ethanol and biodiesel are also cleaner burning fuels, producing fewer air pollutants. It has drawn significant attention due to increasing environmental concern and diminishing petroleum reserves. Bio-diesel fuel can be made from renewable vegetable oils, animal fats or recycled cooking oils by transesterification process. Biodiesel is the fastest growing alternative fuel in the world. Ethanol is a alcohol fuel made from the sugars found in grains such as corn, sorghum, and wheat, as well as potato skins, rice, sugarcane, sugar beets and yard clippings by fermentation.

14.0 Characteristics of bio-fuels

The following are some of the characters for the efficient bio-diesel:

a) Kinematic viscosity
b) Density
c) Calorific value
d) Melt or pour point
e) Cloud point
f) Flash point
g) Acid value
h) Iodine value
i) Cetane number
j) Stability – oxidative, storage and thermal
k) Carbon residue
l) Ash percentage
m) Sulphur percentage

Kinematic viscosity

Viscosity represents flow characteristics and the tendency of fluids to deform with stress. Viscosity affects injector lubrication and fuel atomization. Fuels with low viscosity may not provide sufficient lubrication for the precision fit of fuel injection pumps, resulting in leakage or increased wear. Fuel atomization is also affected by fuel viscosity. Diesel fuels with high viscosity tend to form larger droplets on injection which can cause poor combustion, increased exhaust smoke and emissions.

Density

Is the weight per unit volume. Oils that are denser contain more energy. For example, petrol and diesel fuels give comparable energy by weight, but diesel is denser and hence gives more energy per litre. Biodiesel is generally denser than diesel fuel with sample values ranging between 877 kg/m^3 to 884 kg/m^3 compared with diesel at 835 kg/m^3.Thus, density of the final product depends mostly on the feedstock used.

Calorific Value, Heat of combustion

Heating Value or Heat of Combustion, is the amount of heating energy released by the combustion of a unit value of fuels. One of the most important determinants of heating value is moisture content. Liquid biofuels however have bulk densities comparable to those for fossile fuels.

Melt point or Pour point

Melt or pour point refers to the temperature at which the oil in solid form starts to melt or pour. In case where the temperatures fall below the melt point, the entire fuel system including all fuel lines and fuel tank will need to be heated.

Cloud point

The temperature at which an oil starts to solidify is known as the cloud point. While operating an engine at temperatures below an oil's cloud point, heating will be necessary in order to avoid waxing of the fuel.

Flash point (FP)

The flash point temperature of diesel fuel is the minimum temperature at which the fuel will ignite (flash) on application of an ignition source. Flash point varies inversely with the fuel's volatility. Minimum flash point temperatures are required for proper safety and handling of diesel fuel. The flash point determines the flammability of the material. Neat biodiesel has a flash point (150°C) well above the flash point of petroleum based diesel fuel (±70°C).

Acid value

The total acid number is an indication of the presence of free fatty acids formed due to oil degradation and combustion. It can also result from improper manufacturing, through remaining catalyst or excessive neutralization.

Iodine value

It is an index of the number of double bonds in biodiesel, and therefore is a parameter that quantifies the degree of unsaturation of biodiesel. It is reported in terms of the grams of iodine that will react with 100 grams of a fat or oil under specified condition. It is a value of the amount of iodine, measured in grams, absorbed by 100 grams of given oil. It is commonly used as a measure of the chemical stability properties of different biodiesel fuels against such oxidation.

Aniline point/Cetane number (CN)

It is a relative measure of the interval between the beginning of injection and autoignition of the fuel. The higher the cetane number, the shorter the delay interval and the greater its combustibility. Fuels with low Cetane Numbers will result in difficult starting, noise and exhaust smoke. In general, diesel engines will operate better on fuels with Cetane Numbers above 50. Cetane number is usually measured directly using a test engine.

Cetane tests provide information on the ignition quality of a diesel fuel. No.2 diesel fuel usually has a cetane rating between 45 and 50 while vegetable oil is 35 to 45. Biodiesel is usually have in between 50 to 60.

Stability

Biodiesel ages more quickly than petroleum diesel fuel due to the chemical structure of fatty acids and methyl esters present in biodiesel. Typically there are fourteen types of fatty acid methyl ester in the biodiesel. The individual proportion of presence of these esters in the fuel effects the final properties of biodiesel.

Poor oxidation stability can cause fuel thickening, formation of gums and sediments which inturn can cause filter clogging and injector fouling.

