# Renewable Energy Sources
## AENG 351


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## LECTURE - 1

## RENEWABLE ENERGY SOURCES

**Introduction – Classification – Advantages and Disadvantages.**

The energy resources are available in the following form.

### Primary Energy Resources

These resources are available in the form of raw material. These are conventional as well as non conventional energy resources. Some of these resources are commercialized as fossil fuels, nuclear fuel, water etc. Some of the non commercialized resources are solar, wind, agricultural residue etc.

### Secondary Energy Resources

These resources are usable forms of energy and may be commercial or non commercial in nature. These resources are solar energy, wind energy etc.

### Intermediate Energy Resources

These resources are used for easy transportation from the production place. This resource includes the gasification or in other form.

### Energy Resources

Presently commercial energy resources are being utilized to a large extent. The present contribution of various energy resources in the world is shown in Fig.1.1. The annual energy consumption of the world increases by 10 times and reaches to over 451 EJ in current year. The figure shows that nearly 18% of the world energy supply is renewable and 72% is in the form of coal, oil, natural gas and nuclear power. As the resources of the fossil fuel are confined and if current consumption rate is maintained they will be lasting for 200 years (oil for 40 years, natural gas for 60 year) and peak value of their production will reach by 2030 and decline there after globally. Beside the decline of primary resources they will also produce the adverse effect on the society by air pollution and global warming. On the basis of sustainability and renewability these resources are classified as conventional and non conventional energy resources.

### Conventional Energy Sources

The energy resources which were used during 1950 -1975 are called conventional energy resources and are classified as coal, oil, natural gas and nuclear fuel. These resources are accumulated in nature and cannot be easily replenished once exhausted. The coal deposits continuously exist in different parts of the world. The effect of fossil fuel on the environment is given in Table 1.1 and shows that amount of pollution are much less by using natural gas for energy generation.

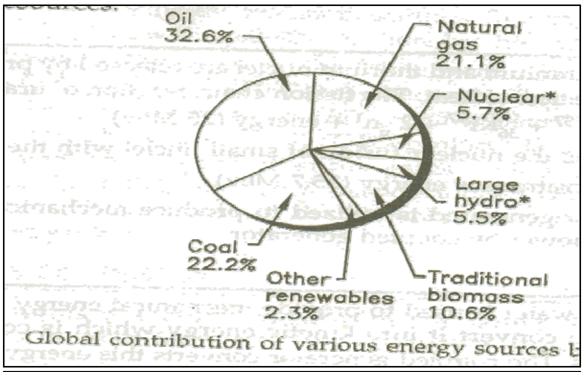



Table 1.1 Comparison of emission of air pollution of fossil fuel (Kg/TJ) with energy consumption

| | *Natural Gas* | *Oil* | *Coal* |
|---|---|---|---|
| Nitrogen Oxides | 43 | 142 | 359 |
| Sulphur Dioxide | 0.3 | 430 | 731 |
| Particulates | 2 | 36 | 1333 |

**Non Conventional Energy Resources**

The energy consumption of the world has been increasing with industrial growth. The fossil fuel is going to be exhausted in future because of limited reserves and it is estimated that by 2050 the 80% of reserve will be exhausted. Also various problems of emission of pollutant gases in environment is another issue. The other conventional resource like nuclear fuel is costly and big problem is in its safe utilization. To overcome the shortage and ecological problem we need to take over the alternative energy resources for use, known as non conventional energy. The reduction in the supply and rise in the prices after 1973, forced the developing countries to adopt an alternate non conventional energy technology as they get replenished again and again and are sustainable. These resources are generated continuously and are also known as renewable energy resources, like solar, wind, bio, tidal etc. The similarity between conventional and non conventional energy sources is that today the sources which are non conventional may be conventional tomorrow. The non conventional energy resources are very attractive now-a-days.

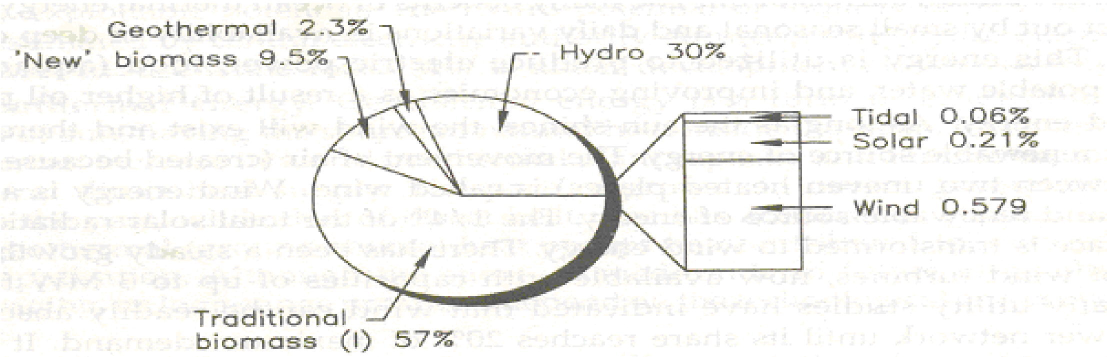
**Advantages:**

- Socially relevant and useful and variety of choice available in practice to shift for renewable energy.
- Pollution free and have much less environment impact compared with conventional energy sources.
- The systems have long life of 10-15 years or more. The non conventional systems can be built at the site need energy, therefore reducing the transmission losses.
- The country does not depend on other country for fuel supply.
- These resources can be adjusted to meet the demand by using hybrid systems.
- Energy cost is very low as the sources are available freely.
- Can be placed at any remote location.
- Renewable energy cannot be depleted unlike fossil fuel and uranium resources.

**Disadvantages:**

- Low energy density and need large size plant
- Intermittent in operation as they depend on seasonal variation
- Conversion efficiency is low.
- Large land area is required for installing the system to get same power as conventional plants
- Large quantity of embodied energy needed because of need of large quantity of material for construction

Renewable energy is a natural source of energy available in large quantity and is sustainable. The various sources of renewable energy are primary or secondary Fig.1.2 shows the estimate percentage of various renewable energy resources globally.




Globally estimated contribution of renewable energy in 2001.

The non conventional energy resources are classified as:

(a) Solar Energy
(b) Ocean Thermal Energy
(c) Wind Energy
(d) Tidal Energy
(e) Wave Energy
(f) Marine Current
(g) Hydro Power
(h) Geothermal Energy
(i) Biomass
(j) Wood and Charcoal Energy
(k) Direct Energy Conversion Resources

# LECTURE - 2

# BIOMASS

## Importance of Biomass

Prior to the industrial revolution, wood and agricultural residues are the primary source of energy for sectors like industry, transport and domestic. The transition took place from wood to coal and to oil and treated wood and agricultural residues as old fuels. Today, many fossil fuel based technologies have reached more advanced form of technological maturity, dependability access and efficiencies, incomparable to past few decades, thus only leaving more scope for conservation and search for new alternatives than changing the pattern of consumption and the domestic oil reserves are insufficient forcing import of oil and related products leading to pollution, global warming etc. The concerted efforts are required to identify new resources to put back the old fuel resources for meeting the requirements on large scale for local area energy demands. This helps in reducing the import of oil and naturally economics will recover. This kind of reversals is quite possible since the time is ripe and ideal to focus on utilization of biomass as a source of energy, food and fodder. Among various renewable energy sources, biomass offers a wide range of products to meet the present days' challenges. Unlike other forms of renewable energy sources, biomass offers a wide variety of bi-products similar to the fuels presently derived from fossils for other applications, where as the residues still offer their energy potential. So biomass is the best and dependable.

A practicable long term strategy helps us to store large quantities of energy in the form of biomass, whereas large investments are required to store solar energy or wind energy in batteries. However, such a large amount of solar energy can be stored in the form of biomass by the process called photosynthesis.

## Exploiting Biomass as a Fuel

Over selling biomass as a source of fuel, may force us to utilize indiscriminately leading to an expensive concept of whole plant utilization. Most of the earth's fertile soil is made of biomass due to death and decay. This allows and supports the standing of crops and trees. To provide macro and micro-nutrients and organic constituents required for an active soil, the minimum required biomass must be left out returnable to the soil. If this requirement is not met, the starving soils will give no biomass to the generation to come. Hence, there is a need to postulate some restrictions based on benchmark studies and to recommend the quantities of biomass to be left for soils without fail. Hopefully, a regularity mechanism to monitor soil fertility and biomass as energy option helps sustainability.

## Scope of Biomass Feed Stocks

Plant stores the solar energy in the form of fixed carbon achieved by the biochemical process called photosynthesis. This biochemical potential is stored by the plants in various forms at different stages of its growth. Based on the nature of these forms of availability, feed stocks can be classified as follows.

1 **Woody:** The wood can be made available from forests and energy plantations. Wood have high density is ideal for direct combustion, gasification and also for the production of ethanol and oils.

2 **Non-woody:** Small branches of trees, annually available agricultural residues like cotton stalk, maize, corn, pulses stalk, bagasse, tobacco etc terrestial weeds like prosophis, lantana, parthenium and others. Though bulk densities are low well suited for gasification, direct combustion and for production of ethanol.

3 **Process residues:** The process residues like ricehusk, coconut shells saw dust, coir pith, groundnut shells, cashew nut shells, etc. The bulk densities are reasonable with advantage of suitable material for gasification and direct burning.

4 **Aquatic plants:** Water hyacinth, lemma, algae, marsh reeds, sea weeds etc. subjected to anaerobic fermentation for biogas. Direct combustion and gasification have limited application due to high moisture content.

5 **Plants oils and fluids:** Agricultural crops like groundnut, soybean, sunflower, sesame etc. yield vegetable oils which are suitable for diesel substitution also. However, these oils are basically edible in nature. The residues viz., oil cakes offer the opportunity for producing appreciable amounts of biogas and the slurry is a good soil conditioner and manure. For eg. oils from Neem, pongamia, mahua, sal and the like produce oils, which are basically non-edible in nature. As on today, these oils are mostly used in sectors like pharmaceuticals, lubricants, dying and others. There are above 120 species classified under non-edible grade oil category both tree-born and crop based. These oils have very high value for substitution for diesel.

**Biomass availability**

The biomass available annually, was put to use only to an extent of 50% and remaining is wasted or lost. Dependence on forests for wood should be discouraged and to provide incentives of utilization for excess available crop residues for judicial application for thermal and power application.

**The following various seven options available for the use of biomass**

(1) Direct combustion as cooking fuel or for the industrial usage

(2) Charcoal production and utilization

(3) Thermal power generation

(4) Production of producer gas

(5) Biogas production

(6) Alcohol production and its utilization

(7) Compaction of solid biomass in the form of briquettes and briquettes utilization

## Advantages and Disadvantages

Biomass has both advantages as well as disadvantages in being used as an energy source which are enumerated below.

i. The biomass provides an effective low sulphur fuel.
ii. It provides an inexpensive and readily available source of energy, and
iii. Processing biomass materials for fuel reduce the environmental hazard.

The major problems or difficulties in utilizing biomass for solar energy conversion as well as a renewable source of energy are:

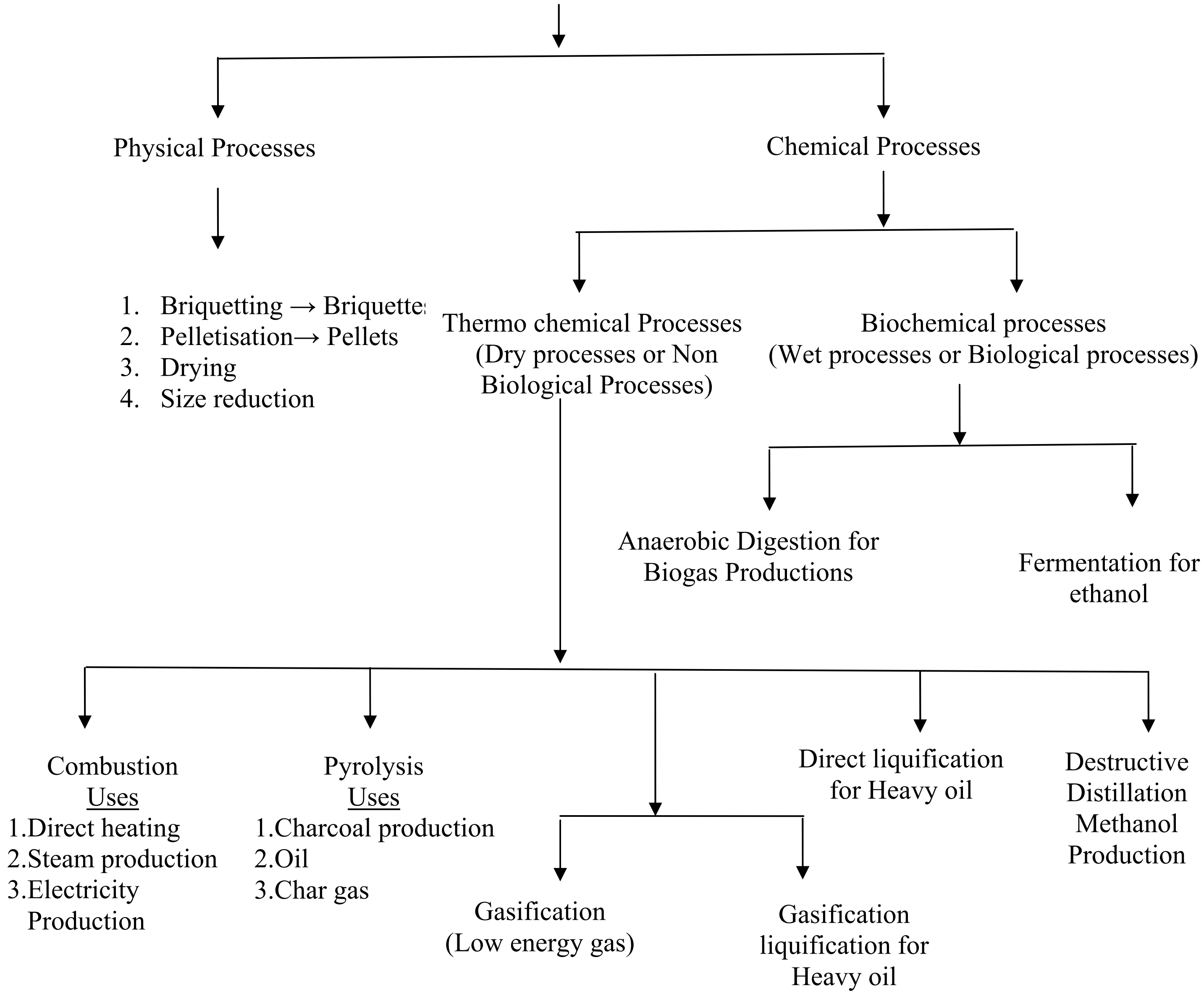
i. The relatively small percentage (less than 0.1%) of light energy is converted into biomass by plants.
ii. The relatively sparse and low concentration of biomass per unit area of land and water
iii. The scarcity of additional land suitable for growing plants.
iv. Scattered and seasonal availability of biomass
v. Their large volume and low bulk density associated with high moisture content that makes their collection and transport expensive and energy conversion relatively inefficient.
vi. The very abrasive nature due to silica cellulose structure causing high wear and tear in grinding machinery and fragile and porous nature of some agro industrial residues like rice husk makes them difficult to be stored in outdoor piles which become vulnerable to fire hazard and be air borne by the wind.

These methods are based on thermal, chemical and enzymatic conversion processes.

In dry process, material is transformed under high temperature

In wet process, Biological processes such as fermentation are involved.

**Classification of energy production from biomass**
**Biomass Conversion Processes**



**Physical Processes / Mechanical Methods**

This method is used to increase the bulk density of biomass material for easy transportation and storage and involves the following processes.

I. **Briquetting:** The briquetting is the process of making small size compressed block to get more surface area per unit weight of biomass by adding suitable binder. It includes the following process.
   a) **Moisture removal**: The process involves the removal of moisture from contents to break down its elasticity to reduce its volume sufficiently.
   b) **Densification:** The product is carried out at high pressure and temperature $180^0C$ to get more homogeneous product after moisture is removed.

II. **Pelletization:** Fuel pellets or refused derived fuel (RDF) are small cubes mode from the solid waste/garbage and are used as a fuel for boilers to produce steam or electricity. Pelletization of the wood is carried out by compressing it in the forms of rods of small diameter 5-12 mm in the extruder after removal of moisture 7-10%.

III. **Size Reduction:** Making small pieces by using shredding machines or Hammer mills.

**Different types of dry processes**

1. **Combustion:** Direct combustion is a complete oxidation process where liberation of heat is the primary objective. Burning of any substance in excess air whether it be solid, liquid or gas is termed as <u>combustion</u>. In combustion, a fuel is oxidized evolving heat and often light

$$C + O_2 \longrightarrow CO_2 + \text{Heat}$$

The combustion of solid fuel occurs in stages. i.e. Actual combustion of organic residues is not a single process but a combination of processes occurring simultaneously.

Three overlapping phases can be identified as

1. Initial phase: Evaporation of moisture
2. Volatilization and burning of volatiles: Dry matter absorbs heat, drives off volatile gases by thermal decomposition of the fuel and burning of volatiles in the air occurs.
3. Final phase: Fixed carbon burns

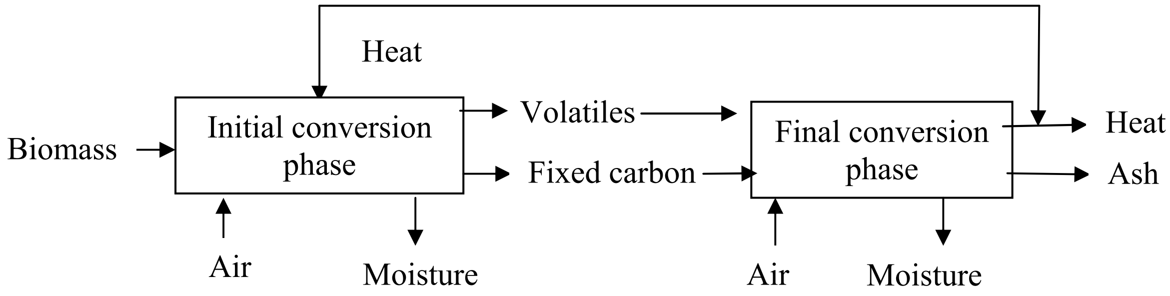



Fig: Schematic of the direct combustion process

At usual combustion temperature, the burning of hot solid residue is controlled by rate at which oxygen of the air diffuses to its surface. If the residue is cooled by the radiation of heat, combustion ceases.
**Eg**: Open chulas thermal efficiency : 3 – 4 %
Improved chulas thermal efficiency :10 – 14%
Consumption of the fuel : 0.5 – 1 Kg /per person
Use: To produce steam for process use and for electricity

2. **Pyrolysis:** Pyrolysis is defined as the destructive distillation of organic material heated to more than $200^0$C in the absence of air/oxygen for several hours to produce combustible gases ($H_2$, CO, $CH_4$), other hydrocarbons, $CO_2$ and $N_2$, solid char, liquid tar and organic liquids. It is a non oxidative thermal process that results in gases, liquids and char. It is thermal degradation of cellulose. In practice, many processes allow a restricted admission of air for partial combustion to achieve the temperature required for pyrolysis. The temperature of pyrolysis, composition of biomass (C, H, N, O, S), retention period and heating rate in pyrolyser etc determine the nature and quantum of these products. The slow rate of heating, low temperature and adequate retention time tend to give high yields of char.

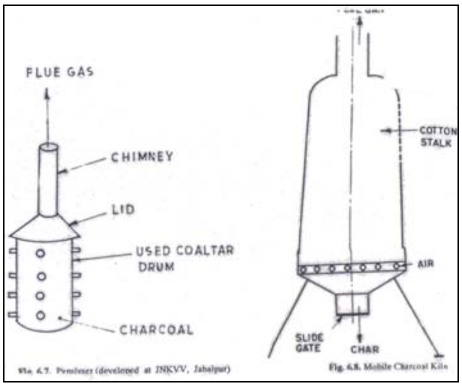
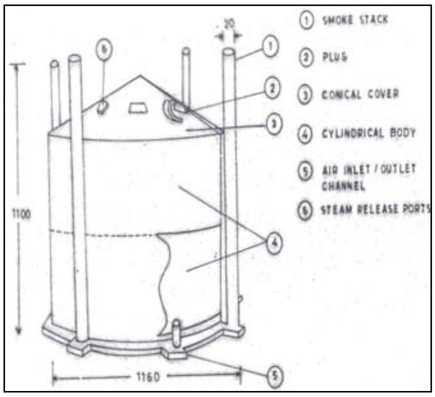



Fig. 4.7. Pyrolyser (developed at JNKVV, Jabalpur)
Fig. 4.8. Mobile Charcoal Kiln




**Uses of pyrolytic products**

| **Product** | **Char** | **Liquids** | **Gases** |
|---|---|---|---|
| Uses | 1. Domestic Fuel<br>2. Industrial Fuel<br>3. Metturgical Fuel<br>4. Chemical feed stock for calcium carbide, silicon carbide etc. | 1. Fuel<br>2. Separation for phenol and other chemicals<br>3. Germicide<br>4. Wood preservative | 1. Industrial fuel<br>2. Fuel for IC engines for mechanical and electrical power |

3. **GASIFICATION**: It is a chemical change involve several chemical reactions which occur simultaneously at varying rates. The dry process is combustion of biomass in a controlled atmosphere. This is a gasification process involving the burning of biomass with a limited air supply at temperature above $1100^0$C. The typical product is a mixture of CO+$H_2$ i.e. producer gas which is $1/10^{th}$ of the petroleum gas.

Useful for cooking, heating and electricity generation.

4. **LIQUIFICATION:** The dry process of biomass conversion is hydro carbonization or liquification which combines high temperature and pressure to produce oil or gas. These Fuels are same as that of petroleum and natural gas. But the operating cost and energy expenditure higher than pyrolysis.

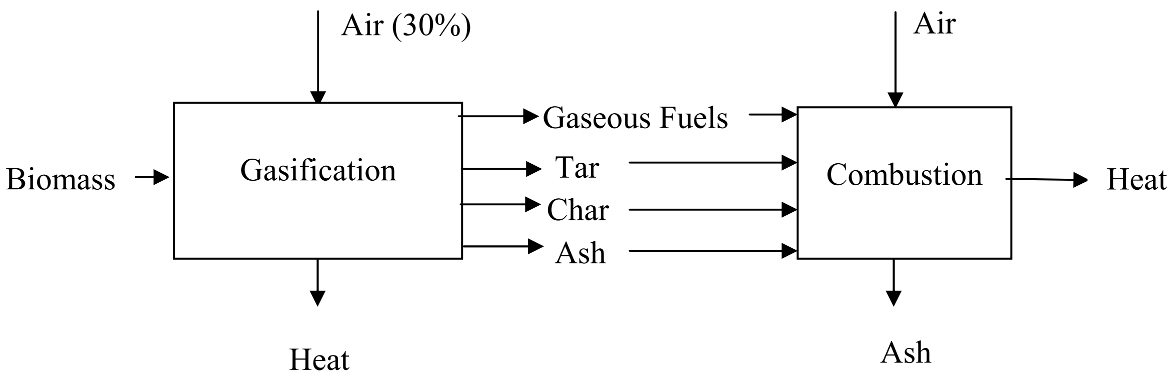



Fig: Schematic showing the gasification process

# LECTURE 3

# Bio-gas

**Biomass resources fall into three categories:**

(i) Biomass in its traditional solid mass (wood and agricultural residues) and (ii) Biomass in non-traditional form (converted into liquid fuels). The first category is to burn the biomass directly and get the energy. In the second category, the biomass is converted into ethanol (ethyl alcohol) and methanol (methyl-alcohol) to be used as liquid fuel in engines. (iii) The third category is to ferment the biomass anaerobically to obtain a gaseous fuel called biogas.

**Biogas Technology**

Biogas production is a microbial process which takes place with organic residues and water in absence of oxygen. The entire process of gas production involves the action of bacteria in three stages in the biogas plant. The stages are as described below.

(i) Enzymatic hydrolysis: The fats, starches and proteins contained in cellulosic biomass are broken down into simple compounds.

(ii) Acid formation: The micro organisms of facultative and anaerobic group collectively called as acid formers, hydrolyse and ferment, are broken to simple compounds into acetic acids and volatile solids. As a result complex organic compounds are broken down to short chained simple organic acids.

(iii) Methane formation: The organic acids are then converted into methane ($CH_4$) and $CO_2$ by the bacteria which are strictly anaerobes. These bacteria are called methane fermentors. For efficient digestion these acid formers and methane fermentors, must remain in a state of dynamic equilibrium. This equilibrium is a very critical factor which decides the efficiency of generation.

**Anaerobic Digester Components**

Methane formation from a complex organic material in the form of chemical reaction is shown as below. The chemical composition of organic waste consists of carbohydrates, proteins and lipids

Three methane forming routes:

Barker (1965) postulated the 3 methane forming routes

$$4(CH_3CH_2COOH) + 2H_2O \longrightarrow 4(CH_3COOH) + CO_2 + 3CH_4$$

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

Crop residues, live stock and poultry manure and food processing wastes may be the suitable substances (feed stock) for methane production under some circumstances.