Thermal degradation occurs at high temperature and degrades hyper peroxide in the fuel more rapidly than oxidative degradation. Biodiesel and biodiesel blends are much more thermally stable than diesel.

Biodiesel and its blends should not be stored in a storage tank or vehicle tank more than 6 months. Depending upon the storage temperature and other conditions suggest the use of appropriate antioxidants.

Carbon residue

This indicates the tendency of fuel to form carbon deposits in an engine. An important indicator of the quality of biodiesel is the carbon residue, which corresponds to the content of glycerides, free fatty acids, soaps, polymers and remaining catalyst.

Ash Percentage

Ash is a measure of the amount of metals contained in the fuel. High concentrations of these materials can cause injector tip plugging, combustion deposits and injection system wear. The ash content is important for the heating value, as heating value decreases with increasing ash content.

Ash content for bio-fuels is typically lower than for most coals, and sulphur content is much lower than for many fossil fuels.

Sulfur percentage

The percentage by weight, of sulfur in the fuel sulfur content is limited by law to very small percentages for diesel fuel used in on-road applications. First use vegetable oil and animal fat based biodiesel has less than 15 ppm sulphur. Many researchers claim that pure biodiesel is essentially sulphur free and therefore biodiesel is an ultra-low sulphur fuel.

The properties of a few bio-diesel fuels made from edible and non-edible oils are shown in Table 2.

Table 2. Properties of edible and non-edible oils

Bio-diesel	Kinematic viscosity at 40°C	Cetane number	Lower heating value (MJ/kg)	Cloud point (°C)	Pour point (°C)	Flash point (°C)	Density (kg/litre)
Edible oils							
Palm	5.7	62	33.5	13		164	0.880
Peanut	4.9	54	33.6			176	0.883
Soyabean	4.5	45	33.5	1	-7	178	0.885
Sunflower	4.6	49	33.5	1		183	0.860
Non-edible oils							
Jatropha	5.2	38	39.2	13		175	0.865
Karanja	4.7	55	37.1	7	4	183	0.876
Diesel	3.06	50	43.8	9	-16	76	0.855
20% biodiesel blend	3.2	51	43.2		-16	128	0.859

The Table 2 shows the properties of conventional diesel and a 20% bio-diesel blend. It shows that the properties of the bio-diesel fuels compare well with the properties of diesel, while the properties of the blend are very close to the properties of diesel. Therefore, bio-diesel fuels and blends are rated as good alternatives to diesel.

Lecture No.15

Bio diesel production –applications, extraction from jatropha.

15.0 Bio fuels

Bio-diesel is a fuel, made from natural (biological) renewable resources which can be used directly in conventional diesel engines. Unlike fossil diesel, pure bio-diesel is biodegradable, non-toxic, essentially free of sulphur and aromatics and releases less emissions during combustion. Bio-diesel some times called FAME (fatty acid methyl ester) or FAEE (fatty acid ethyl ester). It can be produced from edible oils such as palm oil, soyabean oil, rape seed oil, sunflower oil and some other vegetable oils; animal fats and non-edible oils like jatropha, castor beans, pongamia pinnata. In Europe, rapeseed oil is the major feed stock used to make bio-diesel, with some sunflower oil is also used. Soyabean oil is the major feed stock to make the bio-diesel in USA. In tropical and subtropical countries, there are wider feed stocks have been considered including edible and non-edible oils. However, using edible oils to produce bio-diesel is not encouraged in China because China imports more than 400 million tones edible oils annually to satisfy its consumption needs. They tried to make biodisel from recycled waste oils but the scale of production is limited due to higher operating cost. One negative aspect of biodiesel is that, the purity of biodiesel changes during storage due to oxidative and hydrolytic reactions and availability of feed stock (raw material) for production.

15.1 Advantages of biodiesel

1. Produced from sustainable / renewable biological sources
2. Eco-friendly and oxygenated fuel
3. Sulphur free, less CO, HC, particulate matter and aromatic compounds emissions
4. Income to rural community
5. Fuel properties similar to the conventional fuel
6. Used in existing unmodified diesel engines

7. Reduce expenditure on oil imports

8. Non toxic, biodegradable and safety to handle

Biodiesel is produced by transesterification of large, branched triglycerides in to smaller, straight chain molecules of methyl esters, using an alkali or acid or enzyme as catalyst. Alcohols such as methanol, ethanol, propanol, butanol and amyl alcohol are used in the transesterification process. Methanol and ethanol are used most frequently, especially methanol because of its low cost, and physical and chemical advantages. They can quickly react with triglycerides and sodium hydroxide is easily dissolved in these alcohols. The most common form uses methanol to produce methyl esters (commonly referred to as Fatty Acid Methyl Ester **- FAME**) as it is the cheapest alcohol available, though ethanol can be used to produce an ethyl ester (commonly referred to as Fatty Acid Ethyl Ester - FAEE) biodiesel and higher alcohols such as isopropanol and butanol have also been used.