**Anaerobic digestion** of these wastes, offers the following advantages.

1. The organic waste is converted into methane gas, which can be used as a direct energy source.
2. High protein live stock feed is produced which can be used as an indirect energy source.
3. The mass of organic waste is reduced, there by decreasing the pollution problem.
4. The digester effluent can be utilized as a fertilizer.
5. Since there is no aeration in the anaerobic digestion the running costs are low
6. Since the system is enclosed, the odours are contained. The only slight odour of the hydrogen sulphide is normally present in gas.
7. The passage of effluent through anaerobic digester reduces the number of pathogens present, so reducing the subsequent disposal problem.
8. Non putrescable inoffensive sludge can be produced in case of municipal digestion and in many cases, only a proportion of the gas produced was utilized

The Biogas production system consists of the following steps

1. Feed stock handling: Collection, hauling and storage.
2. Feed stock preparation: Grinding, dilution, mixing, preheating and pumping.
3. Anaerobic digestion: Internal agitation and heat exchange equipment.
4. Gas collection: Conveyance pipe, pressure regulator and condensate traps.
5. Gas Scrubbing: Removal of $CO_2$ and $H_2S$ and moisture
6. Gas utilization: Compression, storage, marketing or on site utilization for heat or electricity.
7. Digested slurry handling: Animal feed recovery (Screening, centrifugation, drying) or fertilizer recovery (storage pond and irrigation system).

### The basic process

Methane ($CH_4$) the primary component of natural gas has a heating value of 37.3 MJ/$m^3$. Bacterial degradation of organic matter under anaerobic condition (with out $O_2$) releases a mixture of gases (Biogas), which usually consists of 50-60% $CH_4$, 30-45% $CO_2$, $H_2$ 5-10%, $N_2$ 0.5-0.7% and numerous trace gases such has $H_2S$ that together constitute 0-1% of the gas volume. This gives raw biogas an energy content of only 19-22 MJ/$m^3$. $CO_2$ and trace gases can be removed by chemical means, yielding gas of pipe line quality 37 MJ/$m^3$. Biogas has a calorific value between 5000 to 5500 kcal/kg.

### Terminology:

The following terminology is used to describe the waste characteristics and the theory of anaerobic digestion.

### Biochemical Oxygen Demand (BOD)

The BOD is a measure of quantity of oxygen required for the oxidation of organic matter in dung by microorganisms present in a given time interval at a specified temperature. The standard time for finding BOD is 5 days.

The important quantities determining the strength of the feed stock is the BOD and suspended solids content. These values are normally quoted in ppm or mg/lit of the sample expressed as BODs. BOD is expressed either as the mass of $O_2$ utilized per volume of waste present or the mass of $O_2$ per mass of waste present.

### Chemical Oxygen Demand (COD)

Since BOD test are time consuming, the other commonly used test for finding the polluting nature of specific contaminants is COD test. COD is the indirect measure of the concentration of oxidizable material present in an organic waste. The COD test allows measurement of total quantity of $O_2$ required for oxidation of organic matter to $CO_2$ and water, but it does not differentiate between biologically oxidizable and biologically inert organic matter. COD is expressed as the mass of $O_2$ utilized either per volume or per mass of waste present. COD values are several times larger than BOD value. COD tests appear to be easier to obtain and more useful for work with animal manure.

### The Total Solids

Total Solids content of a waste is the residue after water is evaporated from the sample by heating to $103^0$C. If waste is liquid, the total solids may be divided into suspended solids and dissolved solids. Suspended solids are the solids in suspension that could be removed by ultra filtration. Dissolved solids are those that are dissolved in the sample and precipitate out during drying.

### Volatile Solids

Volatile Solids are the solids driven off as a gas when the total solids are incinerated at $600^0$C for one hour. The solids remaining after incineration are referred to as fixed solids. The volatile solids content of a waste is a measure of the amount of decomposable organic matter in the waste.

Solids content can be further classified into volatile suspended and volatile dissolved solids or fixed suspended and fixed dissolved solids

### Microbiology

The chemical composition of organic wastes consists of carbohydrates, proteins and lipids. Carbohydrates occur primarily as polysaccharides such as starch and cellulose. These polysaccharides are hydrolyzed by extra cellular enzymes to monosaccharides. The monosaccharides are made primarily of glucose with some fructose and mannose.

The monosaccharides are further broken down to organic acids and alcohols. The major organic acids produced by acid forming bacteria are acetic and propionic of which acetic is most important. Studies by Mc Carty (1964) indicate that 72% of the methane produced is formed from propionic acid. The remaining 15% is formed from $H_2$ and $CO_2$, reduction of methanol and degradation of other intermediate compounds.

**Some materials for Biogas**: The following major plants are considered for biogas production.

1. Water – Hyacinth: It is next to animal waste. These plants are grown normally in the rivers and canals, tanks of the hot regions yield 20t/ha/day which has good cleaning ability of dissolved chemicals in the water such as N and P wastes. It contains 95% water and only about 5% cellulose, lignin etc. Its growth is enhanced more in tropical weather and is ideal to grow in India. It

grows extremely well in sewage ponds, their by cleaning the ponds. It sucks water so much that water would become scarce if not supplemented. It gives out 350-420 lit biogas per Kg of dry weight. It absorbs salts of Cu, Lead, silver, cadmium and chromium. The biogas produced out of Water hyacinth is slightly higher in methane content.

2. Algae: Algae are single celled plants grow in lakes, tanks etc. There are several varieties of algae that have protein content up to 50%. Algae that occur in seas is not suitable for Biogas .Algae can either burnt directly to produce heat or anaerobically fermented to produce methane   Calorific value derived from methane is of the order of  3300kcal/kg of dry algae.
3. Ocean kelp: It is a kind of sea weed grown in coastal areas and also in high seas. Yield rate ranges from 300-500 wet tones/acre/year.  Kelp can be used to produce biogas, burnt as fuel or fed to cattle.
4. Certain type of grasses: Napier grass, Sudan grass and Bangola grass. The grass is processed and fed to biogas plants for gas.
5. Trees as biomass: Cotton wood, conifer, sycamore, Eucalyptus and slash pine.

**Gas yield**

The volumetric methane productivity is the amount of gas produced per day per unit of digester volume. For mesophyllic digester it ranges from about 0.5-2.0 $m^3$ methane/day/$m^3$ of digester volume and 3.0-3.8$m^3$/day/$m^3$ of digester volume for thermophilic digesters. The volumetric methane productivity rate is an excellent indicator of digester performance.

**Gas-Scrubbing systems**: The degree of biogas clean up required depends, upon the ultimate use of the gas or alternative utilization strategies.

**Water Vapour** is removed by frost proof condensers and condensate traps to prevent condensation in gas line and excessive corrosion.

**$H_2S$**: It presents a corrosion problem.  It is removed by means of iron sponge (a column of iron impregnated wood chips) so that biogas can be used in IC engines. The iron sponge can be either regenerated or replaced. Additional $H_2S$ removal is necessary if the gas is to be sold to natural gas pipeline companies.

**$CO_2$:** Can be removed by

1. Water Scrubbing
2. Membrane separation
3. Phosphate buffer
4. Regenerative amine absorption.

Water scrubbing is most economical. It consists of bubbling the biogas through water at approximately 3400 Kpa pressure to dissolve the $CO_2$. The heated (regenerative) amine absorption process and multiple stage selective membrane process have also proved successful in providing methane gas from biogas.

**Bio gas utilization:** It is a flammable gas. Methane is the only combustible portion in the gas and hence around 60 per cent by volume is only usable for combustion.  Bio gas may be used for (i) cooking (ii) domestic lighting and (iii) with diesel in IC engines for production of power, utilizing gas for pumping water, chaffing fodder and grinding flour.

1$m^3$ of biogas can be used to

- Illuminate 60 W bulb for a period of 7 hrs.
- Cook 3 meal for a family of five.
- Run 2 HP engine for 1 hr.
- Run 100 liters capacity refrigerator for 9 hrs.
- Generate electricity of 1.25 kwh.

The following table gives the amount of dung required to produce 1 cu m of gas per day under average conditions calculated on the basis of 40 to 60 days retention period:

Cattle dung ………….. 32 kg/day
Pig manure …………….20 kg/day
Poultry manure ………..12 kg/day

**Biogas Plants Operational Modes**

Four basic anaerobic digestion designs are currently used to digest agricultural wastes (1) Continuous- flow (2) Batch (3) Plug flow (4) Continuously expanding digesters

**Continuous Flow**: A set volume of waste is added daily and an equal volume of effluent is removed, keeping the digester volume constant. Different modes of mixing the digester contents have been used all the way from continuous mixing to no mixing.

**Batch load**: This uses two digesters operating in parallel, the first is loaded with a given daily volume until it is filled. When the I digester is filled, 2nd digester is loaded with the same daily volume. While the 2nd digester is being filled, the Ist digester is allowed to ferment without additional loading. At the end of the loading period for the 2nd digester, then Ist is emptied and the process is repeated. Mixing may be either continuous or intermittent.

**Plug Flow:** Influent is introduced at one end of a longitudinal digester and effluent is withdrawn from the other end. No internal mixing is used in this process.

**Continuously Expanding digester** (CED) is a recently introduced process in which a daily loading is made, but no effluent is removed. Thus, the digester volume gradually expands over a cycle of 90 to 180 days, then the effluent is removed and applied to land.

**Advantages**: Operator does not have to dispose of effluent on a daily basis
**Disadvantages**: It requires huge volume which may be expensive.

**Site selection for biogas plant**

Following factors must be considered while selecting the site for a biogas plant.

*(i)* Distance. The distance between the plant and the site of gas consumption should be less in order to achieve economy in pumping of gas and minimizing gas leakage. For a plant of capacity 2 $m^3$, the optimum distance is 10m.

*(ii)* Minimum Gradient. For conveying the gas a minimum gradient of 1% must be made available for the line.

*(iii)* Open Space. The sunlight should fall on the plant as temperature between $15^0C$ to $30^0C$ is essential for gas generation at good rate.

*(iv)* Water Table. The plant is normally constructed underground for ease of charging the feed and unloading slurry requires less labour. In such cases care should be taken to prevent the seepage of water and plant should not be constructed if the water table is more than 10ft. (3m).

*(v)* Seasonal Run Off. Proper care has to be taken to prevent the interference of run off water during the monsoon. Intercepting ditches or bunds may be constructed.

*(vi)* Distance from wells. The seepage of fermented slurry may pollute the well water. Hence a minimum of 15m should be maintained from the wells.

*(vii)* Space Requirements. Sufficient space must be available for day to day operation and maintenance. As a guideline 10 to 12 $m^2$ area is needed per $m^3$ of the gas.

*(viii)* Availability of Water. Plenty of water must be available as the cow dung slurry with a solid concentration of 7% to 9% is used.

*(ix)* Source of Cow dung/Materials for Biogas Generation. The distance between the material for biogas generation and the gas plant site should be minimum to economies the transportation cost

**Factors affecting Biodigestion or Generation of gas**

The following are the factors that affect generation of biogas:
(1) pH or the hydrogen-ion concentration
(2) Temperature
(3) Total solid content of the feed material
(4) Loading rate
(5) Seeding
(6) Uniform feeding
(7) Diameter to depth ratio
(8) Carbon to Nitrogen ratio
(9) Nutrients
(10) Mixing or stirring or agitation of the content of the digester
(11) Retention time or rate of feeding
(12) Type of feed stocks
(13) Toxicity due end product
(14) Pressure
(15) Acid accumulation inside the digester.

1. **$P^H$:** Methane production bacteria are sensitive to small changes in $P^H$. During normal methane operations, the $P^H$ is maintained naturally by the bicarbonate buffer system resulting from the $CO_2$ produced during anaerobic fermentation. If the equilibrium balance is altered and too much organic acid is produced, then the $P^H$ of the system may drop below 6.6 and the methane forming bacteria die off rapidly with out producing methane. The optimum $P^H$ is ranging between 7.0 and 7.2.

2. **Temperature**: It is an extremely important factor. It controls the microbial growth rates during the fermentation process. Three thermal zone of microbial activity have been identified. (1)Psychrophilic (Below 28 $C^0$) (2) Mesophillic (28 – 42$C^0$) and (3) Thermophillic (> $42^0$). $CH_4$ production in psychrophilic zone is small. The mesophillic and the thermophollic are the zones of primany interest for commercial methane production.

3. **Total solid content**: The cow dung is mixed usually in the proportion of 1:1 (by weight) in order to bring the total solid content to 8-10%. The raw cow dung contains 80-82% of water. The balance 18-20% is termed as total solids.

4. **Loading rate**: is defined as the amount of raw material (usually Kg of volatile solids) fed to the digester /day/ unit volume. Most municipal sewage treatment plants operate at a loading rate of 0.5-1.6 Kg VS/ $m^3$/day.

5. **Seeding**: although the bacteria required for acid fermentation and methane fermentation are present in the cow dung, their numbers are not large. While the acid formers proliferate fast and increase in numbers, the methane formers reproduce and multiply slowly. It would be advantageous to increase the number of methane formers by artificial seeding with a digested sludge that is rich in methane formers.

6. **Uniform Feeding**: The digester must be fed at the same time every day with a balanced feed of the same quality and quantity.

7. **Diameter to depth ratio**: Gas production per unit volume of digester capacity was maximum when the diameter to depth ratio was in the range of 0.66 to 1.00. Digesters of 16 ft depth and 4 to 5 ft diameter were reported to be working satisfactory.

8. **Carbon Nitrogen ratio of the input material**: All living organisms require nitrogen to form their cell proteins from a biological view point. Carbon is used for energy and nitrogen for building cell structure. A carbon nitrogen ratio of 30 will permit digestion to proceed at an optimum rate.

9. **Nutrients**: The major nutrients required by the bacteria in the digester are C, $H_2$, $O_2$, $N_2$, P and S. to maintain proper balance of nutrients an extra raw material rich in phosphorus (night soil) and N2 (chopped leguminous plants) should be added along with the cow dung to obtain maximum production of gas.

10. **Mixing or Stirring or agitation of the content of the digester**: Since bacteria in the digester have very limited reach to their food, it is necessary that the slurry is properly mixed and bacteria get their food supply.

11. **Retention time or rate of feeding:** The period of retention of the material for biogas generation, inside the digester is known as the retention period. This period will depend on the type of feed stocks and the temperature. Normal value of the retention period is between 30 and 45 days and in some cases 60 days.

Periods for different materials to get well fermentation are:

| | | |
|---|---|---|
| (i) | Cow and buffalo dung | 50 days |
| (ii) | Pig-dung | 20 days |
| (iii) | Poultry droppings | 20 days |
| (iv) | Night soil | 30 days |

12. **Type of Feed Stocks:** All plant and animal wastes may be used as the feed materials for a digester. When feedstock is woody or contains more of lignin, then biodigestion becomes difficult. The cow and buffalo dung, human excreta, poultry droppings, pig dung, waste materials of plants, cobs, etc., can all so be used as feed stocks.

13. **Toxicity:** The digested slurry if allowed to remain in the digester beyond a certain time becomes toxic to the microorganisms and might cause fall in the fermentation rate. Pesticides and disinfectants from farms can kill bacteria. Many organic and inorganic substances may be toxic to the microbes in the digester if concentrations are excessive. The toxic substances of principal concern are heavy metals, alkaline metals (Mg, Ca, Na, K), $NH_3$ or soluble sulphides.

14. **Pressure:** The pressure on the surface of slurry also affects the fermentation. It has been reported to be better at lower pressures.

15. **Acid Accumulation inside the digester**: Intermediate products such as acetic propionic butyric acids are produced, during the process of biodigestion. This causes in a decrease of the pH, especially when fresh feed material is added in large amount. These acids may be converted into methane by addition of neem cake.

16. **Organic loading ratio**: It is the organic waste added per day per unit volume of digester. The influent solids concentration is the ratio of the mass of the dry solids to the total mass of waste (dry solids + wastes) expressed as a %. Available data indicates that anaerobic digestion has been successful with organic loading rates of 1.6 to 3.2 kg of volatile solids per day per $m^3$ of digester and influent solid concentration of 6-12%.As with other life form, a balanced diet must be maintained for the microbes, microbial cells require carbon, nitrogen, phosphorus and micronutrients for adequate growth. Ratio of 100:2:0.5 (available organic carbon: nitrogen: phosphorus) are necessary to maintain balanced cell growth.

# LECTURE - 4

# BIO–GAS PLANTS

## Classification of Biogas Plants

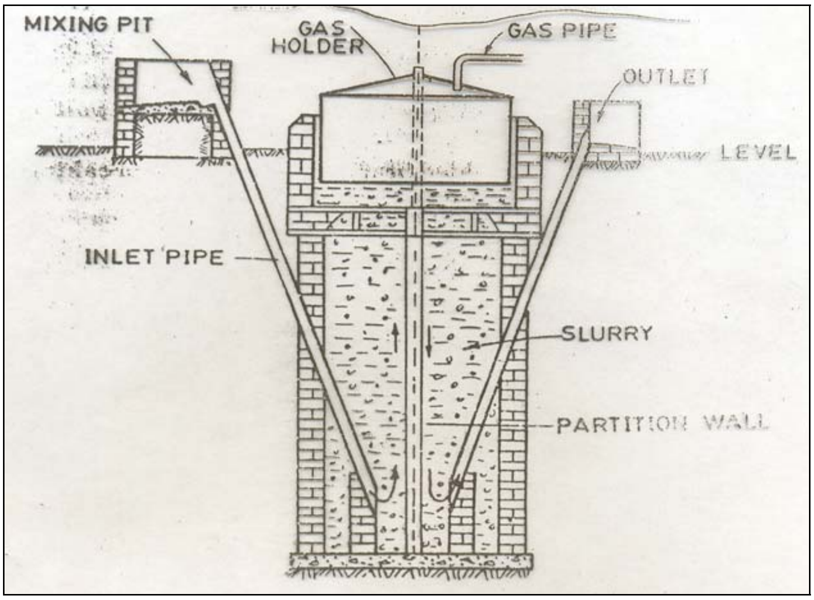
1. Continuous and batch types (as per the process).
2. The dome and the drum types
   (a). Floating gas holder plant
   (b). Fixed dome digester.
3. Different variations in the drum type.
   (a).With water seal
   (b).Without water seal

***KVIC Digester*** (Gobar gas generator): Design which is patented by KVIC India under the name "Grah Luxmi" consists of two main parts – (i) Digester or pit, (ii) the gas holder or the gas collectors.

It consists of a digester or pit which is for fermentation and a floating drum for the collection of gas. Digester is a well of masonry work, dug and built below the ground level, the depth of the well varies from 3.5 to 6 meters and diameter from 1.2 to 6 meters, depending upon the gas generating capacity and the quantity of raw material fed each day. There is a partition wall in the centre which divides the digested well vertically into two semi cylindrical compartments. The partition wall is lower than the level of the digester rim and hence it is submerged in slurry when the digester is full. There are two slanting cement pipes which serves the purpose of inlet and outlet. An inlet chamber near the digester at surface level serves for mixing dung and water (slurry) in the ratio of 4:5, flows down the inlet pipe to the bottom of digester. This type of design can hold raw material for 60 days. The outlet chamber which is also at nearly surface level or just a few cm below the level of the inlet chamber. When more slurry is added and both compartments of the digester are full, then equivalent amount of fermented slurry flows out at the outlet and discharges into a composed pit.

Gas holder of the digester is a drum constructed of mild steel sheets, cylindrical in shape with a conical top radial support at the bottom. It fits into the digester like a stopper. It sinks into the slurry due to its own weight and rests upon the ring constituted for this purpose. As the gas is generated the holder rises and floats freely on the surface of the slurry. A pipe is provided at the top of the holder, for flow of gas for usage. A central guide pipe is provided to prevent the holder from tilting. It is fitted to the frame and is fixed at the bottom in the masonry work. The holder also acts as a seal for the gas. The gas pressure varies between 10-15 cm of water column. The gas before use is passed through a vessel containing soda lime so that it is dried. Generally the pit is deep and narrow, but at places where the water level is low, the design has been modified and the volume has been taken horizontally. The floating drum is metallic and consumes about 40 per cent of the total cost of the plant. Besides, if not properly maintained, the drum corrodes soon and the life of the plant very much gets reduced. Perhaps the cost and the maintenance factors of this type of digesters are prohibitive factors for being not very much liked by users. However, the construction is quite simple and the gas comes out at the constant pressure. Gas is stored in mild steel drum of storage capacity of 30-

40% plant size at pressure of about 10 cm water column which is sufficient to carry it upto a length of 20m – 100m depending on size of plant.




**KVIC Type Bio-Gas Plant**

**Floating drum Plant (KVIC)**

**Advantages**

1. Gas holder can be lifted off to facilitate removal of any build up of scum
2. Gas holder can be rotated to give limited stirring
3. Release of gas at constant pressure
4. Inlet and outlet are straight to facilitate cleaning of blockages
5. It has less scum troubles because solids are constantly submerged
6. No separate pressure equalizing device needed when fresh waste is added to the tank or digested slurry is withdrawn
7. Danger of mixing $O_2$ with the gas to form an explosive mixture is minimized
8. Higher gas productions / $m^3$ of digester volume is achieved
9. Floating drum has welded braces, which help in breaking the scum by rotation
10. No problem of gas leakage

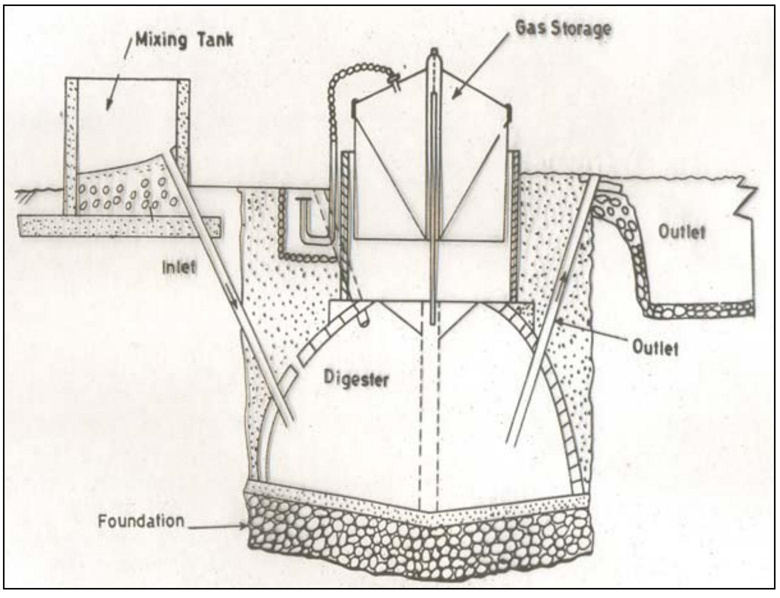
**Disadvantages**

1. Higher cost as cost is dependent on steel and cement
2. Heat is lost through metal gas holder, hence it troubles in colder regions and period
3. Gas holder requires painting once or twice a year depending on the humidity of the location
4. Flexible pipe joining the gas holder to the main gas pipe requires maintenance as it is damaged by ultraviolet rays in the sun

## Pragati Design Biogas Plant

The design has been developed by United Socio-Economic Development and Research Programme (UNDARP) Pune, in order to have a cheaper floating drum biogas plant.

In this design the depth of pit is less than KVIC plants so that it can be constructed in hilly and high water table areas. The cost of pragati plant is 20% less than KVIC plant. The foundation of this plant is conical shape, with difference of one feet between outer periphery and its centre so that to reduce the earth digester wall work. It is constructed at the base of the pit with cement, sand and concrete, keeping the site conditions in view so that it can bear the load due to weight of slurry in the digester. The digester of pragati design plant start from the foundation in dome shape there by reducing the constructional area, for same digester volume, thus reducing the cost of the plant. The wall thickness of digester is kept 75 mm only. Dome shape construction takes place upto a collar base, where a central guide frame is provided. The digester wall above guide- frame is constructed in cylindrical shape. Partition wall is constructed in the digester for $4m^3$ or bigger sizes so as to control the flow of slurry inside the digester. It divides digester into 2 parts separating inlet and outlet. The inlet is through pipe, placed while constructing digester wall. It is used for feeding daily slurry into the digester and is generally of 100 mm dia. The outlet pipe is also 100mm in diameter and fixed while constructing digester wall.The asbestos cement pipe can be used for inlet and outlet. The guide frame is made up angle iron and steel pipe is embedded in the digester wall at top of spherical portion of digester. The central guide pipe holds gas holder which is also made of M.S. sheet and angle iron. It floats up and down along pipe depending on the quantity of gas in the drum.




**Pragati Type Bio-Gas Plant**

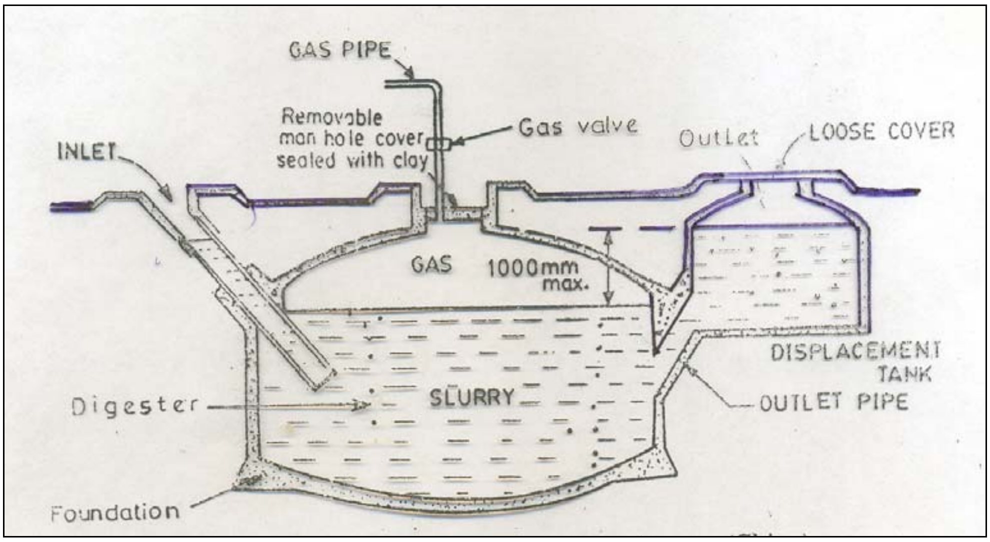
### Janata Type Biogas Plant

This was first developed by the Planning, Research and Action Division, Lucknow in 1978.

It is an improved version of the Chinese fixed dome type biogas plant. The foundation of Janata biogas plant is laid at the base of the underground pit on a leveled ground which bear the load of slurry as well as digester wall. Digester is cylindrical in shape, constructed with bricks and cement. It holds the dung slurry in the digester. The diameter and height ratio of the digester is kept 1.75:1. The gas is stored in gas portion, which is an integral part of plant between dome and digester where the usable gas is stored. The height of the gas portion is above the inlet and outlet opening of dome, and is equal to maximum volume of the gas to be stored (30 – 40% of plant capacity) and equal to volume of slurry to be displaced at inlet and outlet.

**Dome** is constructed over the gas portion, with volume of 60% of the plant capacity. It must be constructed very carefully integrating it with digester and gas portion so that no leakage of gas can take place. The gas outlet pipe is fixed at the top of dome for laying the line.

Inlet and outlet portions are constructed for putting the fresh slurry inside the plant and to take the digested slurry out. The discharge of slurry out of the plant is due to pressure of the gas in the plant. Over the inlet portion, an inlet mixing tank is also constructed to mix the dung and water.




**Janata Type Bio-Gas Plant**

### Advantages

1. Capital investment is low
2. It has no corrosion trouble
3. Heat insulation is better as construction is beneath the ground. Temperature will be constant
4. Cattle and human excreta and by fibrous stalks can be fed
5. No maintenance

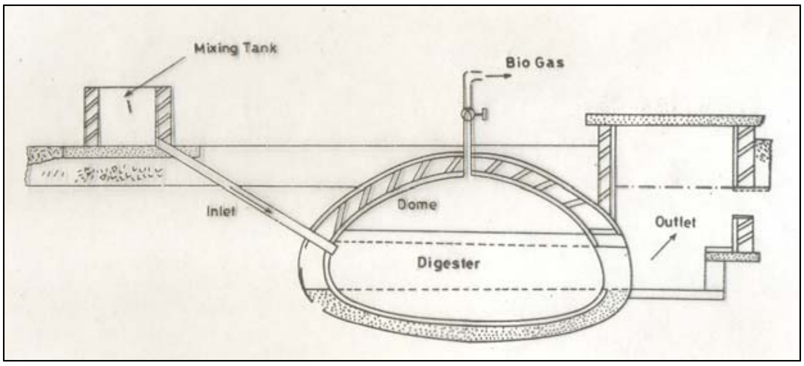
**Disadvantages**

1. No provision for stirring the slurry and hence scum problem is there.
2. Gas production per $m^3$ of digester volume is less
3. It has variable gas pressure
4. Construction of dome portion is a skilled job and requires thorough training of masons
5. Requires more excavation work
6. Location of defects in the dome and repairing are difficult

**Deenbandhu Biogas Plant**

This is also a fixed dome plant developed by action for food production, New Delhi, which is a low cost biogas plant. The principle of working of this plant is same as that of Janata Model, except configuration of inlet entrance and digester.

The foundation of the plant is constructed in the segment of Spherical Shape. On the outer periphery of this foundation, the dome shaped digester is constructed with same base diameter. In this way the digester, gas portion and dome look as a single unit. The surface area of the Biogas Plant is reduced with same digester volume, reducing the earth work and cost of construction without sacrificing the efficiency. The higher compressive strength of the brick masonry and concrete makes it a safe structure as the plant is always under compression. A spherical structure loaded from the convex side will be under compression and so the internal load will not have any residual effect on the structure. At the top of the foundation a window opening is kept (outlet portion) for the outward movement of the digested slurry. The asbestos cement pipe of 15 cm dia is used for inlet instead of separate opening. The pipe is embedded in the digester wall at a fixed position, just opposite to outlet opening, to avoid short circuiting of fresh material for digested slurry. The volume of the outlet is increased to produce requisite gas pressure through the weight of the displaced slurry. At the top of the dome a gas outlet is fixed as in the case of Janata type Biogas plant.




**Deenbandhu Type Bio-Gas Plant**

## LECTURE - 5

## BIOMASS GASIFICATION

Biomass gasification is conversion of solid biomass for eg. wood, wood waste, agriculture crop residue etc. into a combustible gas mixture known as producer gas of low calorific value. The oxygen requirement is (30-40% of stoichiometric) 1/3 of biomass by weight. The producer gas is a mixture of combustible composition of CO, $H_2$, condensable tar, $CH_4$, $CO_2$ and $H_2O$. The producer gas from wood as biomass contains

10 – 20% $H_2$
15 – 20% CO
45 – 60% $N_2$
02 – 04% $CH_2$
05 – 15% $CO_2$
06 – 08% $H_2O$

The energy contents of the producer gas is 3-5 $MJ/m^3$

### Properties of Biomass

These three constituents of biomass are basically made of four important fundamental elements and with traces of sulphur and chlorine as a contaminant as shown below.

### Typical Elementary Chemical Composition of Biomass

| | |
|---|---|
| Carbon | 44-50% |
| Hydrogen | 05-07% |
| Oxygen | 40-50% |
| Nitrogen | 0.12-0.60% |
| Sulphur | 0.0-0.2% |

These fundamental elements along with the trace elements decides properties of biomass like bulk density, ash content, moisture content, volatile matter, heat value of biomass for commercial scale operations.

### Physical property

### Bulk Density

The density of the material is an important physical property in considering energy content of the fuel on volumetric basis such as for transportation, solids handling and sizing the gasifiers.

Straw of cereals : 100-200 $kg/m^3$
Wood : 800-900 $kg/m^3$
Petroleum products and coal : 10 times more than dry biomass.

This is referred as energy potential

### Chemical Properties

Proximate analysis gives moisture content, ash content, volatile matter and fixed carbon

**Moisture Content:** The moisture content determines the suitability of wood for thermo chemical conversion. Biomass materials have varying moisture contents and it is useful to know the moisture content of the fuel to be used in order to determine its drying cost and as received heat content. The actual recoverable heat is reduced because of the heat requirements for vapourising the moisture and for superheating the vapour. The optimal value of moisture is 12%.

**Ash Content:** Ash composed of CaO, $K_2O$, $Na_2O$, MgO, $SiO_2$, $Fe_2O_3$, $P_2O_5$, $SO_3$ and Cl. Ash is the inorganic portion of biomass which is non-combustible, Ash content determines the suitability of biomass for gasification. Ash content plays a major role as the melted ash causes problems in reactors and ash removal systems. Low ash content material like charcoal, wood, coconut shall are extremely suitable for continuous and reliable operation

| | |
|---|---|
| Head Wood | : 0.1-0.5% |
| Agricultural reduce | : 5.0-10.0% |
| Rice husk | : 18-20% |

**Volatile Matter:** Organic portion available in the biomass at 400-500$^0$C, complex organic compounds in the biomass start decomposing into volatile gaseous compounds and left out in the form of char in the solid form. Coal has 20% and biomass 90% of volatile matter. High volatile matter makes biomass suitable for gasification.

**Fixed Carbon:** 1 – M – VM – Ash

**Ultimate analysis** gives C, H, N, O, and S by using elemental analyzer. The elemental analysis helps to evaluate feed stocks in terms of potential pollutants (chlorine) and find the heat value by Dulong's formula or by Bomb calorie meter.

Calorific value = (8080C+34500 (H-O/8) + 2240S) Kcal/Kg,

Where C, H, O and S are fractional composition of elemental carbon, hydrogen, oxygen and sulphur respectively.

**Heat Content:**

Ash not contributing to the heat value. Biomass with 100% moisture cannot be ignited to burn. That means, the heating value of this kind of biomass is low or zero. Heating value ranging from 2500 kcal/kg of dry matter onwards are classified as fuels for commercial use.

**Other Constituents:**

Sulphur → $SO_2$
Chlorine → HCl } causing environmental problems

Nitrogen available in the biomass contributes to Nitrogen oxides ($NO_X$) like NO, $NO_2$, which are toxic.

**Operating Parameters for the Gasifiers**

Various operating parameters which affect the over all performance of the gasification process are quality of biomass

1. Moisture Content: As moisture content increases, hydrogen percentage increases and further increase of moisture content, CO decreases.
2. Size of the biomass: Affect flow properties & influences the pressure drop
3. Operating temperature: Increase in temperature, CO & $H_2$ increases and $CO_2$ decreases. Softening and melting point of ash is $1000^0$C so ash slagging occurs, then keep < $1000^0$C for smooth operation
4. Operating pressure: Upto 15 atm. pressure gas quality or process efficiency is unaffected
5. Air fuel ratio or equivalence ratio = 0.35

Equivalence ratio (ER) = Actual air / Theoretical air for complete combustion

0.2 – 0.4. _______ Gasification

< 0.2 ———— Pyrolysis

> 0.4 ———— Combustion

The theoretical quantity of air necessary to provide sufficient oxygen to completely combine with a quantity of fuel is termed stoichiometric air. The solid fuels gasified in the presence of sub stoichiometric air.

**Processing of Biomass for Gasification**

The gasification systems cannot accept any kind of biomass in their original form of availability. Feed stock/Biomass is woody or non-woody, drying biomass to a maximum of 12-15% moisture content is a pre-requisite. This necessity confirms that biomass is to be processed to suit the gasification systems.

**Woody Biomass:** To maintain uniform density in the gasifiers, chipping of wood to sizes ranging from 0.25 to 0.50 inches is desired to expose more surface area increasing the duration of exposure to combustion zone, to sustain the combustion bed requirements.

**Non – Woody Biomass**

Bulk density ranging between 50-160 kg/$m^3$. Non woody biomass is a candidate for gasification by Densification/Briquetting.

**Gasification System**

The main component of the gasification system is the reactor. The reactor contains feeding port, which the biomass is fed. The required air can be drawn up-wards or down wards depending on the design of the system. The producer gas is collected as shown and ash is collected from the grate at the bottom.

The main trunk of the reactor can be classified based on thermo chemical reactions taking place at different levels as

1 Biomass drying zone
2 Pyrolytic zone /distillation zone
3 Reduction zone
4 Combustion zone or hearth zone

The different reactions takes place in these zones of the reactor and create conditions such that

1. Biomass is reduced to charcoal
2. Charcoal is converted at suitable temperature to produce producer gas.

**Gasifier**

It is an equipment which can gasify a variety of biomass such as wood waste, agricultural waste like stalks, roots of various crops, maize cobs etc. The gasifier is essentially a chemical reactor where various complex physical and chemical processes take place. Biomass gets dried, heated, pyrolysed, partially oxidized and reduced, as it flows through it.

**Advantages of the gasifier**

1. It is very easy to operate the gasifier
2. Its maintenance is easy
3. It is sturdy in construction
4. Reliable in operation

**The Chemistry of Gasification**

The gasification involves the following four steps during the process in the gasifier

1 **Biomass Drying Zone ($120^0$C )**
This zone accomplishes further drying of biomass

2 **Pyrolysis or Distillation Zone (250 to $500^0$C) @ $400^0$C**
Biomass is thermally decomposed to yield volatile gases, oil, char and tar

3 **Reduction Zone $900^0$C** In this zone, carbon further reacts with the available pyrolysed biomass in the presence of $H_2O$. This zone contributes to CO, $H_2$ & $CH_4$ in the producer gas. The reactions are as mentioned below.

$C+2H_2 \rightarrow CH_4$ } Methanation reaction
$C+H_2O \rightarrow CO+H_2$ }
$C+CO_2 \rightarrow 2CO$ -Boudouard reaction
$C+2H_2O \rightarrow CO_2+2H_2$ -Water shift reaction.

$CO_2$ and water vapour can reduce to CO, $H_2$ and $CH_4$. These are endothermic reactions. (Heat is absorbed in the reaction)

4 **Combustion Zone or Hearth Zone or Oxidation Zone 700-$1300^0$C** In this zone, the remaining carbon and hydrogen of biomass is gasified with atmospheric air due to combustion and forms the $CO_2$ and water vapour

$C+O_2 \rightarrow CO_2 + Heat$ } exothermic reactions.
$2H_2+O_2 \rightarrow 2H_2O$ }

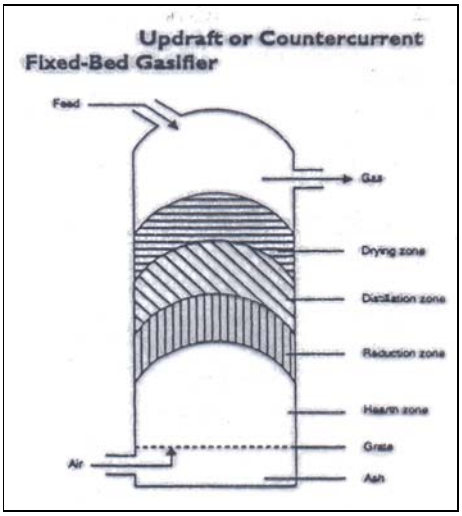
**Types of gasifers**

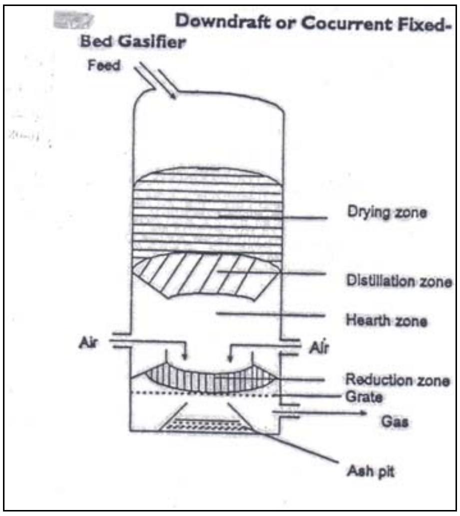
Gasifiers are classified as per

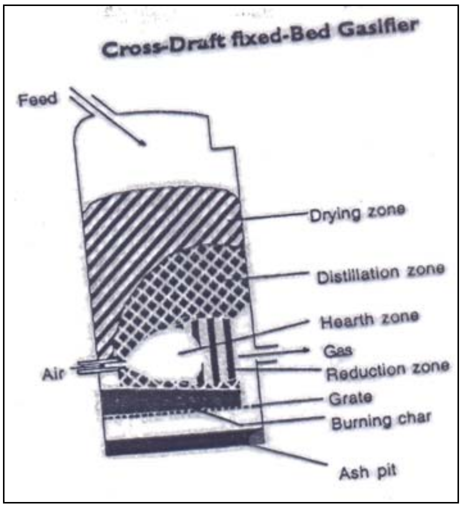
(i) The direction of the gas flow
   (a) Down draught
   (b) Up draught
   (c) Cross draught
(ii) Output or capacity of the gasifiers
   (a) Small size gasifiers (upto 10 kw)
   (b) Medium size gasifiers (10-50 kw)
   (c) Large size gasifiers (50-300 kw)
   (d) Very large gasifiers (300 kw & above)
(iii) Type of the bed
   (a) Fixed bed
   (b) Fluidized bed

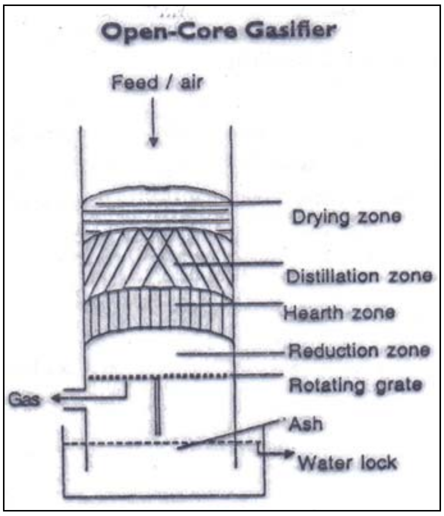
**Detailed description of different types of gasifiers are given below**

1) **Up – Draft Gasifiers (Counter Current Gasifiers):** In this design the biomass moves down wards as the gasification process goes on. The air is taken from the bottom of the gasifier and the producer gas leaves the gasifier from the top portion. This means the producer gas moves counter to the direction of flow of biomass. Wide variety of biomass feedstock is suitable for this design, even with relatively higher moisture contents. Since hot gases passes through biomass, the moisture is driven off. One of the major disadvantages of this design is that the pyrolysis products are not routed through combustion zone and hence the gas cleaning becomes very expensive.






1. This type of gasifier is easy to build and operate
2. The gas produced has practically no ash but contains tar and water vapour because of passing of gas through the un burnt fuel.
3. Up draft gasifiers are suitable for tar free fuels like charcoal

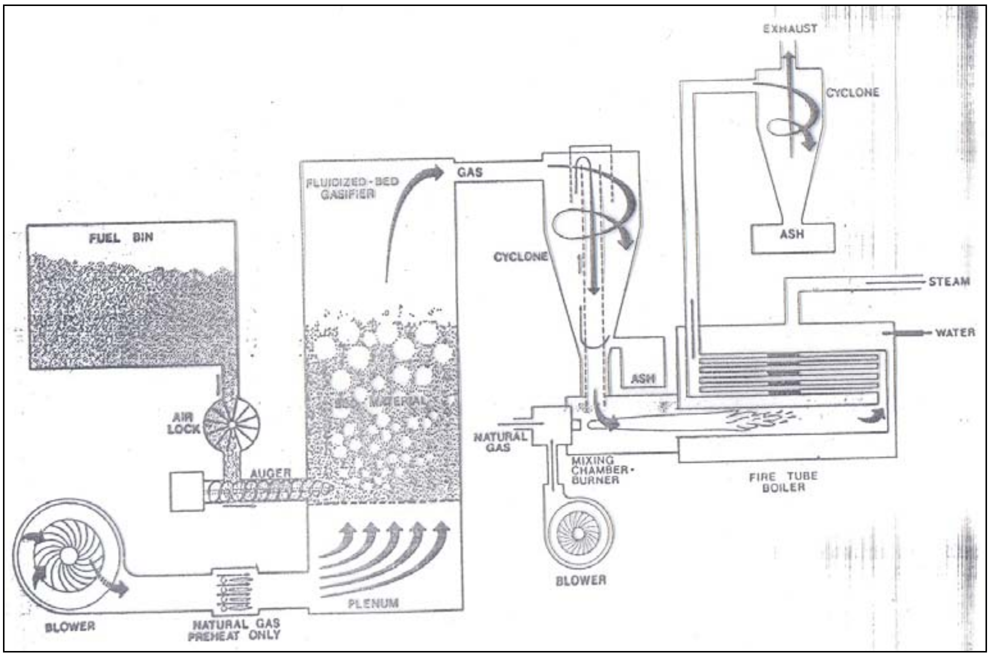
2) **Downdraft Gasifier (Co current gasifiers):** In this design, biomass is fed from the top and air intake is from the top or from the sides also. The producer gas is collected from the bottom of the reactor, moving in the same direction to biomass feeding and air. Since the producer gas moves through the hearth zone, the chances of proper combustion of tar and char is expected. This design requires biomass with minimum moisture content (+15%) and uniformity in size for proper pyrolysis. The producer gas carries away high temperatures, lowering the overall efficiency. Since the gas flows through oxidation zone chances of carrying higher amounts of ash, particulate matter in the gas necessitating efficient gas cleaning mechanism. The gasifiers are suitable for fuels like wood and agricultural wastes. They are cheap and easy to make. They may be used to power generation upto above 150 kw.

3. **Cross Draft Gasifier:** This design is used for char coal gasification to operate 10-50 kwe systems for local applications. The inlet of air and gas outlet are horizontal to the feeding of charcoal from the top.
    1. Short path length for the gasification reactions, responds most rapidly for changes in gas production

4. **Open Core Gasifiers:** These gasifiers are designed to handle low bulk density biomass like rice husk etc to avoid choking of feed port and disturbed flow of feed into the gasifier.
   These gasifiers are fuel dependent. Double wall reactor can be used for recirculation of gas.

5. **Fluidised bed gasifier**

A fluidized bed gasifier is most versatile and any biomass including sewage sludge, pulping effluents, etc. refuse can be gasified using this type of gasifer. It provides a means of burning any combustible material with high efficiency and with minimal pollution.




At the heart of a fluidized bed combustor is a hot bed of inert particles (Sand) which are held in suspension fluidized by an upward current of air. The inert particles aid heat transfer resulting from rapid mixing and turbulence with in the fluidized bed. The operating temperature of the bed is maintained with in the range of 750 – $950^0$C, so that the ash zones do not get heated to its initial deformation temperature and this prevents clinkering or slagging. Rice husk is fuel mostly used

**Advantages**

1. Quick start up
2. High combustion efficiency
3. High output rate
4. Usage of fuel with high moisture content
5. Uniform temperature throughout the furnace volume
6. Reduced emission of harmful NOx, $SO_X$
7. Operation is an simple as that of an oil for red boiler

**Compulsory Add-On Features of Gasifiers**

The producer gas cleaning is a complex job to bring down the temperatures for engine applications. The compulsory add-on features for gas cleaning comprise basically the following

1. Producer gas cleaning in a cyclone
2. Tar cleaning system
3. Dust cleaning system

**Tar Cleaning System:**

1. Gas is passed through wet sand beds for absorption
2. Spraying water against the gas stream

**Dust Removal**

Dust removed by employing techniques like

a. Electrostatic precipitators
b. Sand or Saw dust or rice husk filtering
c. Fabric bag filtering
d. Using ceramic filters.

**Gas purification**

Gas reacted with water forming CO and $H_2$ and additional $CO_2$ is formed, then passes through scrubber cooling the gas to about $32^{O}C$ and removing tars and acid and compressed gas to 700 kpa ($7kg/cm^2$).

The scrubbing is done in two stages (1) Hot $K_2$ $CO_3$ reduces $CO_2$ to 300 ppm (2) Mono ethanolamine (MEA) reduce $CO_2$ to 50 ppm then passes through a cryogenic system power gas 45% $H_2$, 55% $CO_2$.

**Application of producer gas**

Direct heat applications
Pumping of irrigation water
Electricity generation/engines for power generation.

In SI engines only gas is used. Gasoline carburetor replacement is required with air fuel mixer, power recovery 40 to 60% & CI Engine-Dual fuel mode 80-90% producer gas, 15-25% Diesel.

The gas contain tar, solid char and ash particles which need to be removed before using the gas as engine fuel and gas is cooled. For thermal application not required. The complete system for gasificer engine system may be comprising of gasifier, cyclone separator, water scrubber, filter and engine.

1. Gas has to be cleaned
   (a)Removal of large char pentacles
   (b) Scrubbing of gas to remove tar
   (c) Cooling the gas
   (d) Removal of moisture and removal of fine dust particles

2. Tar < 100 $mg/Nm^3$ is acceptable for engine

# LECTURE 6

# BIOMASS BRIQUETTING

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 has been advanced as a solution to large volume - low density- high transportation/ handling cost problems associated with biomass.

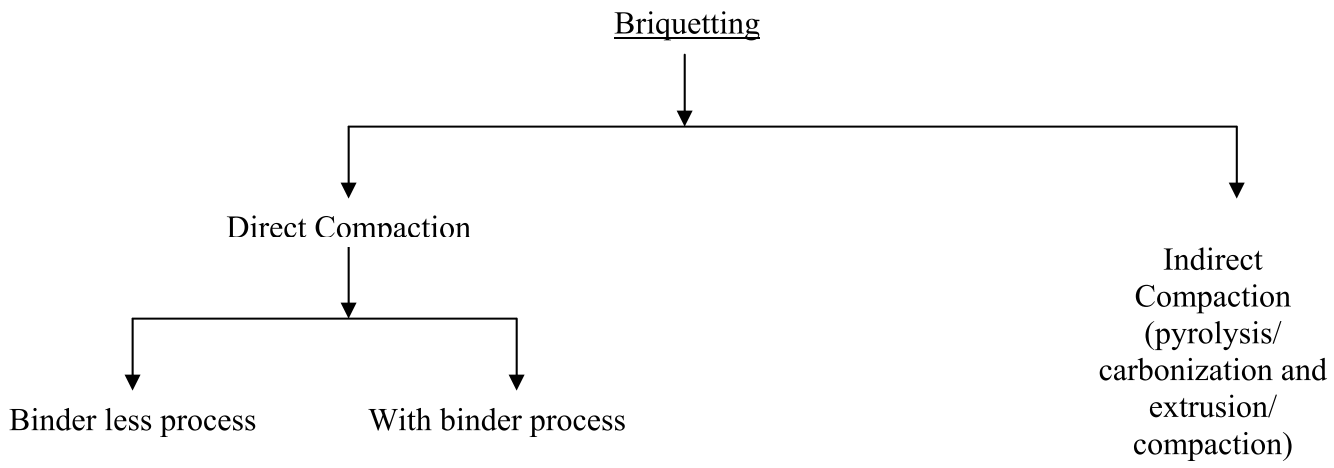
## Advantages in Briquetting of Biomass

1. Avoidance of loose waste /residues of agricultural, forestry and agro-industrial processing so as to check environmental pollution
2. No toxic gas and sulphur emission, even no odour during combustion.
3. Easy to handle and store (1000 kg/cu.m. of briquettes can be stored and transported against 50 kg/cu.m of agro wastes).
4. Fire risk in loose storage of biomass minimized.
5. High quality fuel with very low ash content (2-5%) compared to 30-40% in case of coal.
6. Easy to burn, as briquettes have lower ignition temperature compared to coal. Smokeless burning and sustained combustion temperature requirement achieved due to very efficient combustion, leaves white ash without fixed carbon. Full heat value is recovered.
7. It produces gas during burning which accelerates burning efficiencies and inhales $CO_2$ and releases oxygen to the atmosphere.