15.2 Chemistry of biodiesel production

Transesterification

Biodiesel is commonly produced by the transesterification of the vegetable oil or animal fat feedstock. The process involves reacting vegetable oils or animal fats catalytically with a short-chain aliphatic alcohols (typically methanol or ethanol). There are several methods for carrying out this transesterification reaction including the common batch process, supercritical processes, ultrasonic methods, and even microwave methods. A by-product of the transesterification process is the production of glycerol. For every 1 tonne of biodiesel that is manufactured, 100 kg of glycerol are produced.

15.3 Production methods

15.3.1 Batch process

1) Preparation: care must be taken to monitor the amount of water and free fatty acids in the incoming biolipid (oil or fat). If the free fatty acid

level or water level is too high it may cause problems with soap formation and the separation of the glycerin by-product downstream.

2) Catalyst is dissolved in the alcohol using a standard agitator or mixer.

3) The alcohol/catalyst mix is then charged into a closed reaction vessel and the biolipid (vegetable or animal oil or fat) is added. The system from here on is totally closed to the atmosphere to prevent the loss of alcohol.

4) The reaction mix is kept just above the boiling point of the alcohol (around 70 °C) to speed up the reaction. Some systems recommend the reaction take place anywhere from room temperature to 55 °C for safety reasons. Recommended reaction time varies from 1 to 8 hours; under normal conditions the reaction rate will double with every 10 °C increase in reaction temperature. Excess alcohol is normally used to ensure total conversion of the fat or oil to its esters.

5) The glycerin phase is much denser than biodiesel phase and the two can be gravity separated with glycerin simply drawn off the bottom of the settling vessel. In some cases, a centrifuge is used to separate the two materials faster.

6) Once the glycerin and biodiesel phases have been separated, the excess alcohol in each phase is removed with a flash evaporation process or by distillation. Care must be taken to ensure no water accumulates in the recovered alcohol stream.

7) The by-product (i.e., glycerin) contains unused catalyst and soaps, that are neutralized with an acid and sent to storage as crude glycerin.

8) Once separated from the glycerin, the biodiesel is sometimes purified by washing gently with warm water to remove residual catalyst or soaps, dried, and sent to storage.

15.3.2 Supercritical process

It is a catalyst-free method and continuous process. In this method, transesterification process uses supercritical methanol at high temperatures and pressures. In the supercritical state, the oil and methanol are in a single phase, and reaction occurs spontaneously and rapidly. The process can tolerate water in the feedstock. Also the catalyst removal step is eliminated. High temperatures and pressures are required, but energy costs of production are similar or less than catalytic production routes.

15.3.3 Ultra- and high-shear in-line and batch reactors

Ultra- and High Shear in-line or batch reactors allow production of biodiesel continuously, semi- continuously, and in batch-mode. This method drastically reduces production time and increases production volume. The reaction takes place in the high-energetic shear zone of the ultra- and high Shear mixer by reducing the droplet size of the immiscible liquids such as oil or fats and methanol. Therefore, the smaller the droplet size, the larger the surface area the faster the catalyst can react.

15.3.4 Ultrasonic-reactor method

In the ultrasonic reactor method, the ultrasonic waves cause the reaction mixture to produce and collapse bubbles constantly. This cavitation provides simultaneously the mixing and heating required to carry out the transesterification process. The ultrasonic reactor method for biodiesel production drastically reduces the reaction time, reaction temperatures, and energy input. Industrial scale ultrasonic devices allow for the industrial scale processing of several thousand barrels per day.

15.3.5 Microwave method

Current research is being directed into using commercial microwave ovens to provide the heat needed in the transesterification process. The microwaves provide intense localized heating that may be higher than the recorded temperature of the reaction vessel. A continuous flow process producing 6 liters/minute at a 99% conversion rate has been developed and shown to consume only one-fourth of the energy required in the batch process. Although it is still in the lab-scale, development stage, the microwave method holds great potential to be an efficient and cost-competitive method for commercial-scale biodiesel production.