## Processes of Briquetting

Briquetting is a technological method of compressing and densifying the bulky raw material, the biomass reducing its volume – weight ratio and making it usuble for various purposes.

The vital requirement of briquette formation from woody biomass is the destruction of the elasticity of the wood done by heat treatment or by a high pressure or by a combination of both.



**I. Binder less process involves two steps**

1. **Semi – fluidizing the biomass**: Biomass is semi – fluidized through the application of high pressure in the range of 1200 – 2000 kg/cm$^2$ (120 – 200 mpa) at which condition the biomass gets heated to a temperature of about 182$^0$C and the lignin present in biomass begins to flow and acts as a binder provides mechanical support and repels water.

2. **Extracting the densified material**: The semi – fluidized biomass is densified through briquetting machines available in the capacity range of 100 – 300 kg/h, operating on electric power. The equipment cost of such briquetting units depend open its capacity and costs between Rs 3 – 20 lakhs.

**II. With binder process**

In this process, the biomass requires addition of some external binding materials like molasses, dung, slurry, lingna sulphonate, sodium silicate etc.

The briquetting machines operate at lower pressure range of 500 – 1000 kg/cm$^2$ (50 – 100 mpa) and are powered by electricity. Such machines are available in the capacity range of 100-400 kg/h.

**Indirect compaction**

Pyrolysis / Carbonization and extrusion / Compaction process pyrolysis is the process of destructive distillation of organic materials heated at slow rate at about 270$^0$C in the absence / 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

1. Composition of biomass
2. Residence time in kiln
3. Temperature

During the pyrolysis, the fiber content of biomass is broken which later facilitates in briquetting of produced charcoal.

The charcoal is briquetted through extrusion/ compaction process.

**Power Operated Briquetting Machines**

The Indian Grassland and Fodder Research Institute (IGFRI), Jhansi has developed.

1. Reciprocating crank – piston drive press
2. Auger conveyor type press.

1. **Reciprocating Crank – Piston Drive Press.**

The press mainly consists of the frame, crank and piston mechanism, compression chamber, feeding hopper and V belt drive power transmission system. The machine is operated by a 10 KW electric motor. The piston reciprocates at a speed of 80 strokes/min with a stroke length of 18 cm. Chaffed grass/straw mixed with leguminous material in the ratio of 1:1 is fed into the compression chamber through the hopper and is pressed during the forward stroke of the piston. The application of pressure and the capacity of the machine depend on the diameter of the compression chamber.

2. **Auger Conveyor Type Press**

The machine consists of an auger, auger housing, multi hole pressure plate, feeding hopper and flat belt power transmission system. It is also operated by a 10 kw electric motor. The auger rotates at a speed of 200 rpm and the capacity of the machine varies from 40 to 60 kg/hr depending on the type of fodder material. Chaffed grass/straw mixed with leguminous material in the ratio of 1:1 is fed into the auger housing through the feeding hopper and is pressed and conveyed forward by the auger. Due to its screw type action, the fed material is pressed continuously against the pressure plate and finally comes out of the pressure plate in the form of briquettes.

**Components of Briquetting Machine**

1. **Briquetting stand**: A base is required which adequately supports the drive, bearings and briquetting barrel/screw assembly.

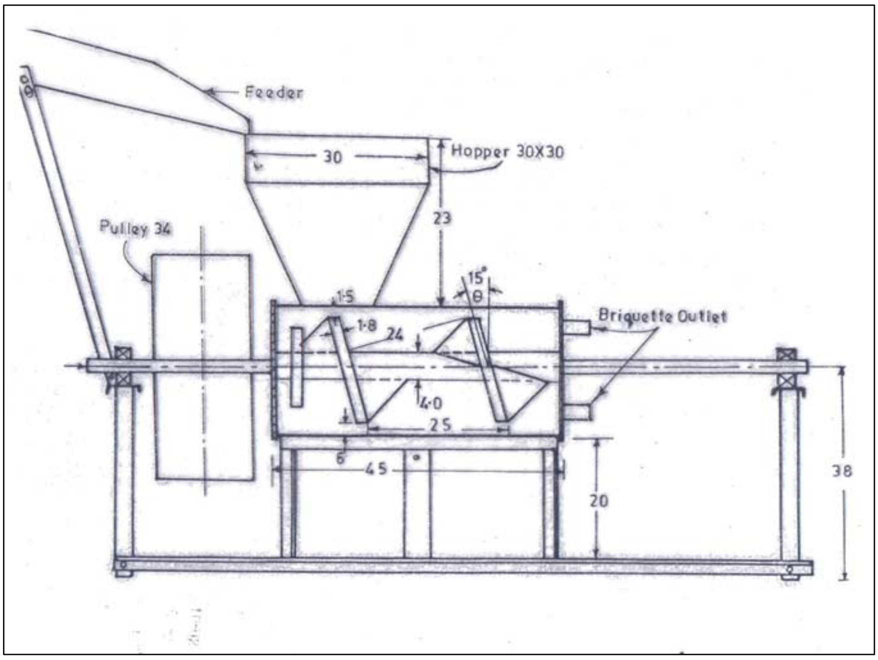
2. **Drive Mechanism**: Briquetting machine is driven with an electrical motor with variable speed drive or some gear reduction to provide the proper screw speed. Power requirements vary with the extrusion operation range from 0.05 – 0.36 kwh/kg

3. **Thrust bearings**: The briquetting screw is normally supported with a bearing at only the driven end or both the ends. A significant rearward thrust must be absorbed in the bearing to compensate for the force to the briquetted material as it is being moved forward along the length of the screw.

4. **Feed hopper**: The feed hopper provides the opening through which feed materials enter the screw. Many times the hopper is equipped with agitators at the bottom to reduce bridging of the feed or vibration of the machine tends to ease the flow when it moves into the screw. To further aid feeding of the screw, the feed hopper is often offset to the side of the barrel in the direction of screw rotation.

5. The barrel of an extruder is often manufactured in sections which are bolted or clamped together. Because barrel sections are heavy, such construction aids dis-assembly and allows for replacement of sections without replacing the entire barrel. Since the barrel is an area of high shear, normally the surface is hardened rendering it abrasion resistant. The internal diameter of the briquetting machine often denotes the basic size. The internal operating pressures in the extruder barrel normally ranges from 15 – 70 atmosphere.

6. **Dies:** The extruder is normally equipped with a series of shaped holes where briquetting material emerges from the machine in the form of briquettes. Expansion occurs as the product leaves the die because of the rapid release of pressure from the end of the barrel to the ambient conditions.




**Utilization of Briquetted Fuel**

Briquettes made from biomass can be used easily anywhere in place of conventional fuels, like, coal, fuel wood, kerosene and diesel. Effectively they can be a substitute for such non-renewable fuels without loss of efficiency.

1. As fuel in cooking stoves
2. As fuel for industrial Boilers and furnaces
3. As fuel for produces gas units.

# LECTURE 7

# SOLAR ENERGY

The sun is a sphere of intensely hot gaseous matter, having its core similar to thermo-nuclear fusion reaction. As a result, it emits continuously heat energy as a by-product when hydrogen atoms are converted to helium atoms. Sun like any other block body radiates this heat energy in all directions in the cosmosphere. The basic concept of nuclear fusion is to produce a heavier nucleus by fusing or combining two nuclei of lower mass. The core of the sun is a continuous nuclear fusion reaction, where four protons of Hydrogen are converted into one Helium nucleus. In fact, the total mass of this Helium nucleus is less than the mass of four Hydrogen protons. This means some amount of mass is lost in the reaction and is converted into Energy. To put it in a nut-shell, for every conversion of four protons of Hydrogen (total combined mass 4.0304) into one Helium Nucleus (mass is 4.0027) an amount of 0.0277 mass units of matter is lost in the form of heat energy. In fact, this is in accordance with the famous mass and heat energy relation expressed as $E = mc^2$ of Einstein. Here E = Energy; m=mass & c = velocity of light. This is the energy sun radiates and sustains the fauna and flora on earth caused by various seasonal changes.

The structure of the sun can be divided into three regions as

(a) Interior or core of sun
(b) Solar photosphere
(c) Solar atmosphere.

(a) Solar core is the fusion reactor from where 90% of the Sun's energy is generated. This core alone constitutes 40% of the total mass of the sun. The pressure in this region will be in the order a billion atmosphere and temperature in the range of $8 \times 10^6$ to $40 \times 10^6$ k. The density is almost 100 times to that of water.
(b) Solar photosphere is the zone from which light and heat are emitted out of sun. This indicates that the → interior core of sun is separated by this photosphere by a zone where there should be a drop in the density to facilitate radiation. This portion is known as convective zone and it is estimated that about $6000^0$ K drop in temperature with concurrent drop in density to a tune of $10^{-8}$ g/cm$^3$ occur.
(c) This chromosphere is named due to its red colour, a gaseous field of 10,000 km in thickness. This zone alone contributes to the total energy emitted by sun a factor of $10^{-3}$.

Apart from these three zones, there is a zone generally visible during eclipses, as a whitish layer. This is known as Corona. This contains low density mass with highly ionized gaseous mixture.

## Schematic Expression of Sun's Structure

As every one knows, earth rotates around sun in a elliptical orbit, which is nearly circular. As a result, the distance from Sun and earth varies only a maximum of 3% to the mean distance which is $150 \times 10^6$ km. The radiation reaching the earth surface has to pass through its atmosphere. As a result, quality of radiation may vary along with energy content when measures above the atmosphere and when compared with radiation measuring on the surface of the earth (at sea level this radiation energy at mid noon is 1 $kw/m^2$). The radiation energy above the atmosphere is calculated as 1.353 $kw/m^2$, which is generally referred as solar constant in outer space when earth is at mean distance from the sun. This indicates that, solar constant is higher than the energy received on earth which is due to the atmosphere and the behaviour of the light passing through the same.

**Behavior of Solar Energy Radiation in the Atmosphere:**

Radiation from sun without undergoing any change in direction or so, that reaches the surface of the earth is known as **direct or beam** radiation. The distance travelled by this direct radiation in the atmosphere is equal to the mass of the atmospheric gaseous mass and is generally known as “air mass”. Otherwise, to put it in a layman’s language, the air mass is the ratio of the path of direct beam in the atmosphere to the beam traveled when sun is overhead to the observer. However, in the atmosphere, due to the presence of different gases, vapour, particles of matter/dust, etc., the direct beam upon reaching the atmosphere will change its direction due to the phenomena of absorption and scattering. In the atmosphere, the solar radiation undergoes absorption of short-wave ultra-violet rays by ozone layer and long-wave infra-red rays by carbon dioxide, vapour and others. Similarly, the above said substances also scatter the radiation in the atmosphere, a part of which finally reaches the earth. Hence, total terrestrial radiation means, the radiation received through beam and diffuse radiation due to scattering. This total radiation falling on earth’s surface will be around 5-7 $kwh/m^2$ or + 6000 $kcal/m^2/day$. India has a total land mass area measuring to $3.28 \times 10^{11}$ square meters. At least if 1% of this radiation is utilized by employing solar devices with as little as with just 10% efficiency can yield us $492 \times 10^9$ kwhr / year of electricity. This clearly indicates the task before us to tap this energy for the betterment of public life needs innovation, commitment and to adopt the required life styles to suit the solar energy utilization. In fact, solar energy is clean, efficient and environment friendly, thus making the technologies also to fall the same suit, where human settlements enjoy the ever ending source of energy.

Even though it is in exhaustible source of useful energy, the major drawback to the extensive application of solar energy are.

1. Intermittent and variable manner in which it arrives at the earths surface
2. Large area required to collect the energy at useful rate.

**Principles Behind Solar Heat Energy Utilization**

Solar radiation from Sun’s surface is subjected to three basic phenomena called Conduction; Radiation and Convection: when the heat of the said electromagnetic waves is to be transferred to other substances. Solar energy devices are designed based on these three principles of heat transfer. As a result, the devices on which the sun rays are trapped also radiate a portion of the energy based on the characteristics of its surface area or so. While designing solar energy devices, all these issues are to be taken in to consideration.

***A. Radiation*:** By and large, heat/energy transfer is in the space or through a medium by means of Electromagnetic waves. This means, if two bodies are separated by a distance, and when temperature difference exists, the body with higher temperature radiates the energy towards the lower side through a medium or space. A perfect radiator (black body) emits its radiant energy from its surface at the rate q as expressed by $q = As\ T^4$; where

A = Area of the body
T = Absolute temperature $^OK$
s = is constant equal to $56.7 \times 10^{-9} w/m^2.k^4$
(This is also known as Stefan Boltzmann's constant)

Exactly the sun is doing this job by radiating the energy through space to earth. Hence the energy radiated in this fashion is known as "Radiant Heat". The intensity of radiant heat is directly proportional to absolute temperature of the body that eminates the energy. In the case of our solar devices, a major portion of the energy received from sun is absorbed by the surface/solar collector. This characteristic incident radiation absorbed is known as "Absorbivity". The energy reflected back is known as "Reflectivity" (reflectivity of a substance depends on its characteristics surface, wavelength and direction of the radiation) and the portion being allowed to be transmitted is "Transmissivity". Transmissivity is a function of wave length and the angle of incidence of the incoming radiation. That means, a surface with '0" transmissivity is known as opaque since both absorbivity and reflectivity are equal to the total incidence radiation. If transmissivity is more or less equal to total radiation, indicates that the surface or material is totally transparent or partial or so on based on its degree of transmissivity. If I denotes the total incident radiation per unit time per unit area of a surface, and Ia, Ir and $I_t$ represent respectively the amount of radiation absorbed; reflected and transmitted; then relationship can be expressed as:

$$a = \frac{Ia}{I} \qquad r = \frac{Ir}{I} \qquad t = \frac{It}{I}$$

This indicates that $I_a + I_r + I_t = I$

***B. Conduction*:** This heat transfer mainly relates to the transfer of heat in solid substances from one place to the other place due to the existence of temperature difference. In solar thermal energy utilization the conduction of heat and transfer are very important since we use solid metallic and non-metallic substances.

The basic conduction equation is:

$$q = K_x .A. \frac{\sigma T}{\sigma_x}$$

Where q = the rate of heat transfer (conduction)
$K_x$ = is the characteristics thermal conductivity of the material used in direction x
A = the area covered in the direction of heat flow
$\frac{\sigma T}{\sigma_x}$ = the temperature gradient (difference in the direction of flow)

***C. Convection***: In moving substances, the molecules of the fluid (water, air, etc) either gain or loose the energy due to radiation or conduction. However, this gain or loss of energy is carried by the flow of fluids from one place to the other. This phenomena is known as convection. The rate of heat transfer by convection $q_c$ between a surface and a fluid can be calculated from the relation;

$$q_c = h_c .A (T_s – T_f)$$

Where, A = Base area of heat transfer by convection is $m^2$

$T_s$ = Surface temperature $^OC$

$T_f$ = Fluid temperature $^OC$

$h_c$ = is convection heat transfer coefficient kCal/hr/$m^2$ $^OC$

The solar energy can be utilized directly and indirectly in different ways which has been listed below

**The direct way of using solar energy are**

(i) Solar thermal technology through solar collectors
(ii) Photo voltaic energy conversion technology
(iii) Solar hydrogen gas production technology.

**The indirect way of using solar energy are**

(i) Wind energy through wind mills
(ii) Biomass through energy plantation
(iii) Biogas through Biogas plants
(iv) Tidal wave energy.

**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

# LECTURE 8

# SOLAR COLLECTORS

Solar thermal energy is the most readily available source of energy. The Solar energy is most important kind of non-conventional source of energy which has been used since ancient times, but in a most primitive manner. The abundant solar energy available is suitable for harnessing for a number of applications. The application of solar thermal energy system ranges from solar cooker of 1 kw to power plant of 200MW. These systems are grouped into low temperature (<150$^{O}$C), medium temperature (150-300$^{0}$C) applications.

## Solar Collectors

Solar collectors are used to collect the solar energy and convert the incident radiations into thermal energy by absorbing them. This heat is extracted by flowing fluid (air or water or mixture with antifreeze) in the tube of the collector for further utilization in different applications. The collectors are classified as;

- Non concentrating collectors
- Concentrating (focusing) collectors

## Non Concentrating Collectors

In these collectors the area of collector to intercept the solar radiation is equal to the absorber plate and has concentration ratio of 1.

## Flat Plate Collectors (Glaze Type)

Flat plate collector is most important part of any solar thermal energy system. It is simplest in design and both direct and diffuse radiations are absorbed by collector and converted into useful heat. These collectors are suitable for heating to temperature below 100$^{0}$C. The main advantages of flat plate collectors are:

- It utilizes the both the beam as well as diffuse radiation for heating.
- Requires less maintenance.

## Disadvantages

- Large heat losses by conduction and radiation because of large area.
- No tracking of sun.
- Low water temperature is achieved.

The constructional details of flat plate collector is given below

(a) **Insulated Box:** The rectangular box is made of thin G.I sheet and is insulated from sides and bottom using glass or mineral wool of thickness 5 to 8 cm to reduce losses from conduction to back and side wall. The box is tilted at due south and a tilt angle depends on the latitude of location. The face area of the collector box is kept between 1 to 2 m$^2$.

(b) **Transparent Cover:** This allows solar energy to pass through and reduces the convective heat losses from the absorber plate through air space. The transparent tampered glass cover is placed on top of rectangular box to trap the solar energy and sealed by rubber gaskets to prevent the leakage of hot air. It is made of plastic/glass but glass is most favourable because of its transmittance and low surface degradation. However with development of improved quality of plastics, the degradation quality has been improved. The plastics are available at low cost, light in weight and can be used to make tubes, plates and cover but are suitable for low temperature application 70-120 $^0$C with single cover plate or up to 150$^0$C using double cover plate. The thickness of glass cover 3 to 4 mm is commonly used and 1 to 2 covers with spacing 1.5 to 3 cm are generally used between plates. The temperature of glass cover is lower than the absorber plate and is a good absorber of thermal energy and reduces convective and radiative losses of sky.

(c) **Absorber Plate:** It intercepts and absorbs the solar energy. The absorber plate is made of copper, aluminum or steel and is in the thickness of 1 to 2 mm. It is the most important part of collector along with the tubes or ducts passing the liquid or air to be heated. The plate absorbs the maximum solar radiation incident on it through glazing (cover plate) and transfers the heat to the tubes in contact with minimum heat losses to atmosphere. The plate is black painted and provided with selective material coating to increase its absorption and reduce the emission. The absorber plate has high absorption (80-95%) and low transmission/reflection.

(d) **Tubes:** The plate is attached to a series of parallel tubes or one serpentine tube through which water or other liquid passes. The tubes are made of copper, aluminum or steel in the diameter 1 to 1.5 cm and are brazed, soldered on top/bottom of the absorber water equally in all the tubes and collect it back from the other end. The header pipe is made of same material as tube and of larger diameter. Now-a-days the tubes are made of plastic but they have low thermal conductivity and higher coefficient of expansion than metals. Copper and aluminum are likely to get corroded with saline liquids and steel tubes with inhibitors are used at such places.

**Removal of Heat:** These systems are best suited to applications that require low temperatures. Once the heat is absorbed on the absorber plate it must be removed fast and delivered to the place of storage for further use. As the liquid circulates through the tubes, it absorbs the heat from absorber plate of the collectors. The heated liquid moves slowly and the losses from collector will increase because of rise of high temperature of collector and will lower the efficiency. Flat-plate solar collectors are less efficient in cold weather than in warm weather.

## Factors affecting the Performance of Flat Plate Collector

The different factors affecting the performance of system are:

(a) **Incident Solar Radiation:** The efficiency of collector is directly related with solar radiation falling on it and increases with rise in temperature.

(b) **Number of Cover Plate:** The increase in number of cover plate reduces the internal convective heat losses but also prevents the transmission of radiation inside the collector. More than two cover plate should not be used to optimize the system.

(c) **Spacing:** The more space between the absorber and cover plate the less internal heat losses. The collector efficiency will be increased. However on the other hand, increase in space between them provides the shading by side wall in the morning and evening and reduces the absorbed solar flux by 2-3% of system. The spacing between absorber and cover plate is kept 2-3 cm to balance the problem.

(d) **Collector Tilt:** The flat plate collectors do not track the sun and should be tilted at angle of latitude of the location for an average better performance. However with changing declination angle with seasons the optimum tilt angle is kept $\phi \pm 15^0$. The collector is placed with south facing at northern hemisphere to receive maximum radiation throughout the day.

(e) **Selective Surface:** Some materials like nickel black ($\alpha$ = 0.89, $\varepsilon$ = 0.15) and black chrome ($\alpha$ = 0.87, $\varepsilon$ = 0.088), copper oxide ($\alpha$ = 0.89, $\varepsilon$ = 0.17) etc. are applied chemically on the surface of absorber in a thin layer of thickness 0.1 $\mu$ m. These chemicals have high degree of absorption ($\alpha$) to short wave radiation (< 4 $\mu$m) and low emission ($\varepsilon$) of long wave radiations (> 4 $\mu$ m). The higher absoption of solar energy increase the temperature of absorber plate and working fluid. The top losses reduce and the efficiency of the collector increases. The selective surface should be able to withstand high temperature of 300-400$^0$C, cost less, should not oxidize and be corrosive resistant. The property of material should not change with time.

(f) **Inlet Temperature:** With increase in inlet temperature of working fluid the losses increase to ambient. The high temperature fluid absorbed the less heat from absorber plate because of low temperature difference and increases the top loss coefficient. Therefore the efficiency of collector get reduced with rise in inlet temperature.

(g) **Dust on cover Plate:** The efficiency of collector decreases with dust particles on the cover plate because the transmission radiation decreases by 1%. Frequent cleaning is required to get the maximum efficiency of collector.

**Concentrating Collectors**

Concentrating collector is a device to collect solar energy with high intensity of solar radiation on the energy absorbing surface. Such collectors use optical system in the form of reflectors or refractors.

These collectors are used for medium (100-300$^0$C) and high-temperature (above 300$^0$C) applications such as steam production for the generation of electricity. The high temperature is achieved at absorber because of reflecting arrangement provided for concentrating the radiation at required location using mirrors and lenses. These collectors are best suited to places having more number of clear days in a year.

The area of the absorber is kept less than the aperture through which the radiation passes, to concentrate the solar flux. These collectors require tracking to follow the sun because of optical system. The tracking rate depends on the degree of concentration ratio and needs frequent adjustment for system having high concentration ratio. The efficiency of these collectors lies between 50-70%. The collectors need more maintenance than FPC because of its optical system. The concentrating collectors are classified on the basis of reflector used; concentration ratio and tracking method adopted.

### FPC with Reflectors

The mirrors are placed as reflecting surface to concentrate more radiations on FPC absorber. The fluid temperature is higher by $30^0$C than achieved in FPC. These collections utilize direct and diffuse radiation.

### Lens Focusing Type

The fresnel lenses are used to concentrate the radiation at its focus. The lower side of lenses is grooved so that radiation concentrates on a focus line.

### Compound Parabolic Collectors

These collectors are line focusing type. The compound parabolic collectors have two parabolic surfaces to concentrate the solar radiation to the absorber placed at bottom. These collectors have high concentration ratio and concentrator is moving to track the sun.

### Cylindrical Parabolic Collectors

The troughs concentrate sunlight onto a receiver tube, placed along the focal line of the trough. The temperature at the absorber tube is obtained at nearly $400^0$C. The absorber in these collectors is moving to receive the reflected radiations by reflector, while the concentrators (trough) remains fixed. Because of its parabolic shape, it can focus the sun at 30 to 100 times its normal intensity (concentration ratio) on a receiver. The heat transfer medium carries the heat at one central place for further utilization.

### Parabolic Dish Collector

The collectors have mirror-like reflectors and an absorber at the focal point. These collectors are point focusing type. The concentrating ratio of these collectors is 100 and temperature of the receiver can reach up to $2000^0$C. These collectors have higher efficiency for converting solar energy to electricity in the small-power plant. In some systems, a heat engine, such as a Stirling engine, is connected to the receiver to generate electricity.

### Center Receiver Type (Solar Power Tower)

These collectors are used to collect the large solar energy at one point. This system uses 100-10000 of flat tracking mirrors called heliostats to reflect the solar energy to central receiver mounted on tower. The energy can be concentrated as much as 1,500 times than that of the energy coming in, from the sun. The losses of energy from the system are minimized as solar energy is being directly transferred by reflection from the heliostats to a single receiver where the sun's rays heat a fluid to produce steam.