15.4 Preparation of bio diesel from jatropha curcas

In most of the developed countries, biodiesel is produced from soybean, rapeseed, sunflower, peanut, etc., which are essentially edible in Indian context. Among the various vegetable oil sources, non-edible oils are suitable for biodiesel production. Because edible oils are already in demand and too expensive than diesel fuel. Among the non-edible oil sources, *Jatropha curcas* is identified as potential biodiesel source and comparing with other sources, which has added advantages as rapid growth, higher seed productivity, suitable for tropical and subtropical regions of the world.

The Jatropha plant can reach a height up to 5 m and its seed yield ranges from 7.5 to 12 tonnes per hectare per year, after five years of growth. The oil content of whole Jatropha seed is 30-35 % by weight basis. Several properties of the plant including its hardness, rapid growth, easy propagation and wide ranging usefulness have resulted in its spread far beyond its original distribution.

Preparation of bio diesel from jatropha requires a two-step approach; the extraction of the Jatropha oils from the seed, and the conversion of the extracted oil to Biodiesel, according to the following transesterification reaction.

The mechanical extraction was done using a hydraulic press. After dehulling, the Jatropha seeds were first pressed to extract oil and then placed inside a soxhlet and brought into contact with a condensed solvent. The solvent dissolves the oil and then it is later separated using a rotor vapor. The obtained Jatropha oil was used for Biodiesel production. The transesterification reaction was done using methanol and two basic catalysts. Solvent extraction has higher oil yield than hydraulic press extraction.

15.5 Biodiesel production

The process flowchart for biodiesel production from Jatropha curcas seeds and by products is shown in figure 36.