**Advantages of concentrating collector over flat collector**

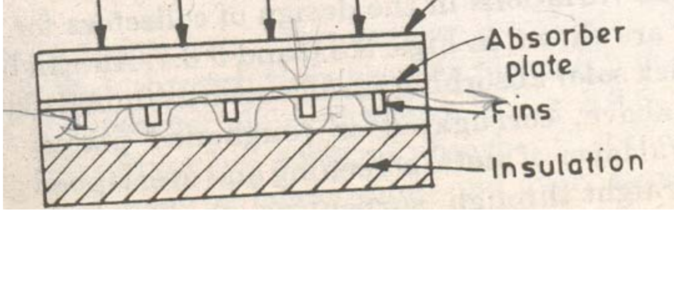
- The size of the absorber can be reduced that gives high concentration ratio.
- Thermal losses are less than FPC. However small losses occur in the concentrating collector because of its optical system as well as by reflection, absorption by mirrors and lenses.
- The efficiency increases at high temperatures.
- In these collectors the area intercepting the solar radiation is greater than the absorber area.
- These collectors are used for high-temperature applications.
- Reflectors can cost less per unit area than flat plate collectors.
- Focusing or concentrating systems can be used for electric power generation when not used for heating or cooling
- Little or no anti freeze is required to protect the absorber in a concentrator system whereas the entire solar energy collection surface requires anti freeze protection in a flat plate collector

**Disadvantages**

- Out of the beam and diffuse solar radiation components, only beam component is collected in case of focusing collectors because diffuse component cannot be reflected and is thus lost.
- In some stationary reflecting systems it is necessary to have a small absorber to track the sun image; in others the reflector may have to be adjustable more than one position if year round operation is desired; in other words costly orienting systems have to be used to track the sun.
- Additional requirements of maintenance particular to retain the quality of reflecting surface against dirt, weather, oxidation etc.
- Non –uniform flux on the absorber whereas flux in flat-plate collectors in uniform.
- Additional optical losses such as reflectance loss and the intercept loss, so they introduce additional factors in energy balances.
- High initial cost.

**Solar Air Heaters**

Air stream is heated by the back side of the collector plate in flat plate collector. Fins attached to the plate increase the contact surface. The back side of the collector is heavily insulated with mineral wool or some other material. 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 favourable orientation of a collector for heating only is facing due south at an inclination angle to the horizontal equal to the latitude plus $15^0$. The use of air as the heat transport fluid eliminates both freezing and corrosion problems and small air leaks are of less concern than water leaks

**Disadvantages:**

1. Need of handling larger volumes of air than liquids due to low density of air as working substance.
2. Thermal capacity of the air is low.
3. They have relatively high fluid circulation costs (especially if the rock heat-storage unit is not carefully designed)
4. They have relatively large volumes of storage (roughly three times as much volume as for water heat-storage)
5. They have a higher noise level.
6. The system has difficulty of adding conventional absorption air-conditioners to air systems
7. The space is required for ducting.

**Types of Air Heaters**

1. Non porous absorber in which air stream does not flow through the absorber plate
2. Porous absorber that includes slit and expanded material, transpired honey comb and over lapped glass plate

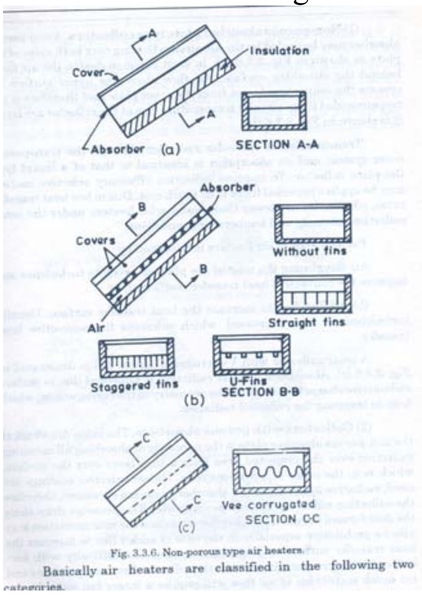
**1. Non-porous absorber plate type collectors:** A non-porous absorber may be cooled by the air stream flowing over both sides of the plate. In most of the designs, the air flows behind the absorbing surface. Air flow above the upper surface increases the convection losses from the cover plate and therefore is not recommended if the air inlet temperature rise at the collector are large.

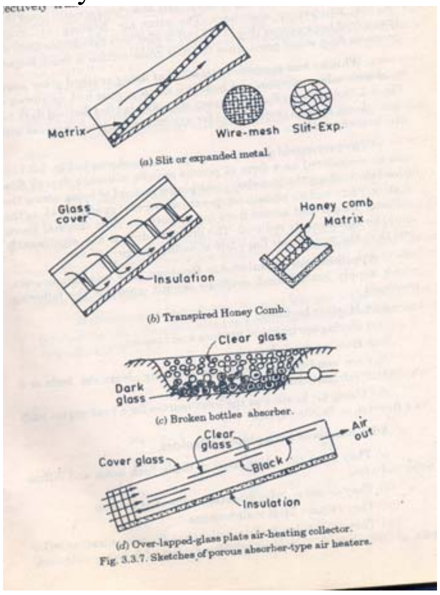
Transmission of the solar radiation through the transparent cover system and its absorption is identical to that of a liquid type flat-plate collector. To improve collection efficiency selective coating may be applied provided there is no much cost. Due to low heat transfer rates, efficiencies are lower than liquid solar heaters under the same radiation intensity and temperature conditions. Performance of air heaters is improved by:

(a) Roughening the rear of the plate to promote turbulence and improve the convective heat transfer coefficient
(b) Adding fins to increase heat transfer surface. Usually turbulence is also increased which enhances the convective heat transfer. Absorption of solar radiation is improved due to surface radioactive characteristics and the geometry of the corrugations, which help in trapping the reflected radiation.

**2. Collectors with porous absorbers:** The main drawback of the non-porous absorber plate is the necessity of absorbing all incoming radiation over the projected area from a thin layer over the surface, which is in the order of a few microns. Unless selective coatings are used, radiative losses from the absorber plate are excessive, therefore, the collection efficiency cannot be improved. Too many surfaces and too much restriction to air flow will require a larger fan and a larger amount of energy to push the air through. The energy required for this cancels out saving from using solar energy, particularly if fan is electrical and if the amount of energy which is burned at the power plant to produce the electrical energy is included.

The solar air heating utilizing a transpired honey comb is also favourable since the flow cross section is much higher.  Crushed glass layers can be used to absorb solar




radiation and heat the air. A porous bed with layers of broken bottles can be readily used for agricultural drying purposes with minimum expenditure. The overlapped glass plate air heater can be considered as a form of porous matrix, although overall flow direction is along the absorber plates instead of being across the matrix.

**Applications of Solar air heaters**

- Heating buildings
- Drying agricultural produce and lumber
- Heating green houses
- Air conditioning buildings utilizing desiccant beds or a absorption refrigeration process
- Heat sources for a heat engine such as a Brayton or Stirling cycle

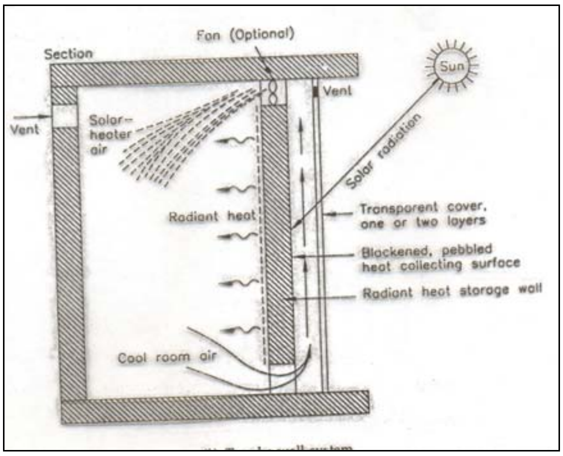
## LECTURE 9

## SPACE – HEATING (OR SOLAR HEATING OF BUILDING)

Many different concepts have been proposed for using solar energy in space heating of buildings. There are two primary categories into which virtually all solar heating systems may be divided. The first is passive systems, in which solar radiation is collected by some element of the structure itself, or admitted directly into building through large, south facing windows. The second is the active system which generally consists of (a) separate solar collectors, which may heat either water or air, (b) storage devices which can accumulate the collected energy for use at nights and during inclement days, and, (c) a back up system to provide heat for protected periods of bad weather. Heat is transferred from the collectors or from the storage means by conventional equipment, such as fan coil units, when hot or cold water is provided; fan, ducts, and air outlets, when the heat transfer medium is air; and radiant means when heating is the only task which must be accomplished.

### Passive systems

Passive heating systems operate without pumps, blowers, or other mechanical devices; the air is circulated past a solar heated surface (or surface) and through the building by convection (i.e., less dense, cooler air tends to rise while more dense, cooler air moves downward). These systems are more practical in locations where there is ample winter sunshine and an unobstructed southern exposure is possible. The building to be heated is an essential part of the system design. 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 a blower. A diagram of such a system designed by Professor Trombe.




The south facing wall of the house is double glazed. Behind it is a thick, "Black"' concrete wall, which absorbs the sun's radiation and serves as a thermal storage. Vents (A and B) which can be kept open or closed are provided near the top and bottom of the storage 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 radiation from the inner surface of the storage wall. During the night, both vents are closed and energy transfer takes place only by radiation. The 'Trombe' wall design can also provide summer ventilation by using vents C and D near the top of the glazing and on the north-facing wall. On a hot summer day, vents B, C and D would be kept open, while vent A would 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 the vent D. The vent D should be located such that the air pulled in through it comes from a shaded and cool area. It should be noted that the overhang on the roof prevents direct radiation from falling on the glazing during summer

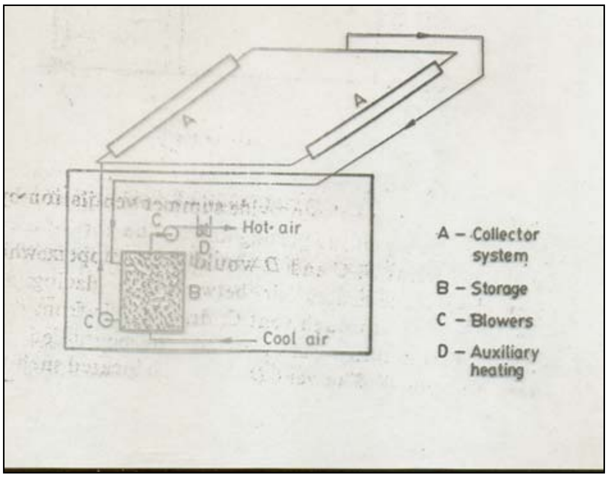
**Active systems**

Active systems, on the other hand, can be adapted to almost any location and type of building; however they are more expensive than passive systems to construct and operate. An advantage of active solar systems is that the building air temperature can be controlled in the same way as with the conventional heating, but in most passive systems substantial temperature variations may occur in the course of the day.

In principle, it should be possible to provide all the heating (and cooling) needs of a building by solar energy. However, to do this, the heating system would have to be designed for minimum sunshine conditions and hence would be over-designed for the majority of the situations. In most cases, solar-energy systems provide roughly 50 to 75 per cent of the annual heating requirements. The remainder is supplied by an auxiliary-heating systems using gas, oil, or electricity.

**Active Heating**

In active heating systems, fans and pumps are used to circulate the air and often a separate heat absorbing fluid. A space-heating system is illustrated. Water is heated in the solar collectors (A) and Stored in the tank (B). Energy is transferred to the air circulating in the house by means of the water-to-air heat exchanger (E). Two pumps (C) provide forced circulation between the collectors and the tank, and between the tank and the heat exchanger. Provision is also made for adding auxiliary heat.



An alternative approach to space heating is to heat air directly in the collectors. The heat is then stored in a tank packed with rock, gravel or pebbles. Space heating is of particular relevance in colder countries where significant amounts of energy are required for this purpose. In India, it is of importance mainly in the northern regions in winter.

In contrast to the above methods, which are often called active methods, space heating giving a fair degree of comfort can also be done by adopting passive methods.

**Solar Cooker**

Though there are many types of solar cookers, all of them have a concentrator or lenses to increase the available solar energy and insulation to reduce heat loss. There is an oven type cavity to place food into the box for cooking. Solar cookers are commonly able to reach cooking temperatures of 90-150$^0$C and some can even reach 230$^0$C. With these temperatures, it is possible to cook virtually any food as long as it is sunny outside.

The first solar cooker was developed in the year 1945 by Mr. M.K. Ghosh of Jamshedpur. He developed a box type solar cooker with a reflecting mirror and a copper coil inside, on which the food materials used to be placed in pots. Basically there are three designs of solar cookers:

(i) Flat plate box type solar cooker with or without reflector

(ii) Multi reflector type solar oven

(iii) Parabolic disc concentrator type solar cooker.

Flat plate box type design is the simplest of all the designs. Maximum no load temperature with a single reflector reaches upto 160$^0$C. In multi reflector oven four square of triangular or rectangular reflectors are mounted on the oven body. They all reflect the solar radiations into the cooking zone in which cooking utensils are placed. Temperature obtained is of the order of 200$^0$C. The maximum temperature can reach upto 250$^0$C, if the compound cone reflector system is used. With parabolic disc concentrator type solar cooker, temperatures of the order of 450$^0$C can be obtained in which solar radiations are concentrated on to a focal point.

**The advantages of solar cooker**

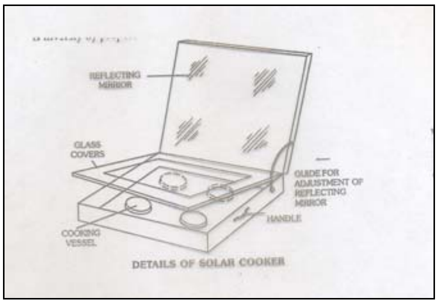
- There is no problem of charring of food and no over flowing.
- Orientation or sun tracking is not needed.
- No attention needed during cooking as in other devices.
- No, fuel, maintenance or recurring cost.
- Simple to use and easy to manufacture.
- No pollution of utensils, house or atmosphere.
- Vitamins in the food are not destroyed and food cooked is nutritive and delicious with natural taste.
- One can relay on cooker’s efficiency for longer period.

**Disadvantages of solar cooker**

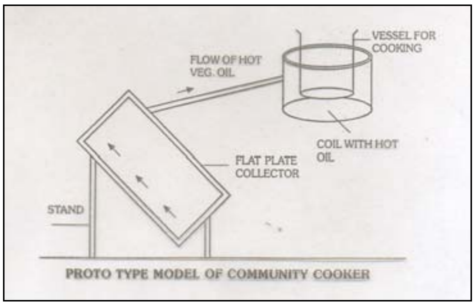
- Traditional cooking habit.
- No cooking after sunshine hours.
- Focusing on sun needed.
- No temperature control.
- Cost is high.
- Some food items cannot be prepared.
- Takes long time to prepare.
- Initial cost is more.

**Types of Cooker:** The different types of solar cookers are:

(a) **Box type:** Shows the box type cooker. The salient feature of the solar cooker is that there is no flow phenomenon in the devices. It operates under stagnant condition or equilibrium condition. Therefore, the governing parameters of the cooker are different from many other devices. The solar cooker is made up of inner and outer metal or wooden boxed with double glass sheets on it. Absorber tray is painted black with suitable black paint like boiler interior paint. The paint should be dull in colour so that it can withstand the max temperature attained inside the cooker as well as water vapor coming out of the cooking utensils. The top cover contains two plain glasses each 3mm thick fixed in the wooden frame with about 20mm distance between them. The entire top cover can be made tight with padlock hasp. Neoprene rubber sealing is provided around the contact surfaces of the glass cover and cooker box. A small vent for vapour escape is provided in the sealing. A mechanism is provided to adjust the reflector at different angles with the box cooker box. A $15^0$ to $25^0C$ rise in temperature is achieved inside the cooker when reflector is adjusted to reflect the sun rays into the box. Overall dimensions of a typical model are 60x60x20cm height. 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.




Box Type cooker




Community type cooker

The temperature inside the solar cooker with a single reflector is maintained from 70 to $110^0C$ above the ambient temperature. This temperature is enough to cook food slowly, steadily and surely with delicious taste and preservation of nutrients. Maximum air temperature obtained inside the cooker box (without load) is $140^0C$ in winter and $160^0C$ in summer. Depending upon the factors, such as, season and time of the day, type of the food and depth of the food layer, time of cooking with this cooker ranges from 1 hour to 4 hours. Meat should be allowed to stay for 3-4 hours. Vegetables take from ½ to 2 ½ hours. All types of Dals can be cooked well between 1 ½ to 2 hours. Rice is cooked between 30 minutes and 2 hours. The best time of the day for cooking is between 11 a.m. and 2 p.m.

(b) **Focusing Type of Indirect Type:** Shows the focusing type cooker in the shape of parabolaid. The glass surface or aluminum foil is used as a reflector coating from inside. The cooking pot is placed at the focus of parabolaid, where reflected rays get focused to heat the pot. The temperature of the pot achieved is more than $200^0$C. The system is adjustable to track the sun.

(c) **Collector Type (community Cooker):** These cookers are used to cook the food during day and night by utilizing the collector and storage as the excess thermal energy in day and utilized it at night. The shows the schematic of such device and it can be operated in three modes i.e., day cooking, day non cooking period and night cooking by opening and closing the different passes through the control valve.

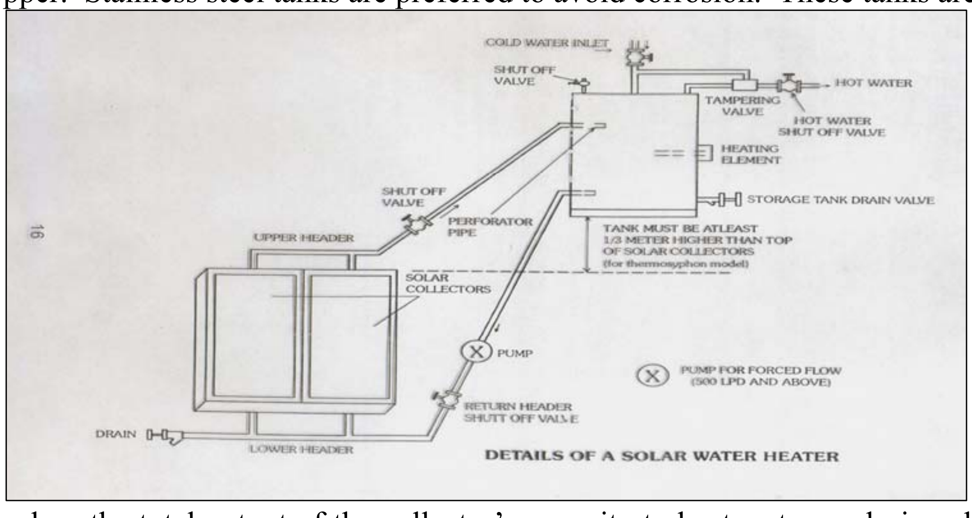
## Solar Energy Applications

A perfect black body (like sun) radiates its energy in the form of Electro-magnetic waves. These waves have two characteristics. When these waves fall on surfaces, they transfer the heat value to the surface wherein the transferred heat can be utilized for various purposes. Based on this principle, the present-day solar thermal devices are designed. However, there are substances on which these sun rays induce flow of electrons in a particular direction due to photo-electric effect. These substances are known as semi conductors. Based on the principles of photo-electric effect of sun rays, various photo-voltaic devices are designed to utilize solar energy for generation of electricity.

## Solar hot water heating system:

***Solar Collector***: Solar Collector is a complex component of the system, where solar radiation is absorbed and transferred to the water flowing all along in fin-tubes. Hence, solar collector consists of a flat surface with high absorbivity, generally made of metal (Copper, steel, aluminum, GI sheet of 1 to 2 mm thickness). The fin-tubes are longitudinally inserted with maximum provision of contact to facilitate heat transfer. In practice, various versions are commonly used where these fin-tubes are either pressed under pressure, bonded thermally or by soldering or otherwise as suited. This absorber is also coated with black paint of high quality to improve absorption of radiation. These absorbers are covered by suitable tempered glass with a gap of maximum 3cm on to the absorber plate and are suitably fixed on all sides in a frame. This is called paneling and suitable measures are taken to ensure very minimum heat losses by padding with thermal insulators. In these flat plate collectors, no complicated tracking mechanism is required. Components are fixed permanently and hence no moving parts. These flat plate collectors can absorb both direct and diffuse radiation. These solar panels/collectors are typically of $2m^2$ in size. Depending on the requirement, these panels can be arranged serially to maximize the output based on end use. The maximum temperatures that can be reached by these panels are around $100^0$C. The panels are to be kept clean to avoid dust which in turn reduces the performance.

***Hot Water Storage Tank***: These tanks are generally made of stainless steel, M.S. or Copper. Stainless steel tanks are preferred to avoid corrosion. These tanks are sized



DETAILS OF A SOLAR WATER HEATER

based on the total output of the collector's capacity to heat water as designed. These tanks are insulated to reduce heat losses. The storage tank capacity should not be oversized than the practical limits of the performance of the collectors, since increased surface area and large storage of hot water may offset the advantages associated with a system planned properly.

***Pumps:*** Once the solar panel increases the temperature of the water flowing in the fin-tubes the same is stored in the storage tank. This is achieved by two means generally.

***Natural or thermo-siphon circulation:*** Generally in small systems (100-500 lpd) this natural circulation of hot water to the tank is achieved by positioning the storage tank above the collectors. Under these circumstances, the hot water rises to the top of the panel due to less density and slowly reaches the top of the storage tank. The high density cold water naturally enters the bottom tubes of the panel and slowly rises to the top of the panel through fin-tubes due to absorption of heat. This cycle gets repeated during the day and the storage tank finally gets to full. However, to avoid reverse flow during the night, care should be taken in positioning the storage tank and panels.

***Forced circulation:*** Here there is no need for locating the tank above collectors. As a result, the system can be scale independent to suit larger end usages. A separate pump is fitted for circulation with a controller thermostat which will judge temperature differences between tank and collectors.

***Backup Heaters:*** To tide over the long spells of monsoon and cloudy days; the storage tanks are fitted with electrical heating elements of suitable capacity. Generally in domestic systems these electrical elements are fitted to the storage tanks.

***Heat Exchangers:*** Generally the water used for domestic applications is passed through the fin-tubes along the absorbers. However, in some specific occasions, (industrial application; chemical processing etc) the material to be heated cannot be passed through the absorbers. This may be due to the chemical nature of the fluid which may interact with metallic absorbers. To avoid this kind of situation, “Heat Exchangers” are used. These heat exchangers are either single loop or double loop. Let us imagine a tank with a liquid substance to be heated which can not be heated by normal solar absorbers. In such cases the solar hot water will be passed through a tube passing through or coiled in the tank, to transfer the heat (of solar hot water) to the contents in the tank. This water (Which has lost its energy value) can be recirculated through the absorbers/solar panels, to re-transfer the heat. This process is known as closed-loop heat exchangers. These exchangers can be made of copper, Aluminium, G.I. or steel. These heat exchangers are required only for specific applications.

***Miscellaneous Items:*** These are the items which include stands on which the panels are mounted, and other various accessories to erect the system, comprising pressure gauges; valves; water flow meters and the like.

## Basic principles of Solar Water Heater

The basic principle employed in these systems is similar to the green house effect. In these phenomena, accumulation of energy is achieved in between absorber and a re-emitting object. For example, radiation received on earth’s surface emits infra-red light back to the atmosphere. $CO_2$ in the atmosphere can absorb a portion of this and remaining is radiated back. This brings accumulation of heat energy on the ground. Similarly the black coated absorber in the solar panel takes the heat of sunlight and its temperature is increased. As a result, this black absorber emits thermal energy in the form of infra-red radiation. The glass fitted on the absorber plate absorbs this infra-red radiation and re-emits the same in all directions. In fact, 40-50% of this falls again on the absorber. As this process goes on, the temperature of the absorber also increases. Generally these absorbers in the panels are black coated selectively and have high absorption and also high emission coefficient for all wavelengths of light. As the temperature of the absorber increases, the heat value of emission of infra-red light by glass also increases. At one point of time, equilibrium is reached when energy gain of the glass by absorbing visible light is balanced by the re-emittance of the infra-red light on to the absorber. At this stage, the absorber plate works at its peak efficiency. In fact, this is the heat energy evacuated by the running water in the fin-tubes by heat transfer. This water is stored in the storage tank.

***Solar Panel Efficiency:*** Solar energy collection efficiency of a panel is defined as a ratio of useful gain over a period of time to the total solar energy incident in the same period of time. For eg. The total solar radiation in a day received by the panel is 5 kWh and the water heating energy contributed by the panel by heat transfer stands at 2.5kWh; the efficiency of the panel is 50%.

## LECTURE 10

## SOLAR STILLS

Solar distillation of brackish water has been practiced for centuries and solar stills with basin type have been proposed and used for over 100 years because of their simple design, technology, operation and low maintenance.

There are different designs of solar still available and i.e., basis type and wick type are more common. The still having 1-2 cm water depths are called shallow type and for 10-20 cm water depth called deep type still. The insulated box is made of fiber reinforcement plastic and black coated from inside to absorb the solar radiation. The glass cover is placed at angle (latitude ± $15^0$) on the top of the box and sealed by rubber gasket and putty to prevent vapour leakage. The distillate channel is provided at lower side of the glass, to collect the distillate trickled from the glass. The opening provided at the side through which the distillate water is taken out in the container placed outside.

When the saline water is heated in the basin by direct radiation as well heat transferred by basin liner it gets evaporated. The vapour moves up and condenses on the inner side of glass cover. The water particle will trickle downward and collect in the channel. The quantity of distillate depends on various factors i.e. wind velocity, ambient temperature, solar radiation, inclination, salt concentration, depth of water and design. The yield varies with seasons and is higher in summer than in winter. Higher the depth less distillate and lower the depth more distillate. The distillate collected from the 5cm depth may vary from 1.5-2.25 $L/m^2$ day during the summer.

### Crop Drying

Food is a basic need of human beings beside water and air, to survive. The food harvested from fields have high moisture contents in it, therefore, it causes spoilage during the course of storage after harvesting. In order to reduce this high moisture content to a safe level in food, it needs to be dried for long period storage without spoilage. The various advantages of drying are:

- Facilitates early harvest
- Helps for long time storage, to supply food for non production period
- Give better return to farmers
- Better quality of product available
- Better handling, transportation and distribution
- Reduces requirement of storage
- Reduces transportation cost per ton

Drying is basically heat and mass transfer phenomenon. It is generally achieved by the use of hot air over crop surface. The heat energy of hot air supplied to the crop surface is utilized in three i.e.,

I. To increase the surface temperature of crop in the form of sensible heat and to vaporize the moisture present in crops in the form of latent heat of vaporization.

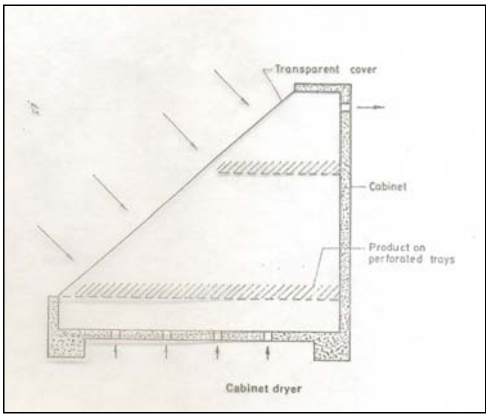
II. To remove the moisture content from interior of the crop that takes place due to difference in induced vapor pressure and surrounding media. This desired difference in vapour pressure may be obtained either by increasing vapor pressure of surface or by decreasing vapor pressure of surrounding or by both.

III. The absorbed thermal energy by products is conducted into the interior of the products. This causes rise in temperature and formation of water vapour inside the products. This water vapour diffuses towards the surface of the products and finally loses thermal energy in the form of evaporation.

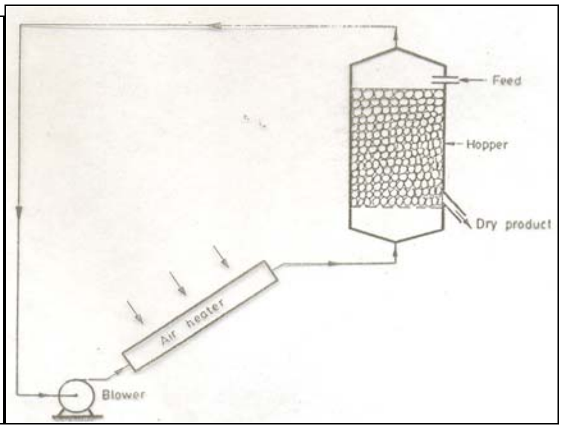
The different methods of drying are:

(d) Open sun drying
(e) Direct sun drying
(f) Indirect sun drying

Solar drying is done particularly by open sun drying under the open sky. This process has several disadvantages like spoilage of product due to adverse climatic conditions like rain, wind, moist, and dust, loss of material due to birds and animals, deterioration of the material by decomposition, insects and fungus growth. In drying under controlled conditions, all the above means may be employed with better control over the drying rate, while it is not so in open sun drying, where it all depends upon the weather conditions.




**Cabinet dryer**




**Convective dryer**

**A cabinet-type solar dryer**, suitable for small-scale use, the dryer consists of an enclosure with a transparent cover. The material to be dried is placed on perforated trays. The dryer is kept insulated from bottom and side like air collector and sun ray enters through the top glass cover to heat the perforated tray and air. Solar radiation entering the enclosure is absorbed in the product itself and the surrounding internal surfaces of the enclosure. The cold air enters from bottom, gets heated and moves upward and discharges through the opening provided at back surface by carrying away the moisture of crop. The air is heated and circulated naturally by buoyancy force or as a result of wind pressure or in combination of both. Suitable openings at the bottom and top ensure a natural circulation. Temperatures ranging from 50 to $80^0$C are usually attained and the drying time ranges from 2 to 4 days. Typical products which can be dried in such devices are dates, apricots, chillies, grapes, etc.

For large-scale drying, **a convective dryer** is use. In this dryer, the solar radiation does not fall on the product to be dried. Instead, air is heated separately in a solar air heater and then ducted to the chamber in which the product to be dried is stored. Generally, forced circulation is used. Such dryers are suitable for food grains and many other products like tea and tobacco. Modified versions are also used for drying lumber.

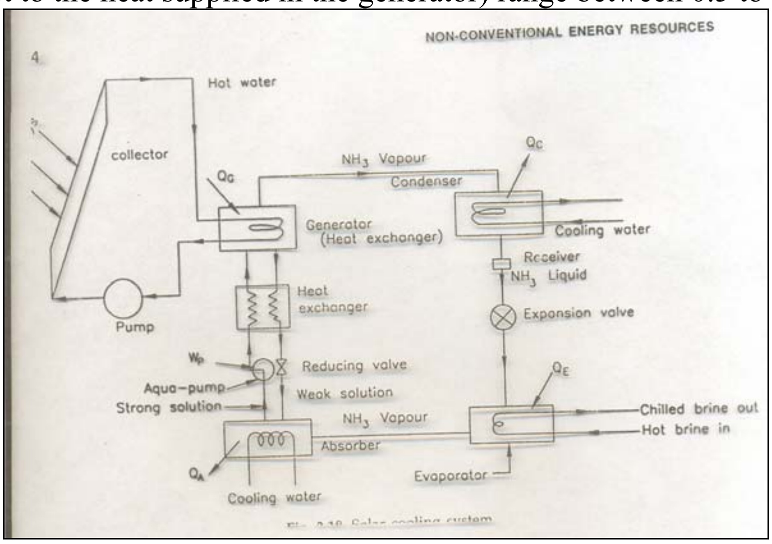
## Solar Cooling

One of the promising thermal applications of solar energy is for the purpose of obtaining cooling. Space cooling may be done with the objective of providing comfortable living conditions or of keeping a food product cold. Cooling is required mostly in summer. Hence, in this case, there is a seasonal matching between the energy needs of the refrigeration system and the availability of solar radiation. The current interest is in mechanical cooling systems that depend on solar heat for their operation and are unaffected by atmospheric humidity. The two most common refrigeration techniques are vapour compression and absorption and both could be adopted for use with solar energy, although the temperatures required are higher than those adequate for space heating. Absorption cooling with solar energy, which is regarded as more practical, is possible with current technology.

The operation of air conditioners with energy from flat plate collector and storage systems is the most common approach to the solar cooling today. In essence cooling is accomplished as the generator of the absorption cooler is supplied with heat by a fluid pumped from the collector storage system or from auxiliary.

1. Water heated in a flat plate collector array is passed through heat exchanger called generator, where it transfers heat to a solution mixture of absorbent and refrigerant, which is rich in refrigerant.
2. Refrigerant vapour is boiled off at high pressure and goes to condenser where it is condensed to high pressure liquid
3. The high pressure liquid is throttled to a low pressure and temp in an expansion valve and passes through the evaporator coil.
4. Here refrigerant vapour absorbs heat and cooling is therefore obtained in the space surrounding this coil
5. The refrigerant vapour is now absorbed back into a solution mixture with drawn from generator which is weak in refrigerant concentration and pumped back to the generator their completing the cycle.

Some of the common refrigerant- absorbent combinations used are Ammonia water and water lithium bromide, the latter being used essentially for air conditioning purposes. Typical values of COP (The ratio of the refrigerating effect to the heat supplied in the generator) range between 0.5 to 0.8



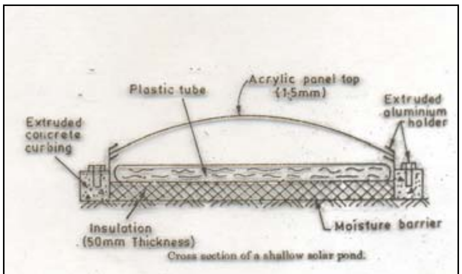

Ammonia /Water absorption system requires generator temperature of the order of $120^0$C to $150^0$C, such a temperature is higher than a flat-plate collector can provide, without special techniques. But this system could be possible with concentrating type collectors. The LiBr-$H_2O$ system requires lower generator temperature of the order of $85^0$ to $95^0C$ which are achievable by a flat plate collector. The LiBr-$H_2O$ system possess higher C.O.P than the aqua ammonia ($NH_3 – H_2O$)

The effective performance of an absorption cycle depends on the two materials that comprise the refrigerant-absorber pair. These two working fluids must have the following characteristics:

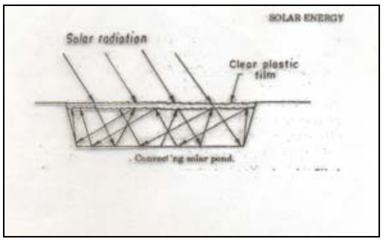
1. The absence of a solid phase absorbent.
2. A refrigerant more volatile than the absorbent, in order to be separated from the absorbent easily in the generator.
3. An absorbent that has small affinity for the refrigerant.
4. A high degree of stability for long-term operations.
5. The refrigerant that has a large latent heat so that the circulation rate can be kept at the minimum
6. A low corrosion rate and non toxicity for safety reasons.

## Solar Ponds

The solar pond is a simple device for collecting and storing solar heat. 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. Solar ponds may be classified as convecting or non-convecting.



Cross section of a shallow solar pond.



Convect'ng solar pond.

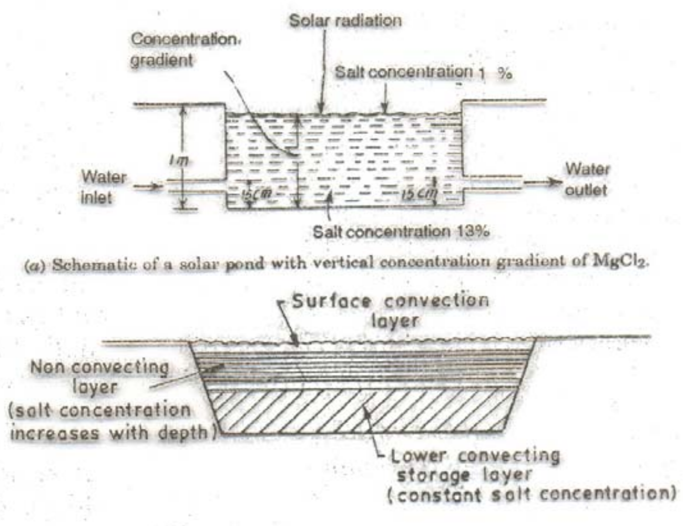
## Convecting Solar Ponds

A convecting solar pond reduces heat loss by being covered by a transparent membrane or glazing. One type of convecting solar pond uses a plastic tube filled with water, as illustrated. Each pond module includes a long, narrow plastic bag measuring 5 x 60m 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. Glazing materials for the solar pond may include polyvinyl chloride (PVC) film and clear acrylic panels. The panels covering the plastic bags screen out ultraviolet (UV) radiation and greatly increase the life of the plastic bags.

**Non-convencting Solar Ponds**

Non-convecting solar ponds prevent heat losses by inhibiting the convection to forces caused by thermal buoyancy. In convecting 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 non-convective solar ponds, the warm water is prevented from rising to the surface. Non-convective ponds may be stabilized by viscosity, a gel or to a salt. The salt gradient pond is the most common type of non-convecting solar pond; it will be described in the following sections.

**Salt Gradient Ponds**



(a) Schematic of a solar pond with vertical concentration gradient of $MgCl_2$.

Salt-gradient solar pond.

The concept of solar pond is based on the observation that some natural lakes have higher temperature at bottom where salt concentration is higher. Solar pond is an artificial pond in which salt concentration at lower level is higher and higher temperature rise occurs at lower regions. The convection losses are avoided in such ponds and only heat losses by conduction. The convection losses do not occur in these ponds. The solar ponds are used for storing the large thermal energy more economically than flat plate collector for a long time and can be utilized for the entire year by using it effectively in the field of mechanical or electrical as well as for some industrial process.

Solar pond is the different approach of solar thermal electricity production. The large salty lake or artificial ponds of 1-2 m deep are constructed and plastic liner is placed at bottom (Artificial pond) with black coating to absorb the maximum solar radiation. For right salt concentration the solar energy is absorbed at bottom layer of pond, having high salinity of 20-30%. The solar ponds have three zones. The upper zone of 10-20 cm thick is known as surface convective zone at temperature near the ambient. The mid zone is thicker and nearly half of the depth and is called non convective zone with temperature gradient and acts as an insulator to prevent the heat from traveling upward. The lower convective zone is thicker and serves the heat collecting media at nearly constant concentration and temperature. The salts most commonly used for salt gradient ponds are sodium chloride and magnesium chloride, although there are many other possibilities.

W**orking of pond**: The hot water from the bottom cannot come up because of insulating blanketed layer and the temperature at bottom nearly reaches $90^0$C in summer while in winter it reaches nearly $60^0$C. This is sufficient temperature to use for direct heating, air conditioning, drying, desalination plant, water heating and run the Rankine cycle. However because of the limitation of low temperature the efficiency of the system is less than 2%, but it is advantageous to run the plant day and night because of large thermal mass of water. The hot water from bottom of pond is continuously circulated in heat exchanger, where heat is removed by Freon gases to run the turbine coupled with generator. The hot water is returned to the bottom of the pond. The cold water is circulated through the condenser and returns back to top of the pond. The great disadvantage is the difficulty to maintain the salt concentration. The fresh water has to be added from top and in remote desert areas it is difficult to get fresh water. Also because of losses by evaporation nearly 50g/$m^2$ day salt is added to maintain the salinity.

# LECTURE 11

# PHOTOVOLTAIC

## Introduction

Photovoltaic energy is the conversion of sunlight into electrical energy through a photovoltaic (PVs) cell, commonly called a solar cell. Solar cells are the solid state electronic device used to convert the electromagnetic energy of solar radiation directly into direct current electricity. This conversion takes place inside the cell. The PV cell itself is the most common form and made of almost entirely (95%) from silicon available on earth's crusts in large amount.

## Metals

Based on the electric conductivity behavior the solid through them, the metals are classified in three categories.

## Conductors

The conductor contains many electrons in its conduction band at normal room temperature and does not have band gap between valance and conduction band. The energy of both the band is same and overlaps in some portion between these bands. The conductor has many electrons to conduct electricity without application of external source of energy.

## Insulators

These metals do not conduct electricity because of large band gap between valance band and conduction band and no transfer of electrons takes place from valance band to empty conduction band.

## Semiconductors

The electrical characteristics of these materials lie between conductors and the insulators. The band gap (forbidden gap) in these semiconductors is less than the insulator and able to transfer the electrons from valance band to the conduction band after acquiring some energy. The minimum energy required to jump the electron is equal to the forbidden gap ($hv \geq h_g$).

## The Photoelectric Effect

Operation of solar cells is based on the Photovoltaic effect. Sunlight is composed of photons and these photons contain various amounts of energy corresponding to the different wavelengths of the solar spectrum. When photons strike a transparent photovoltaic cell, they may be reflected, pass through or absorbed by material. These absorbed photons provide the thermal energy to excited electrons to generate electricity. When enough solar energy is absorbed by the material of cell, electrons break through from the atoms.

According to quantum theory electrons are forming a bond to hold the material together and remain in the lower energy level. This lower energy state is called the valance band state. However, in certain conditions some electrons after acquiring some energy move to higher energy level, called conduction band. The energy difference between these two levels is called band gap energy and measured in ‘eV’. The electrons in conduction band move around to conduct electricity.

Incident light on cell material generates mobile charge carriers. The photon incident must have sufficient energy to remove (1.12eV for silicon) the electrons from valance band and allow them to reach on conduction band. The energy lower than this will go as wastage. However excess energy of photon is dissipated as a heat.

### Terminology

**Solar Cell:** The solar cell is responsible for converting solar energy to electricity. Some materials (e.g., silicon is the most common) produce a photovoltaic effect, where sunlight frees electrons striking the silicon material. The solar cell is also called PV cell

**Doping:** The semiconductors are having very less electrons in conduction band than metal. In order to improve the conductivity some impurity is being added. This method is known as doping.

**PV Module:** A PV module is composed of interconnected solar cells. A packaged weather-tight module is used to connect the cells and these modules can be further connected to form an array.

**PV Array:** PV modules are connected in series and parallel to form an array of modules, therefore increasing total available power output to the desired voltage and current for a particular application.

### Solar Cell Materials

The solar cell is made of different material and silicon is one used for nearly 90% applications. The choice of material depends on the band energy gap, efficiency and cost. The maximum efficiency of solar cell is achieved with the band gap energy of 1.12eV-2.3eV. The various materials like aluminum silicon, Si (1.12eV) Aluminium antimonide, AlSb (1.27 eV), Cadmium telluride, CdTe (1.5eV), Zink telluride, ZnTe (2.1 eV), Cadmium sulphide, CdS (2.42eV) etc. are the materials suitable for solar cell. The smaller the energy gap, the large number of photon of solar spectrum will be useful to produce the required energy for electrons to jump the forbidden band gap. The semiconductor should meet the requirement that electron hole pair should produce near the junction otherwise they will get combined within without giving the cell output

### Advantages and Disadvantages of PV System

**Advantage:** Silicon PV cells manufactured today can provide over thirty years of useful service life. PV systems are cost effective for many remote power applications, as well as for small stand-alone power applications in comparison to existing electric grid. The various advantages are:

- Direct conversion of electricity from sunlight and avoiding bulky systems.
- The modular characteristic allows arrays to be installed quickly and in any size required.

- The environmental impact of a photovoltaic system is minimal.
- It requires no water for system cooling.
- The photovoltaic have been used at remote sites to provide DC electricity which can be converted to AC by using inverter.
- No moving part
- Unlimited life.
- The PV systems are expandable and components easily repaired or replaced if needed.
- Sun tracking is not essential.
- Easy to fabricate.
- Used in space application because of high power to weight ratio.

**Disadvantages:**

- High cost because of costly production process.
- Energy storage system is needed.
- Large area is required for solar power plant.
- Energy required in manufacturing increase the pay back time of Photovoltaic.

**Applications of PV System**

The PV systems are used for various purposes by suitably designing the system as per the need. The PV systems are used to supply power in remote areas for their use as well as supply excess power to national grid. It does not have moving part and therefore can supply power for indefinite period without damage. Solar radiation gets converted into DC electricity directly. This electricity can either be used as it is or can be stored in the battery and can be used. Most solar electric systems are more cost effective in remote areas where there is no existing power supply.

The various applications of PV system are:

- Used in watches, calculator etc.
- Small capacity system are mounted at house wall / roof and used for various purposes at residences.
- Solar power is used on road, lighting tower, parking light, traffic signaling, radio stations etc.
- Space satellite power generation.
- Solar water pump
- Central power station.
  One 50 Watt PV module is enough to power four or five small fluorescent bulbs, a radio, and a 15-inch black – and – white television set for up to 5 hours a day.

## Solar Photo Voltaic Water Pump

The system comprises of SPV module, panel frame structure, mono block pump set with suction and delivery pipe lines, foot valve and electrical accessories. The solar modules are mounted on a mechanically strong metallic panel frame which is firmly fixed on a concrete bed. The south facing surface of the panel frame has a provision to rotate three times a day from east to west during the day.

The pump is very compact and light, the motor and pump are in a mono block. The pump is provided with a volute type casing. It is provided with a dynamically balanced impeller. The pump is mounted on a stainless steel shafting with deep grove ball bearings. It is also provided with mechanically sealed stuffing box. The motor rotates in clock wise direction from driving end. The d.c motor pump set is manufactured by M/S. Kirloskar Brothers Ltd. Pune. The SPV module is manufactured by Central Electronic Ltd, Sahibabad (U/P). The solar photo voltaic consists of suitable number of PV modules connected in series or in parallel combination to give the required power out put (900).

**Working of the system:** All the photo voltaic cells in the panel are connected in series. When the solar light falls on the panel, it is converted into electricity. The power so generated is in series and is available at a controlling switch. The controlling switch is provided below the panel boards. When the switch is on, the motor gets power and starts pumping water from the well. When the switch is off, the motor stops pumping water. Maximum discharge can be obtained on a clear day. The SPV pump can be adopted for open well as well as bore well with in the limits of total head.

**Specifications:**

- Model = SW 900
- Type of motor = DC motor
- Capacity = 1.2 HP
- Maximum suction head = 7.5
- Maximum total head = 15m
- Capacity of SPV array = 900 w
- Require shade free area = 30 sq.m
- Water out put = 65000 liters / day
- Cost = Rs. 55000/-

### Dimensions of SPV Panel

- Panel = 864 w, 60 v, panel
- Length = 2470 mm
- Width = 2070 mm

## Solar Street Light

A solar street light mainly consists of a PV module battery, CFL tube light, electronic controller, mounting lamp post etc. A 36 cells photovoltaic module converts the solar light incident on it to electricity (70 w). The electricity is used to charge a lead acid battery of 12 volts and 75 amp hr capacity. The module is fixed on top of the pole at an inclination of $15^0$ facing south. A metallic box containing battery is arranged to the lamp post with suitable clamps at a height of 75 cm from the ground. A CFL tube light is arranged to the pole at suitable or required direction. The lamp post is fixed with two clamps at the bottom and given a concrete foundation to a depth of 0.5m and 0.6 m wide into the ground. The foundation is a must for the lamp post to keep it in erect position in all conditions of weather. The lamp post is designed to with stand a wind speed of 120 km/hour. The lamp post and other mountings are galvanized to avoid any kind of rusting. The battery is arranged in a safe box to protect the battery from weather and rain. The electronic controller is arranged inside to make the system more compact. The system is to be installed as in the installation diagram. The battery, PV module and controller are connected with suitable cable as shown in circuit diagram. Erect the lamp post and place it in the pit. Adjust the position of the lamp post such that the PV module is facing south direction and luminaire is facing the street.

**Auto working system**: When once the street lighting system is installed, the solar light is converted into electricity and the battery is charged in the day time. When the day light falls to a particular level the lamp gets on in the night and glows. Again before the sun rises when the light comes up to a certain level the light puts off itself automatically. The system is not provided any ON and OFF controlling switch

## Maintenance of the System

1. Clean the PV module surface with a neat cloth at least once in a month
2. The electrolyte level in the battery is to be checked once in a month
3. The electrolyte level in the battery to be maintained at least 14 mm above the plates
4. To top up the battery open the vent plugs, fill distilled water up to the specified level and close the vent plugs.
5. Equalizing or freshening charge is recommended once in six months for proper mixing of electrolyte
6. After long working the CFL becomes blackened and finally may not glow, then replace the lamp with new lamp
7. Before replacing the lamp remove battery connections and after replacing lamp give battery connections properly if there is no Switch
8. If On and OFF switch is available the switch is put off and replace the lamp and on the switch again.

## 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.
A solar Lantern is made of three main components - the solar PV panel, the storage battery and the lamp. The lamp, battery and electronics all placed in a suitable housing made of metal, plastic or fiber glass. The operation is very simple. The solar energy is converted to electrical energy by the SPV panel and stored in a sealed maintenance-free battery for later use during the night hours. A single charge can operate the lamp for about 4-5 hours. The lantern is basically a portable lighting

device suitable for either indoor or outdoor lighting, covering a full range of 360 degrees.

## Solar Fencing System

Solar Fencing 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.

## LECTURE 12

## Wind Energy

Wind results from air in motion. Air in motion arises from a pressure gradient. It has been estimated that 2% of the solar radiation falling on the face of the earth is converted to KE in the atmosphere and 30% of the KE occurs in the lowest 1000 m elevation. The energy available in the wind over the earth surface is $1.6 \times 10^7$ MW which is of the order of magnitude of present energy consumption on the earth.

In India air speed values lies between 05-20 km/hr. Wind speed increase with height. They are measured at standard height of 10m where they are found to be 20-25% greater than close to the ground surface.

### Wind Power:

Wind possesses kinetic energy by virtue of its motion. Factors that determine the output from wind mill (1) Wind Speed (2) Cross Section of wind swept by rotor (3) Over all conversion efficiency of rotor, transmission system and generator/ pump.

Wind mill works on the principle of converting KE of the wind into mechanical energy. Power is equal to energy per unit time

$$KE = \frac{1}{2} mV^2$$
$$= \frac{1}{2} \rho AV.V^2$$
$$= \frac{1}{2} \rho AV^3, \text{ watts}$$

Where $m = \rho AV$, $\rho$= Air density = 1.225 kg/$m^3$ at sea level and changes by 10% with altitude

Area swept by the rotor, $A = \pi /4 D^2$, V = wind velocity

Maximum available energy = $\frac{1}{2} \rho\pi/4 D^2 V^3 = 1/8 \rho\pi D^2 V^3$

From equation,

1. The wind power available is directly proportional to the air density
2. By doubling the diameter of the rotor the power will increase 4 fold
3. By doubling wind speed the power available will increase 8 fold

### Suitable places for erection of wind mill

1. Off shore and on the sea coast – wind energy availability is 2400 KWH/$m^2$/year
2. Mountains – 1600 KWH/$m^2$/year
3. Plains – 750 KWH/$m^2$/year

### Places unsuitable for wind mill

1. Humid equatorial region. In these area wind velocity is minimum
2. Warm, windy countries where frequency of cyclones is more

### Advantages of Wind Energy

1. It is renewable source of energy
2. Now polluting and no adverse influences on environment.
3. No fuel and no transportation is required
4. The cost of electricity production is comparatively low

**Disadvantages**

1. Wind energy is dilute and fluctuating in nature
2. It requires storage capacity
3. Machines operating on wind energy are noisy
4. Wind power machines are relatively have high overall weight (110 kg/kw)
5. large area is required for wind mill
6. Efficiency of operation is poor and maintenance costs are high

**Wind mills Types and Performance**

A 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.

Wind mills are generally classified as

- Horizontal axis type, and
- Vertical axis type,

depending on their axis of rotation.