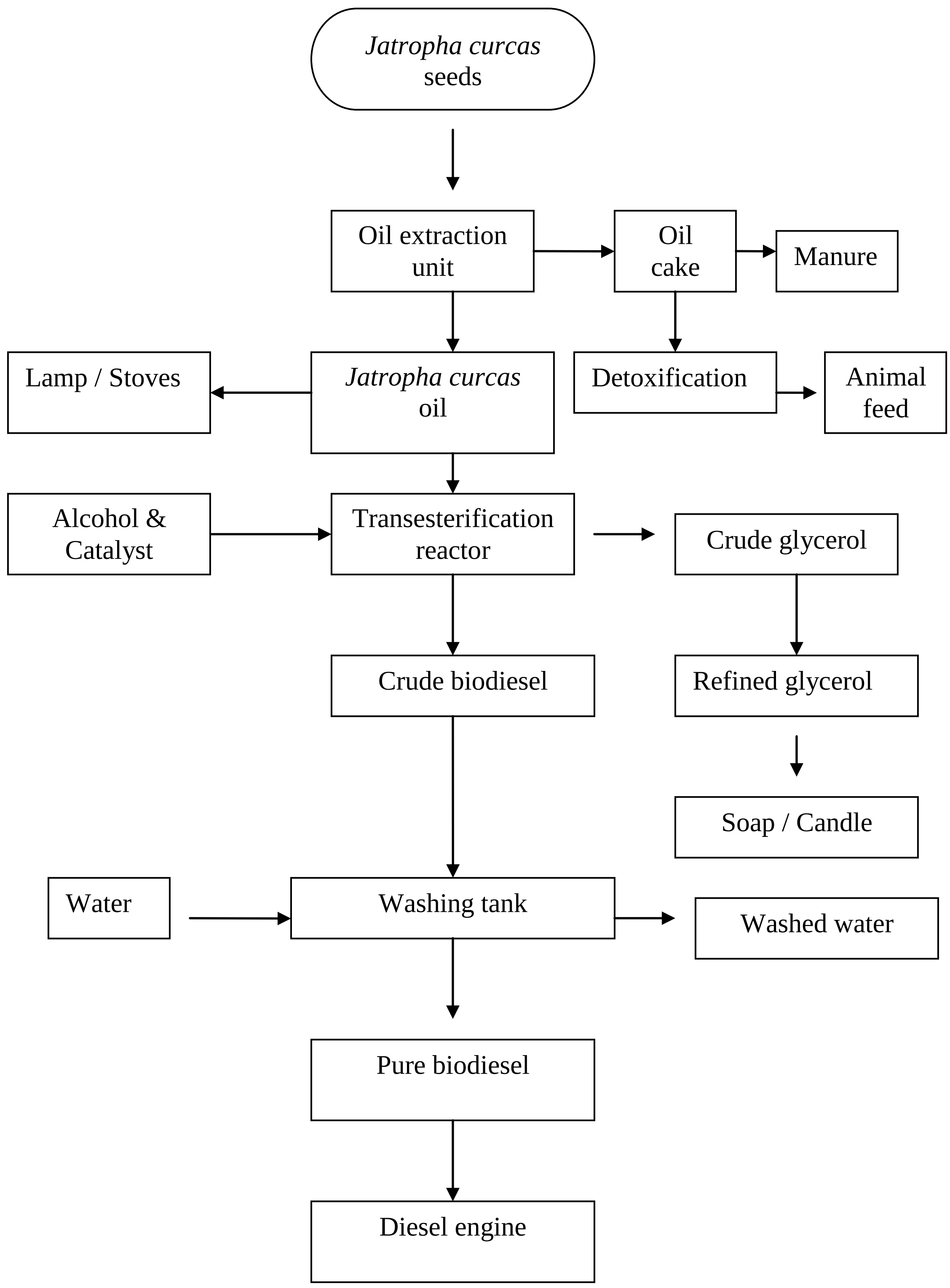


Fig. 36. Process flow chart for biodiesel production from jatropha seeds and by products

15.6 Applications

Biodiesel is the only alternative fuel that can be used directly in any existing unmodified diesel engine, because it has similar properties to diesel fuel. Biodiesel can be used in pure form (B100) or may be blended with petroleum diesel at any concentration in most modern diesel engines. Biodiesel has different solvent properties than petrodiesel, and will degrade natural rubber gaskets and hoses in vehicles (mostly vehicles manufactured before 1992. Biodiesel has been known to break down deposits of residue in the fuel lines where petrodiesel has been used. As a result, fuel filters may become clogged with particulates if a quick transition to pure biodiesel is made. Therefore, it is recommended to change the fuel filters on engines and heaters shortly after first switching to a biodiesel blend.

Bio diesel has better lubricating properties and much higher cetane ratings than today's lower sulfur diesel fuels. The fuel properties of jatropha oil, jatropha biodiesel and conventional fuel is given in Table 3.Bio diesel addition reduces fuel system wear, and in low levels in high pressure systems increases the life of the fuel injection equipment that relies on the fuel for its lubrication.

The calorific value of bio diesel is about 37.27 MJ/L. Bio diesel is a liquid which varies in color - between golden and dark brown - depending on the production feedstock. It is immiscible with water, has a high boiling point and low vapor pressure. The flash point of bio diesel (>130°C) is significantly higher than that of petroleum diesel (64°C) or gasoline (−45 °C). Bio diesel has a density of ~ 0.88 g/cm^3, less than that of water (Table 2). Bio diesel has virtually no sulfur content, and it is often used as an additive to **Ultra-Low Sulfur Diesel** (ULSD) fuel.

Table 3. Fuel properties of jatropha oil and its biodiesel Properties

	Jatropha Oil	**Jatropha biodiesel**	**Diesel**
Density, g/ml	0.920	0.865	0.841
Viscosity @ 40 ^{o}C, Cst	3.5	5.2	4.5
Calorific value, MJ/kg	39.7	39.2	42.0
Flash point, ^{o}C	240	175	50

15.7 Economics of biodiesel production

Cost of raw jatropha oil = Rs. 22/litre

Biodiesel processing cost = Rs. 9/litre

Cost of production = Rs. 31/litre

Less return from crude glycerol = Rs. 3/litre

Net cost of production = Rs. 28/litre

Dealers margin = Rs. 1/litre

Profit = Rs. 3/litre

Sale price of biodiesel = Rs. 32/litre

Lecture No.16

Ethanol from agricultural produce (Sugarcane and corn)

16.0 Ethanol from agricultural produce (Sugar cane and corn)

Non-petroleum fuels liquid fuels find use when petroleum fuels are scarce or costly. The scientists have been in search of new fuels to replace conventional fuels that are used in IC engines. 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.. But in countries like India, ethanol is a strong candidate since they posses the agricultural resources for it production. It is a more attractive fuel for India because the productive capacity from sugarcane crops is high, of the order of 1345 l/ha. 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.

16.1 Manufacture 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.

16.1.1 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. The process flow chart for production of ethanol from grains is shown in fig.37.