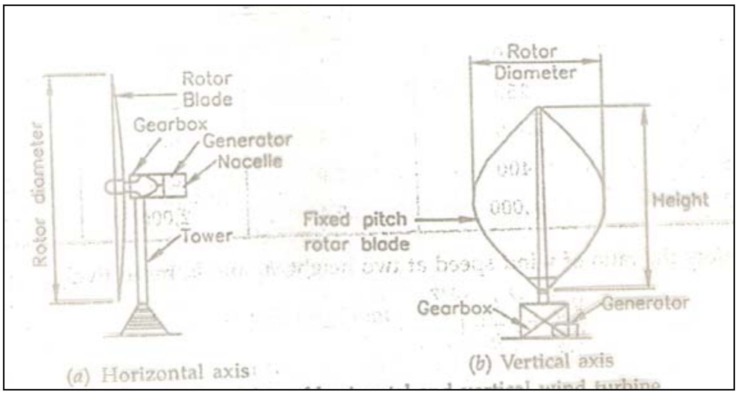
Horizontal axis wind mills further sub-classified as single bladed, double bladed, multiblade and bicycle multibladed type, sail, wing.

The vertical axis wind mill is again sub-divided into two major types:

(i) Savonius or 'S' type rotor mill (low velocity wind),

(ii) Darrieus type rotor mill (high velocity wind), based on the working speed of the machine and the velocity ranges required by the machine for operation.

Vertical axis machines are of simple design as compared to horizontal axis.




**Vertical Axis Type Wind Mills**

**The Savonius Rotor:** The simplest of the modern types of wind energy conversion systems is the Savonius rotor which works like a cup anemometer. This type was invented by S.J. Savonius in the year 1920. This machine has become popular since it requires relatively low velocity winds for operation.

**Constructional details and principle of operation**. It consists of two half-cylinders facing opposite directions in such a way as to have almost an S-shaped cross-section. The S shaped rotors are supported at top and bottom by two circular plates. These curved blades fixed on central pipe and free to rotate.

There two semi-circular drums are mounted on a vertical axis perpendicular to the wind direction with a gap at the axis between the two drums. Irrespective of the wind direction the rotor rotates such as to make the convex sides of the buckets head into the wind. However, instead of having two edges together to make an S-shape, they overlap to leave a wide space between the two inner edges, so that each of these edges is near the central axis of the opposite half cylinder, as shown in the figure. The main action of the wind is very simple; the force of the wind is greater on the cupped face than that on the rounded face. The wind curving around the back side of the cupped face exerts a reduced pressure much as the wind does over the top of an air-foil and this helps to drive the rotor. The wide slot between the two inner edges of the half cylinders, lets the air whip around inside the forward-moving cupped face and then around the inside of the backward moving face, thus pushing both in the direction of the rotation.

The ratio of height to the overall diameter of the machine can be varied, but it is generally less than 3 to 1. Power coefficient of S rotor is low, but it might possibly be improved by changes in the design number and arrangement of the vanes. It has low efficiency, low speed and self starting capacity. It is not good for generating electricity because of low rpm. The rpm above 1000 is generally best for generating electricity.

### Advantages

1. Performs at low wind velocity ranges
2. It has its low cut in speed (Wind speed required for switching electric power into the line)
3. Generator can be mounted on ground
4. Low system cost
5. Simple structure, easy to manufacture
6. Since it has vertical axis energy conversion system, it eliminates expensive power transmission system from the rotor to the axis
7. Yaw and Pitch control are not required. A constant speed vertical axis wind turbine, automatically stalls at high wind speeds
8. Overall weight of the turbine may be substantially less than that of conventional systems.

### Disadvantages

1. This type of machine is too solid
2. It is not useful for a very tall installation because long drive shaft problems.

### Areas of Concern

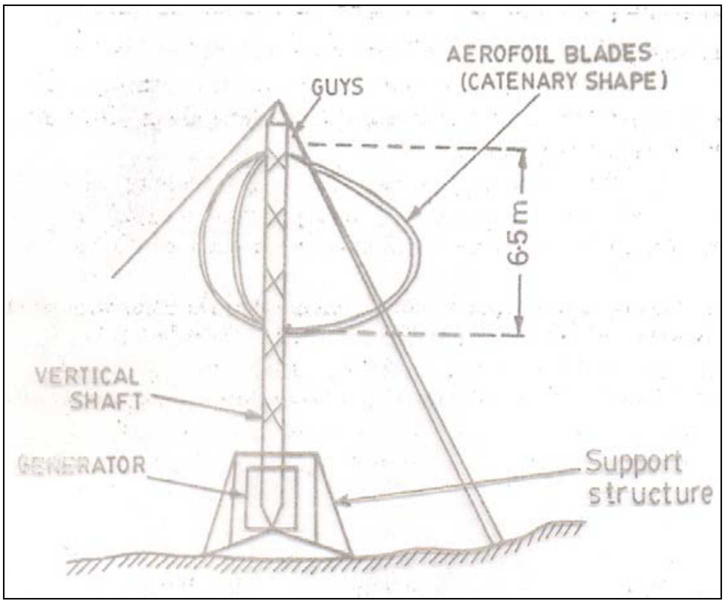
The Savonius rotor has moderately good efficiency and a satisfactory starting characteristics, the latter being particularly important for use with a positive displacement pumps. The rotor area requirement for getting the required amount of power is higher than any other systems. It is commonly used for pumping, and to operate small agricultural machines like winnowers, blowers, bird scarers, grinders etc. The another use of this type of wind energy conversion system is to use this machine along with Darrieus rotor for starting purposes.

**The Darrieus type machines (High velocity wind).**

This machine was invented originally and patented in 1925 by G.J.M. Darrieus a French Engineer and this concept has recently been given serious consideration once again. This type of windmills is already in use in Canada. As noted, a modern rapidly rotating propeller type windmill, by use of an efficient air foil, effectively intercepts large area of wind with a small blade area. The Darrieus wind mill is a type of vertical axis machine that has the same advantage. An additional advantage is that it supports its blades in a way that minimizes bending stresses in normal operation.

**Constructional details and principle of operation**.

In this type of machine, the blades are curved and attached to hubs on the vertical shaft at both ends to form a cage-like structure suggestive of an ordinary egg beater. The curved blade has the shape that a rope would take if subjected to centrifugal force in rapid rotation, some think like the shape of the rope in the exercise of skipping rope. 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 help withstand the wind forces it experience. The blades can thus be made lighter than in the propeller type. When rotating, these air foil blades provide a torque about the central shaft in response to a wind stream. This shaft torque is being transmitted to a generator at the base of the central shaft for power generation.




**Vertical Axis Wind mill**

**Characteristics of Darrieus Rotor**

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

**Advantages**

1. The rotor blades can accept the wind from any compass.
2. The machine can be mounted on the ground eliminating tower structures and lifting of huge weight of machine assembly
3. It eliminates yaw control requirement for its rotor to capture wind energy
4. Airfoil rotor fabrication costs are expected to be reduced over conventional rotor blade costs.
5. The absence of pitch control requirements for synchronous operation may yield additional cost savings.
6. The tip speed ratio and power coefficient are considerably better than those of the S-rotor but are still below the values for a modern horizontal-axis, two-bladed propeller rotor.

**Disadvantages**

1. It requires external mechanical aid for start up
2. Rotor power output efficiency of a Darrieus wind energy conversion system is also some what lower than that of a conventional horizontal rotor
3. Because a Darrieus rotor is generally situated near ground proximity, it may also experience lower velocity wind and yield less energy output.
4. Because a Darrieus rotor encounters greatly varied local flow conditions per revolution, greater vibratory stresses are encountered which will affect rotor system life.
5. Finally since a Darrieus rotor cannot be yawed out of the wind or its blades feathered, special high torque breaking system must be incorporated

**Horizontal Axis Type Wind Mills**

The blade of the wind mill may have a thin cross-section or the more efficient thick cross section of an aerofoil. The motion causing the "wind due to motion" here is the rotation of the blades. At the tip of the blades of a modern wind turbine, the velocity is about six times the wind velocity. This means that the blades are set rather flat at a small angle with the plane of the rotation and almost at right angles to the direction of the wind so that the effective wind properly approach from ahead of the leading edge. At other parts of the blade, between the tip and the axle, the velocity and the ideal set of the aerofoil is at a greater angle to the plane of rotation. Ideally the blade should be twisted, but because of construction difficulties this is not always achieved.

Some of the horizontal axis type wind mills are briefly described below.

**(1) Horizontal axis using two aerodynamic blades**

In this type of design, rotor drives a generator through a step-up gear box. The blade rotor is usually 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 rotor blades are continuously flexed by unsteady aerodynamic, gravitational and inertia loads, when the machine is in operation. If the blades are made of metal, flexing reduces their fatigue life. 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, the system may shake itself to pieces. Because of the high cost of the blade rotors with more than two blades are not recommended. Rotors with more than two, say 3 or 4 blades would have slightly higher power coefficient.

**(2) Horizontal axis propeller type using single blade.**

In this arrangement, a long blade is mounted on a rigid hub induction generator and gear box. If extremely long blades (above say 6.0m) are mounted on rigid hub, large blade root bending moments may occur due to tower shadow, gravity and sudden shifts in wind directions. To reduce rotor cost, use of low cost counter weight is recommended which balances long blade centrifugally.

**(3) Horizontal axis multiblade type**.

This type of design for multiblades as shown in fig are made from sheet metal or aluminium. The rotors have high strength to weight ratios and have been known to servive hours of freewheeling operation in 60 km/hr winds. They have good power coefficient, high starting torque and added advantage of simplicity and low cost.

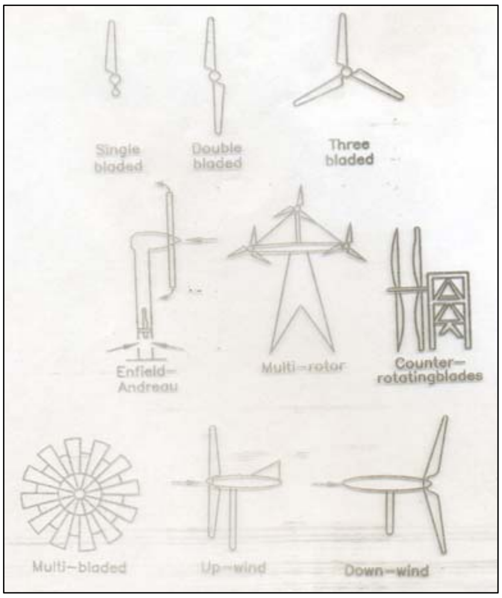
**(4)Horizontal axis wind mill – Dutch Type**.

It is one of the oldest designs. The blade surfaces are made from an array of wooden slats which 'feather' at high wind speeds.

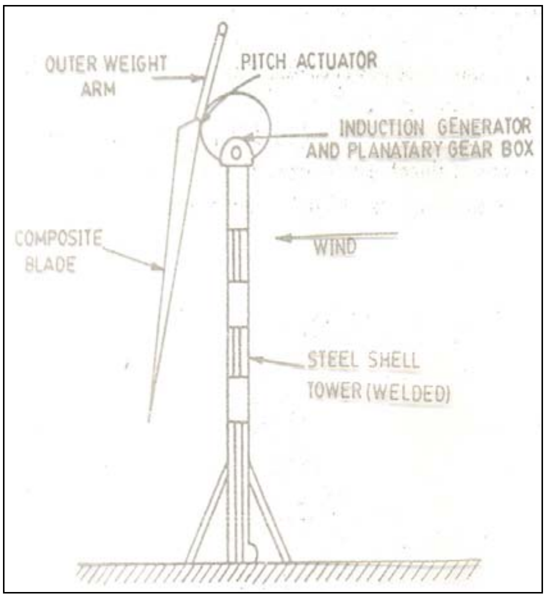
**(5) Sail type.**

It is of recent origin. The blade surface is made from cloth, nylon or plastics arranged as mast and pole or sail wings. There is also variation in the number of sails used.

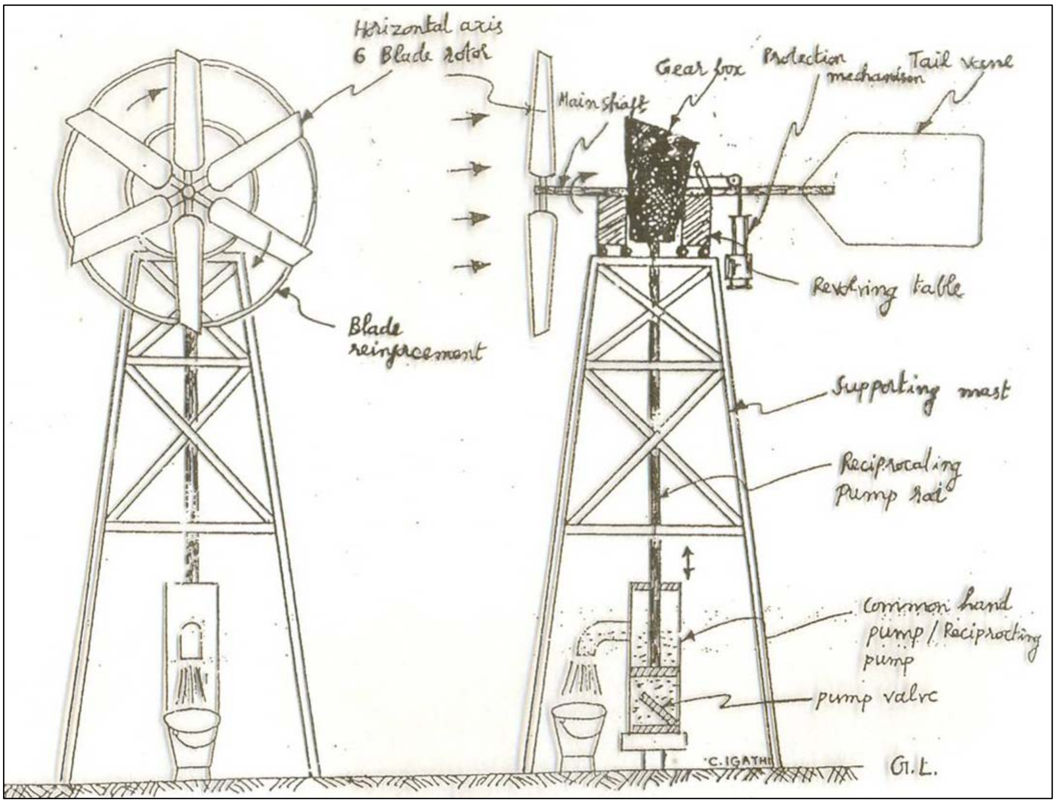
The horizontal axis types generally have better performance. They have been used for various applications, but the two major areas of interest are electric power generation, and pumping water.



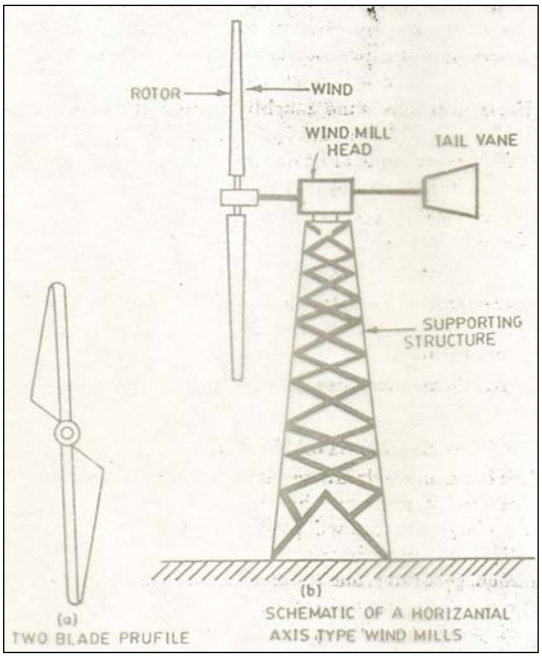

**Different types of Horizontal Axis Wind mills**



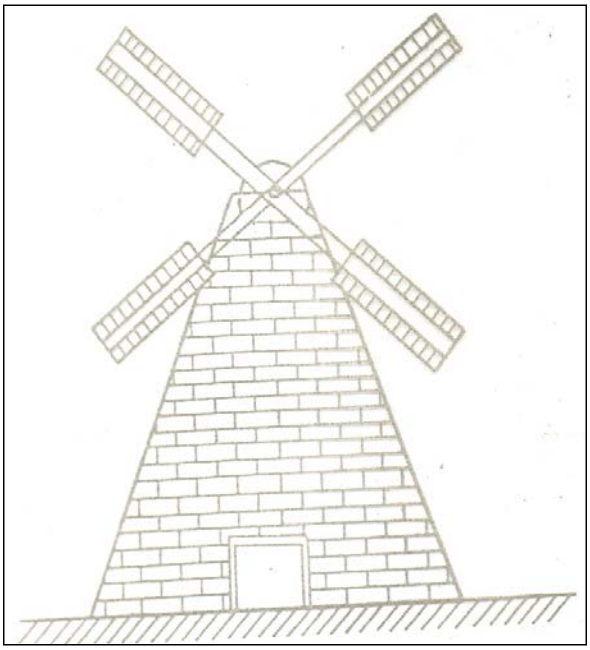

**Single Blade Horizontal Axis Wind mill**




**Water pumping Wind mill**




**Horizontal axis using two aerodynamic blades**



**Horizontal axis wind mill – Dutch Type**

**Water Pumping Wind Mill:** Conversion of wind energy into mechanical power is the technology of wind mill.

The water pumping wind mill consists of a horizontal axis rotor with 10 – 12 blades. The pumps set consist of a piston with washer and valve arrangement. The rotor is mounted on the top of the tower to obtain sufficient wind velocity erected over a well at a height of about 10m and the pump is mounted in the well. A crank mechanism enclosed in the gear box fixed to the shaft of the rotors converts the rotary motion into a reciprocating motion of the piston inside the pump body. This action causes the piston – washer – Valve assembly to suck the water from the well and discharge through the delivery pipe. When blowing winds are allowed to strike a set fitted rotor blades arranged in the form of rotor, makes it to rotate and the rotation is utilized to run the mechanism. The rotor is always made to face wind direction automatically by a tail vane arranged at right angle to the rotor plane. At normal operating conditions the tail vane is locked up with rotor consisting of a rope, pulley and counter weight mechanism. The windmill starts rotating at certain velocity and is known as cutting speed. High velocity winds cause damage to the rotor assembly and the damage is prevented by resting the rotor using safety mechanism.

When the wind velocity exceeds the cut off limit, the relative shift between rotor and tail vane occurs and the safety mechanism automatically releases the connection between them. After the connection is broken, the rotor and tail vane come together and align in one plane parallel to the wind direction and resting of rotor takes place. To restore the operation of wind mill at normal wind speed, a man has to climb the tower and manually lock the tail vane with rotor. The wind speed at which the rotation occurs, ranges from 6-35 km/hr for pumping the water. Pump driving mechanism for piston rods are aligned in line of pump shaft so that a $360^0$ rotation of the entire rotor assembly is possible when the pump is in operation. Common hand operated bore well pump can also be attached to the wind mill with a min. modification. Pumped water can directly let in to the channel for irrigation or directed to over head storage tank.

## LECTURE – 14 & 15

## Bio – Diesel

Because of the oil embargo and rapidly escalating prices of diesel fuels in the early 1970s, interest on plant oils as alterative fuels reemerged.

Plant and animal oil generally considered substitute for diesel fuels are composed mainly of triglycerides which are branched molecules having approximately three times the molecular weight of typical diesel fuel components.

**What is Bio diesel:** Bio diesel is a vegetable oil processed to resemble diesel fuel

### Importance of Bio diesel:

1. Environment friendly
2. Clean burning
3. Renewable fuel
4. No Engine modification
5. Increase engine life
6. Easy to handle and store

### Raw Materials for Bio diesel

1. Rape seed – the major source > 80%
2. Sunflower oil
3. Soybean
4. Palm oil (Malaysia)
5. Lin seed –oil (Spain)
6. Cotton seed oil (Germany )
7. Non edible oils – Jatropha and Pongamia

**Bio diesel:** Selection of seed stock depends upon

1. Availability
2. Price
3. Policy

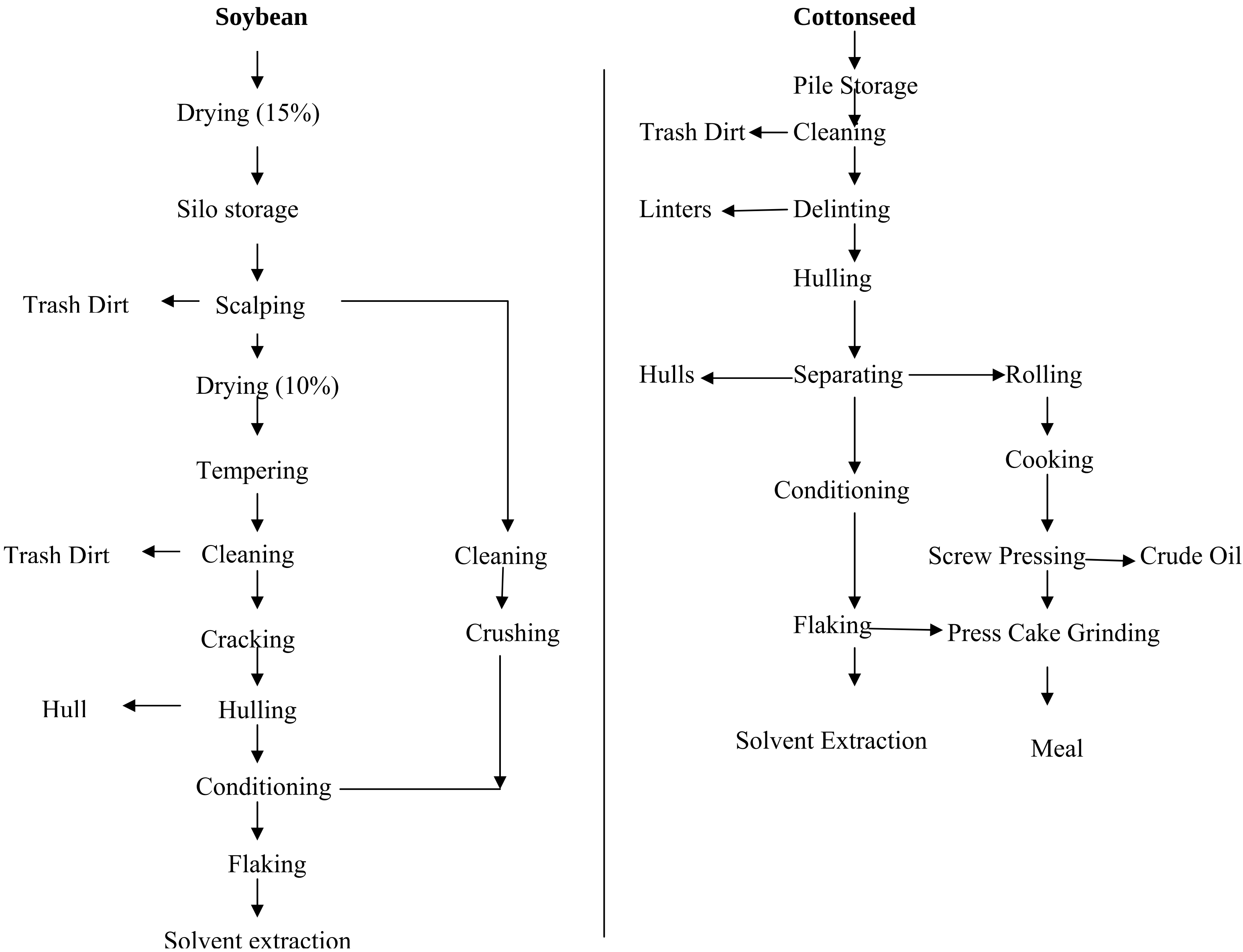
France, Germany, Italy – Currently the leaders in the of Bio diesel usage

### Extraction Technology

Current practice in the oil seed milling (extraction) industry is the use of screw pressing (expelling) or solvent extraction to separate the oil from the oil bearing seeds. The objective of both processes is to obtain high quality oil as free from impurities as possible, to obtain the oil in high yield and to produce high quality cake or meal residue suitable for animal feed or for further processing to protein isolates and concentrates. For small scale production of oil for fuel, the following steps are important.

## Seed preparation

Process flow diagram for seed preparation




Oil seeds are heat treated or cooked prior to extraction to coagulate protein and make the cell wall structure permeable to oil. Heating ruptures the cell wall by thermal stress and facilitates the flow of oil from the solids by reducing viscosity. Cooking also may inactivate the toxic components; reduce the solubility of phosphotides and reduce the affinity of solid surfaces for oil. In preparing seed for solvent extraction, the cooking is generally done prior to flaking to aid in the formation of thin, coherent flakes.

### Screw Pressing

Screw pressing is the simplest mean of extracting oil from oil seeds and is suitable for small scale production of oil. In screw pressing cooked oil seed flakes are subjected to increasing pressure as they are conveyed through a barrel cage using tapered screw. The barrel cage in usually made up of rectangular bars spaced upto 0.25 mm apart to allow drainage of oil from the barrel. Bar spacing may vary along the length of the barrel and for the type of seed being pressed. Screw design also may vary. Cake is discharged from the end of the barrel past a choke device that regulates the pressure generated in the barrel.

Under optimum operating conditions, screw presses yield cake with a residual oil content of only 3 to 4 percent; however, small- scale presses, which are much less efficient, generally yield a cake with 12 percent or greater oil content. The lower efficiency of small presses is due in part to non optimal seed preparation and in part to the fact that those presses are not designed to operate at the high pressures required for hard-pressing of oilseed. Residual oil content of the cake is a function of seed preparation and press operation; it does not depend on the amount of oil initially present in the seed.