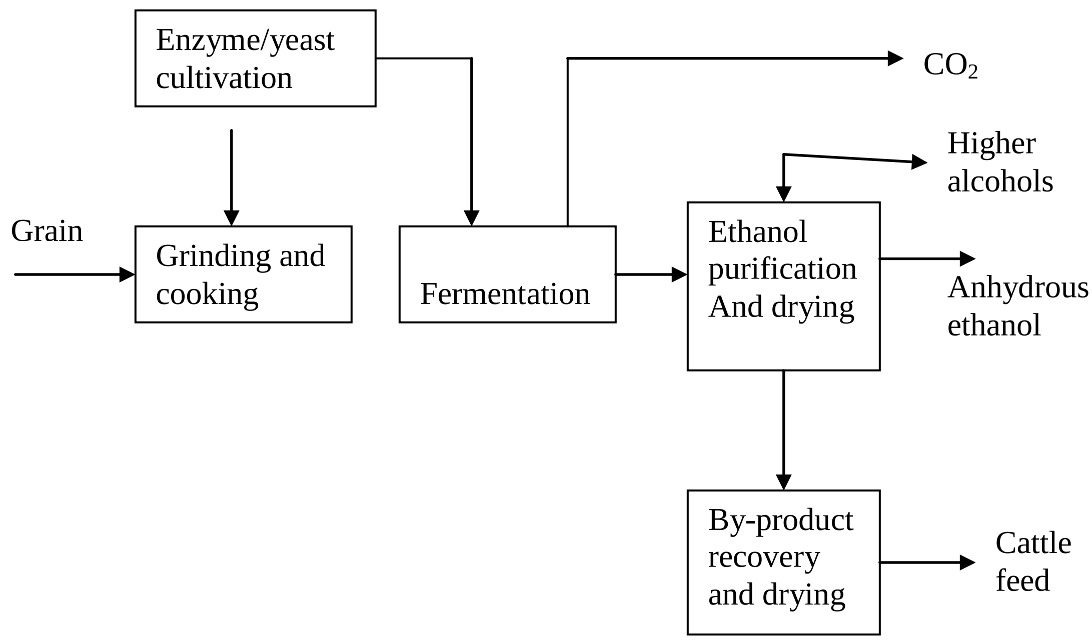


Fig. 37. Process flow chart for the production of ethanol from corn

16.1.2 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.38.

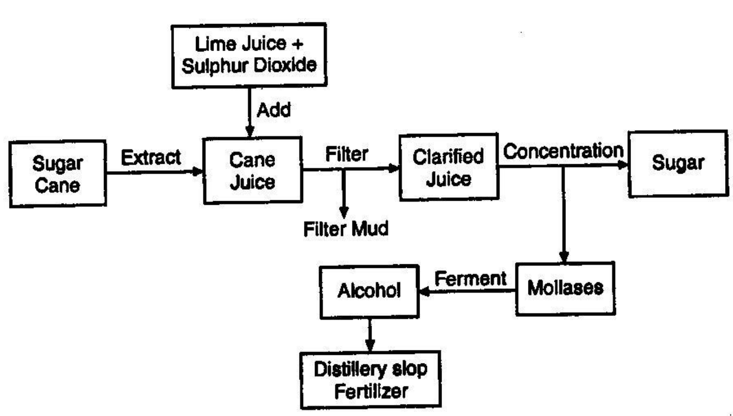


Fig. 38. Process flow chart for production of ethanol from sugarcane

References

1. Chakraverty, A. 1989. Biotechnology and other alternate technology. Oxford & IBH Publishing Co., New Delhi.
2. Bansal, N.K. 1990. Renewable energy sources and conversion technology. TATA McGraw Hill Publishing Company Limited, New Delhi.
3. Rai, G. D. 1984. Non-Conventional Energy Sources. Khanna Publishers, New Delhi.
4. Rai, G. D. 1995. Solar Energy and Its Utilisation. Khanna Publishers, New Delhi.
5. Sukatme, S.P. 1985. Solar Energy. TATA McGraw Hill Publishing Company Limited, New Delhi.
6. Vijayalakshmi, Meena Devi, and Nagendra Prasad. 2007. Production of biodiesel from Jatropha carcus oil by using pilot biodiesel plant. AGROBIOS (India), Jodhpur, India.
7. Sukhatme, S.P., and Nayak, J.K. 2008. Solar Energy-Principles of Thermal Collection and Storage. TATA McGraw Hill Publishing Company Limited, New Delhi.
8. Singhal, R.K. 2006. Non-Conventional Energy Resources. S.K.Kataria & Sons, New Delhi.