High-oil-content seed may be processed by a combination of screw pressing and solvent extraction: seed is pressed to a residual oil content of approximately 12 percent, and the press cake is then solvent extracted as below.

## Solvent Extraction

While screw pressing gives a high recovery of oil from kernels initially having high oil content, as much as 20 percent of the total oil may be left in the cake of low-oil-content seeds such as soybeans. Solvent extraction has been developed to increase the recovery of oil. Typically meal from a solvent extraction process has a residual oil content less than 1 percent.

Although a number of different solvent extraction systems have been developed, commercial plants in the U.S. use continuous counter current percolation extractors following the process flow scheme shown in Figure. In these systems, flakes entering the extractor are sprayed with a relatively concentrated miscella (oil-solvent mixture) which percolates by gravity through the bed of flakes. The bed of flakes is contacted by successively less concentrated miscellas until near the exit it is contacted with fresh solvent. Operating temperatures generally are 2 to $5^0$C below the solvent boiling point. The average capacity for an extractor is 750 tons per day although some extractors can process up to 3,000 tons per day.

The most common solvent for oilseed extraction is hexane (boiling range 63-$69^0$C). Because of fire and explosion hazards, limitations on environmental emissions, and the increasing costs of hexane and other hydrocarbon solvent, there has been considerable interest in alternative solvents. The most commonly considered alternatives to hexane are ethanol, isopropanol, acetone and methylene chloride. Supercritical carbon dioxide also has been studied as an alternative oilseed extraction solvent. Because in addition to extracting oil alternative solvents may extract varying amounts of carbohydrates, toxic components (such as gossypol and aflatoxin) and other components of oilseeds some modification of oil refining and solvent recovery steps are required. An aqueous process also has been developed whereby the oil is emulsified with water and recovered by centrifugation (Rhee Cater and Mattil. 1972).

## Oil Processing

Crude oils obtained by either screw pressing or solvent extraction contain varying amounts of impurities that may affect the oils performance as fuel. The behavior of plant oils as fuel is considerably different from that of diesel fuel therefore; plant oils cannot be required to meet the same specifications. Crude oil may be processed to remove impurities such as particulate matter, phosphatides, waxes, pigments, and free fatty acids. Oils also may undergo chemical modification to change the degree of saturation or to convert the triglyceride structure to esters of fatty acids and monoalcohols. It is also possible to crack plant oils with the aid of shape-selective catalysts to produce essentially the equivalent of diesel fuel.

**Filtration**

Particulate matter must be removed from oils to prevent plugging of fuel lines and filters. Unless it is filtered, particulate matter will cause rapid buildup of carbon deposits in the engine and increased wear from abrasion. Crude oil from either screw pressing or solvent extraction contains a significant quantity of seed fragments termed foots. Large particles in the foots are removed by settling, and smaller particles in pressed oil are removed by filtration. Solvent-extracted oil may be processed through hydroclones or filters to remove smaller particles prior to solvent evaporation. For fuel use, the oil must be filtered to remove particulate down to approximately 4μm as a final processing step.

**Degumming**

Crude plant oils contain from 0.5 to 3.0 percent phosphatides and other mucilaginous materials, which are removed by degumming. Degumming is a simple hydration process that reduces phosphatide content to approximately 0.15 percent but does not significantly affect the free fatty acid content of the oil. When phosphatides are hydrated, they become insoluble in oil and can easily be removed by centrifugation. Gums in solvent-extracted oils can be hydrated with condensate formed in the final stage of the steam stripping that removes the last traces of solvent from the oil. Dry oils, as from screw pressing are degummed by mixing them with a small amount of water (1-3 percent) and heating to $35 – 50^0$C. Although heating is not necessary for hydration to occur, it reduces oil viscosity, thus making separation of the gums easier. For small-scale degumming, hydrated gums can be allowed to settle in a tank and the degummed oil decanted.

**Alkali Refining**

Free fatty acids are probably not detrimental to the combustion characteristics of plant oils but may cause increased corrosion problems in fuel systems and engines. Among the several methods of removing or neutralizing free fatty acids, the simplest is refining with caustic soda. In this process, free fatty acids react with sodium hydroxide to form soap, which is insoluble in oil. The amount of caustic required is affected not only by the level of free fatty acids but by pigments and surface active agents present in the oil and by the methods used to process the oilseeds. A standard laboratory analysis (AOCS, 1971) is used to determine the amount of caustic needed to refine given oil without causing excessive refining losses.

**Refining losses**

Alkali refining is generally carried out as a continuous process. Crude oil is continuously mixed with a dilute caustic soda solution, held for short time to allow reactions to occur, and then heated to break the emulsion that formas. Soap stock (Reaction products) is separated from refined oil by continuous centrifugation; the oil is washed with hot water and centrifuged again to remove trace quantities of soap. Refined oil is finally passed through a vacuum dryer to remove traces of moisture. Since alkali refining is carried out in an aqueous environment, gums are hydrated and separated along with soap stock, there by eliminating the need for a separate degumming step.

For small scale operation alkali refining can be done by mixing caustic soda solution with oil at room temperature. Agitation must be sufficiently vigorous to emulsify the mixture. When the tank content are thoroughly emulsified agitation is reduced and the tank contents are heated to 55-60C$^{O}$ causing the emulsion to break and soap stock to coalesce. Heating and agitation are then stopped and the soapstock is allowed to settle.

**Interestirification**

Plant oil have significantly higher viscosity than diesel fuel at normal injection temperatures (40-60C$^{0}$). This has been identified as one of the major factor causing problems in using plant oil as alternative fuels. Methyl or ethyl esters of plant oils have viscosities similar to that of diesel fuel.

The term interesterification refers to several different reactions but for alterative fuels the only reaction of interest is the inter change of fatty acids between glycerol and low molecular weight mono hydroxy aliphatic alcohols (Methanol, ethanol). This reaction also may be called as esterification, transestirification or alcoholysis.

The basic reaction of interesterification is shown below.

| | | | | |
|---|---|---|---|---|
| $CH_2\,COOR^{I}$<br>\|<br>$CH\,COOR^{II}$<br>\|<br>$CH_2\,COOR^{III}$ | 3 ROH | Catalyst<br>$\longrightarrow$ | $CH_2\,OH$<br>\|<br>CH OH<br>\|<br>$CH_2\,OH$ | $R^{I}$ COOR<br>+<br>$R^{II}$ COOR<br>+<br>$R^{III}$ COOR |
| 60 Kg Plant oil | 6.78 Kg of Alcohol | 0.6 Kg NaOH | 6.5 Kg Glycerin | 58 Kg of Bio Diesel |

Another Way: The reaction with methanol is as given below

$CH_2\,O_2\,CR$ $\quad$ $CH_2\,OH$
|
$CH\,O_2\,CR^{I} + 3\,CH_3\,OH \longrightarrow CH\,OH + R\,CO_2\,CH_3 + R^{I}\,CO_2\,CH_3 + R^{II}\,CO_2\,CH_3$
| (Methanol) | (3 methyl ester)
$CH_2\,O_2\,CR^{II}$ $\quad$ $CH_2\,OH$
(Triglyceroid) Glycerin

The conversion of plant oils to lower alcohol esters have two effects on physical properties which lead to improve fuel characteristics.

1. One effect is reduction in molecular weight to nearly 1/3 that of the original triglyceride

2. Second effect is conversion of long branched molecules into shorter straight, chain molecules. Together these effects produce significantly lower viscosities for lower alcohol esters.

Interesterification reactions between plant oils and lower alcohols can be catalyzed by either acid or alkali, but alkali catalysis is superior. Several alkali catalysts are effective for interesterification reactions including potassium or sodium hydroxide, sodium methoxide, sodium ethoxide and metallic sodium. The oil must be clean, dry and low in free fatty acids and the alcohol must be anhydrous.

The catalyst 0.1 – 0.5% by weight of oil, is dissolved in alcohol and the alcohol mixture is added to oil that has been heated to $80^0$C. For complete conversion of plant oil the amount of alcohol added must be approximately two times the stochiometric requirement. After thorough stirring the mixture is allowed to stand. Glycerol begins to separate almost immediately as it is immiscible with other components in the system. The ester layer contains the catalyst, un reacted alcohol, traces of glycerol and soap. The un reacted alcohol may be removed by vacuum distillation for recycling and other impurities can be washed from the ester phase with hot water.

Separation of catalyst from the lower alcohol esters to be used for fuel is imperative; otherwise, the fuel will be highly alkaline and may cause deposit formation or corrosion problems in the engine. In addition, during storage the fuel might absorb moisture from air which would react with the catalyst and ester to form soap.

Engine tests of plant oil esters have shown their performance to be equal to or better than that of diesel fuel with out any of the engine fouling problem that have occurred with direct use of plant oils.

Economic consideration of bio diesel manufacturing process of small scale production

1. Strict adherence to anhydrous conditions and low free fatty acid content of the oil makes the process more appropriate for large scale centralized plants.
2. Difficulty in finding market of glycerol since it is normally handled as a bulk commodity.
3. Unless alcohol is stripped from the esters for re-cycling which increase the complexity of the process
4. Water washing cannot be used to remove catalyst with out incurring significant alcohol losses

**PLANT OIL**

Viscosities of plant oils and Diesel fuel at normal injection temperature of $40^0$C

| Oil | Viscosity (M pa s) |
|---|---|
| Cotton seed | 31 |
| Pea nut | 36 |
| Rape Seed | 34 |
| Soybean | 30 |
| Sunflower | 31 |
| Tallow (Beef) | 24 |
| Cotton seed ethyl ester | 4 |
| Soybean ethyl ester | 4 |
| Cotton seed methyl ester | 4 |
| Sunflower methyl ester | 4 |
| Diesel | 3 |

**Cracking**

Plant oil molecules can be broken into small fragments by thermal or catalyst cracking. These processes give a variety of products including light paraffin's, olefin and aromatics, distillates in the gasoline and diesel boiling ranges and in some cases tar or coke.

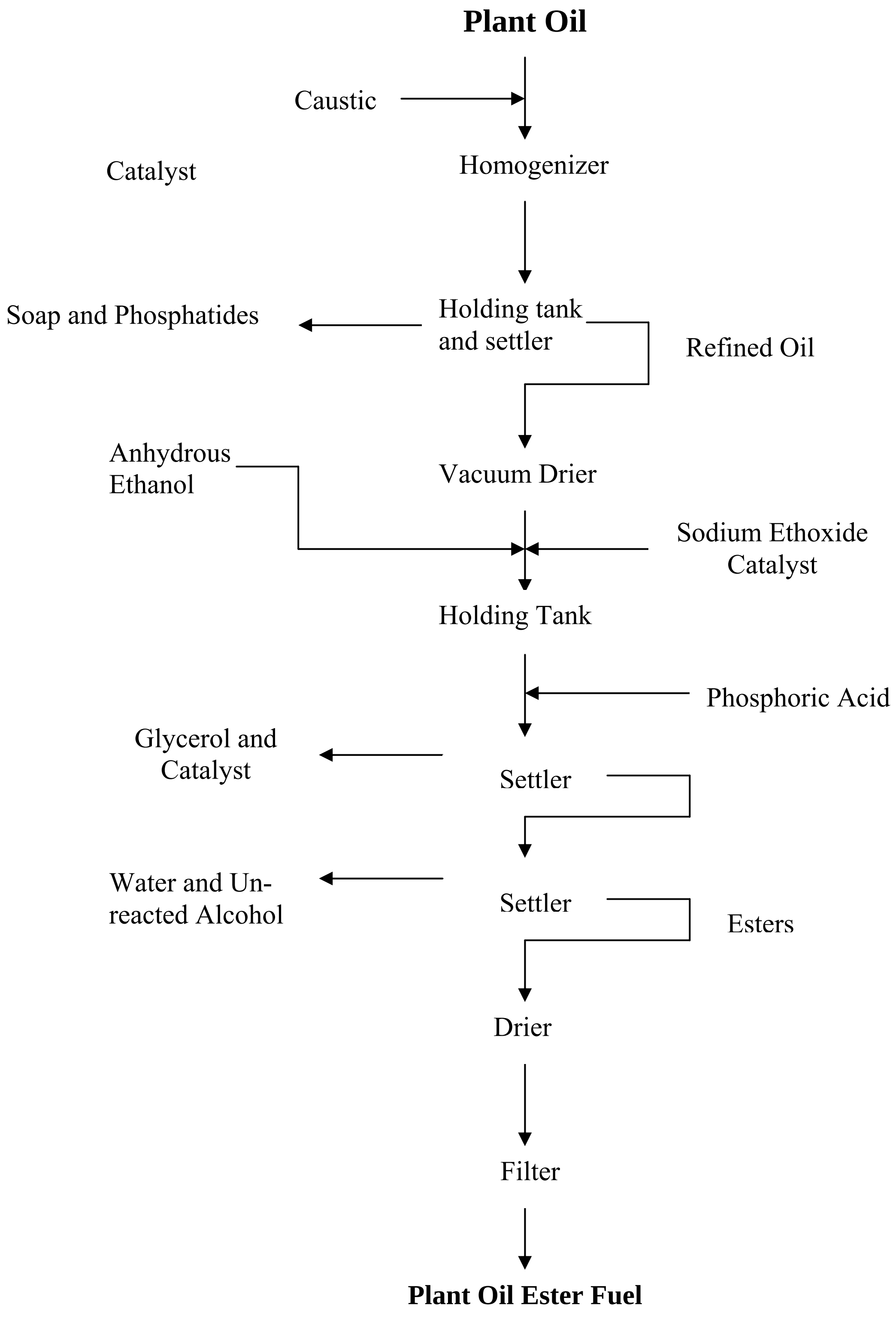



Fig: Process flow Diagram for processing Crude sunflower oil into ethyl ester fuel

# LECTURE - 16

# ETHANOL

Generally an alcohol production facility is part of corn wet milling operation. It has been demonstrated that small scale facilities ( 6 million litres/year) cannot effectively compete for cash sales and are not economically viable for fuel ethanol production unless some un usual condition exists or feed stock locally available at low cost.

Two kinds of alcohol might be used an gas-engine fuel namely methyl alcohol ($CH_4O$) and ethyl alcohol ($C_2H_6O$), neither of these is available in its pure form. A third which is known as denatured alcohol and it is satisfactory fuel under certain conditions. Denatured alcohol consists largely of grain alcohol with some wood or methyl alcohol added to it together with pyridine which gives it a distinct odour and colour.

**Reasons for not using ethyl alcohol or methyl alcohol as a fuel**:

1. It offers no advantage over hydrocarbon fuel
2. Cost of manufacturing is greater
3. It has about one-half heat value of other fuel and hence more quantity is required to generate same amount of power for the same period of time.
4. It does not vapourise so readily as gasoline
5. It requires higher compression pressure for best results

**Requirements of a good fuel:**

1. Have low ignition point should have low ignition point
2. High Calorific Value
3. Burn freely with high efficiency
4. Do not produce harmful gas
5. Produce least amount of smoke and gas
6. Be economical and easy to start and transport

A fuel having free-flow characteristics at all temperatures at which the engine may be operated is also important.

For the purpose of comparing and designating the ignition qualities of such fuel, the so called cetane rating method has been developed. The **cetane rating** of diesel fuel is its designated ignition quality determined by comparing it with standard reference fuel.

Standard reference fuel: It consists of a blend of cetane ($C_{16}H_{34}$) and Alfa methyl naphthalene ($C_{11}H_{10}$).

Eg: - A 40 cetane fuel is one having the same ignition qualities as a blend containing 40% cetane and 60% Alphamethyl naphthalene.

**Detonations – pre ignition – knock rating:**

In high compression pressure engine, in order to obtain more power and speed and increased efficiency has resulted in pronounced fuel-knocking effect. This knocking is termed as detonation, cause unpleasant – sharp clinking sound when engine is operating at low speed with wide throttle. Detonation occurs during the process of combustion of the mixture with in the cylinder after ignition has taken place.

**Antiknock (Octane rating):-** Antiknock quality of certain fuel is desirable. It is based on the fact that certain pure hydrocarbons have a very high anti knock quality and are given a rating of 100 while others are very poor and are given a rating of 0.

Ex: - Isooctane ($C_8 H_{18}$) has 100 rating
Normal heptanes ($C_7 H_{16}$) has 0 rating

The antiknock value of a fuel is determined by comparing it with a mixture of Isooctane and heptane. The fuel is given an octane rating value based on percentage by volume of isooctane in an Isooctane- heptane mixture. It is a fuel having the same knock characteristics as 70-30 percent isooctane - heptane mixture and is called as 70 octane fuel. Anhydrous or absolute ethanol will mix with petrol in all proportion. Commercial alcohol (95% purity) will not mix with petrol.

**Alcohol has the following advantages:**

1. It burns without releasing smoke and disagreeable odour
2. It produces no carbon and regarded as carbon absorber
3. It could be needed with considerable excess inorder to avoid the formation of corrosive product, such as aldehyde and acetic acids

**Calorific value:**

The amount of heat liberated by burning the unit weight or volume of the fuel.

**Raw material for ethanol production:**

Materials containing sugar require the least costly preparation, as the sugars are already available in degradable form. Sucrose occurs in free form in sugarcane, and clarified can juice may be used directly for ethanol production. However, molasses is used rather than the corresponding juices for various reasons. This class of raw materials is relatively the most expensive to obtain since it has other markets. Sugar beets and sweet sorghum also have potential for ethanol production, but sweet sorghum juice contains some starch and aconitic acid that cause difficulties in sugar crystallization.

Starch or carbohydrate is an attractive feed stock for many fermentation processes. High yields and starch content (50 – 60 percent) give corn an advantage. Spoiled and low quality starches, not suitable for food or animal feed, can be effectively used for production of alcohol. Even if food grade starch is used, the resulting biomass by product represents an excellent, protein – fortified human or animal food

Potatoes and cassava offers a high yield of starch per hectare of cropland, but the problem of storage to allow year – round ethanol production has not been overcome. Cassava, one of the most efficient photosynthetic plants, contains 20-35 percent starch and 1-2 percent protein.

Ethanol yield: 387 - lit/tone of corn
343 – lit/tone of wheat
373 – lit/tone of grain sorghum

Ethanol production from unit land area:

Sweet sorghum – 4000 lit / ha
Corn - 2290 lit / ha
Wheat - 917 lit/ha
Grain sorghum - 822 lit/ha

**Ethanol Production Process**

The basic process of ethanol production by fermentation is given in four general steps

1. Enzymatic conversion of starch into fermentable sugars by hydrolysis and saccharification gives a product called mash. But, for sugar crops like sweet sorghum and sugar cane, the steps of hydrolysis and saccharification are not necessary. Instead a sterilization is done to the juice.
2. Fermentation – Yeast converts the fermentable sugar in the mash into ethanol and $CO_2$. The percentage of ethanol varies 8-12% in the beer which is end product of fermentation process.
3. Ethanol is separated from the beer by distillation.
4. Dehydration

Ethanol can be produced as (1) Batch Process (2) Continuous process

**Starch Hydrolysis**: Before fermentation can take place, the carbohydrates in starch material must be broken down to fermentable sugar. Liquefying enzyme, or ∞ - amylase are used to break down the starch into oligosaccharides such as maltose. The chemical equation describing the over all reaction is given below showing maltose as the end product

$$2n\, C_6 H_{10} O_5 + n\, H_2O \rightarrow n\, C_{12} H_{22} O_{11}$$

$$\text{Starch + Water} \xrightarrow{\infty \text{ - amylase}} \text{maltose}$$

$$(1\text{kg}) + (0.056\text{Kg}) \longrightarrow (1.056\text{ Kg})$$

This hydrolysis process also known as liquification is a straight forward and can be carried out as either batch or continuances process

**Saccharification:** Ologo saccharides must be broken down into fermentable sugars before actual fermentation can take place. Invertase or gluco amylaze ( sacriffing enzymes) are used to split the ologo saccharides into monosaccharids such as glucose or fructose. These simple sugars can be converted $C_2H_5OH$ by various type of yeasts.

The sugar of obtained from such feed stocks like Sugar Cane and Sweet sorghum does not require cooking step and directly saccharification can be done.

The chemical equations describing the over all reaction for maltose (present in liquefied starch feed stock) and for sucrose present in feed stocks such as sugar cane and sweet sorghum are as below.

$C_{12}H_{22}O_{11} + H_2O \rightarrow 2\ C_6H_{12}O_6$

Gluco amylaze

Maltose + Water $\longrightarrow$ Glucose
(1 Kg ) (0.053Kg) = (1.053 kg)

Invertase

$C_{12}H_{22}O_{11} + H_2O \longrightarrow C_6H_{12}O_6 + C_6H_{12}O_6$

Sugar Water $\rightarrow$ Glucose +Fructose
(1 Kg) (0.053h) (1.053h)

After cooking is completed the mash is diluted with water or stillaze and cooled to$\simeq$ 49C$^0$ for sacchareification. The mash should be cool as quick as possible to retard the growth of bacteria.

The glucose amylase in added at the rate of 0.03-0.15 % of initial grain weight. The actual amount varies some what with different enzyme manufactures. The PH is normally reduced to 4.0-5.5 with HCl or $H_2SO_4$ for saccharification and fermentation. Some types of enzymes may require a holding period at specified temperature.

**Fermentation**: After inversion has been accomplished yeast must be added to the mash to convert the simple sugar, into ethanol and $CO_2$. The over all reaction for glucose is as follows.

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

Yeast

Glucose $\rightarrow$ ethanol + carbon dioxides
(1 kg) (0.511kg) (0.489 kg)

Fermentation of fructose has the same stochiometric reaction as does for glucose

Fermentation requires 48 – 72 hr at a temperature of 29 – 35C$^0$. The sugar concentration of the mash should be adjusted with water to about 16 – 24% to obtain an ethanol concentration in the beer of 8 – 12%. The optimum PH range for average yeast is 4.5 – 5.0. In batch fermentation process the mash stays in the fermenter for about 48 hr before the distillation process is started.

**Distillation**

Fractional distillation at atmospheric pressure is the most common method for separating ethanol from fermentation beer. Distillation is the physical separation of a mixture into two or more fractions that have different boiling points. When this liquid mixture is heated to a given temperature, the resulting vapour will have a higher concentration of more volatile substance, in this case ethanol with boiling point 78.3$^0$C at 1 atmospheric pressure. The liquid in equilibrium with the vapour will be richer in the less volatile substance. When hot vapor condenses, the reverse process occurs. The condensing liquid will contain more of less volatile substance than the vapour from which it is condensed.

At every given temperature between the boiling points of the pure substances, there is an equilibrium stage between the liquid and vapour.

The separation of ethanol from beer is made possible is a distillation column that contains a series of equilibrium stages with in a temperature gradient. At progressively higher temperatures, the stages contain more water and less ethanol. As the temperature decreases, the equilibrium stages contain more ethanol and less water.

The two sections of the distillation column are often constructed as two separate columns. The section below the beer feed is known as the beer column as stripping column. The function of stages in this section is to increase the recovery of ethanol. Above the feed stage is the rectifying column. The equilibrium stages in this section serve to increase the purity of the ethanol.

The distillation columns contain devices to increase the vapour – liquid contact area. The perforated metal plate, the most common in ethanol distillation. Beer or aqueous ethanol from the higher stages flows down the column through a down comer and accumulates on the plate. Vapour from the lower stage flows up the column through perforations in the plate and heats and vaporize the liquid on the plate until equilibrium is reached.

As the liquid flows down the beer column, the ethanol concentration becomes progressively less as the temperature increases. The heat required for distillation process is normally in the form of steam injected into the base of the beer column.

The vapour that flows up the rectifying column becomes richer in ethanol until it is removed from the top of the column and condensed. The final concentration is about 95% ethanol.

After condensation, a portion of the ethanol produced is returned to the rectifying column as reflux. The reflux serves as the liquid feed to the final equilibrium stage and is used to maintain the temperature of the final stage. The temperature of the final stage determines the concentration of the final product.

**Ethanol Dehydration Method :**

Removing of water from ethanol to make it anhydrous is called dehydration

1. **Conventional method:** This is called on tertiary azeotropic distillation. In this method a third component such as Benzene or pentane is used. The $C_6H_6$ is added to a concentrated ethanol solution. The remaining water, the benzene and a fraction of the ethanol form a minimum boiling - azeotropic, which is distilled of to leave pure ethanol in the reboiler. The distillate is reprocessed to recover the benzene. Energy consumption is 9,400 KJ/lit
2. **Vacuum distillation:** It is a method for obtaining anhydrous ethanol from a dilute solution in one step. At pressure below 11.7 Kpa, ethanol – water azeotropic does not form and anhydrous ethanol is obtained as a distillate. However because of the change of the liquid -vapour equilibrium relationships with the reduced pressure a very large reflux ratio is required and the total energy consumption becomes very high 10,300 KJ/lit.

**Advantages:** Reduced pressure results in lower boiling point. This fact would allow cheaper materials like PVC to be used for column construction rather than stainless steel.

**Solvent Extraction:** Solvent extraction has been used as a mean for dehydration of ethanol. A $CO_2$ extraction process uses liquid $CO_2$ at 6200 – 6900 K pa to extract ethanol from 20 – proof fermentation beer. Ethanol is more soluble in liquid $CO_2$ than in water. The $CO_2$ ethanol phase is separated from the water phase, then the pressure is reduced to about 4830 Kpa to flash the $CO_2$ leaving anhydrous ethanol.

**Gashole:** Low temperature blending of water-ethanol mixture with gasoline can be used to produce gashole in a process very similar to extraction. The water-ethanol mixture is blended with gasoline at – $29C^0$. The water separates, from the gasoline to form an ethanol proof phase. The water phase in then removed and distilled to recover any remaining ethanol. The gasoline phase is used as an ethanol – enhanced fuel.

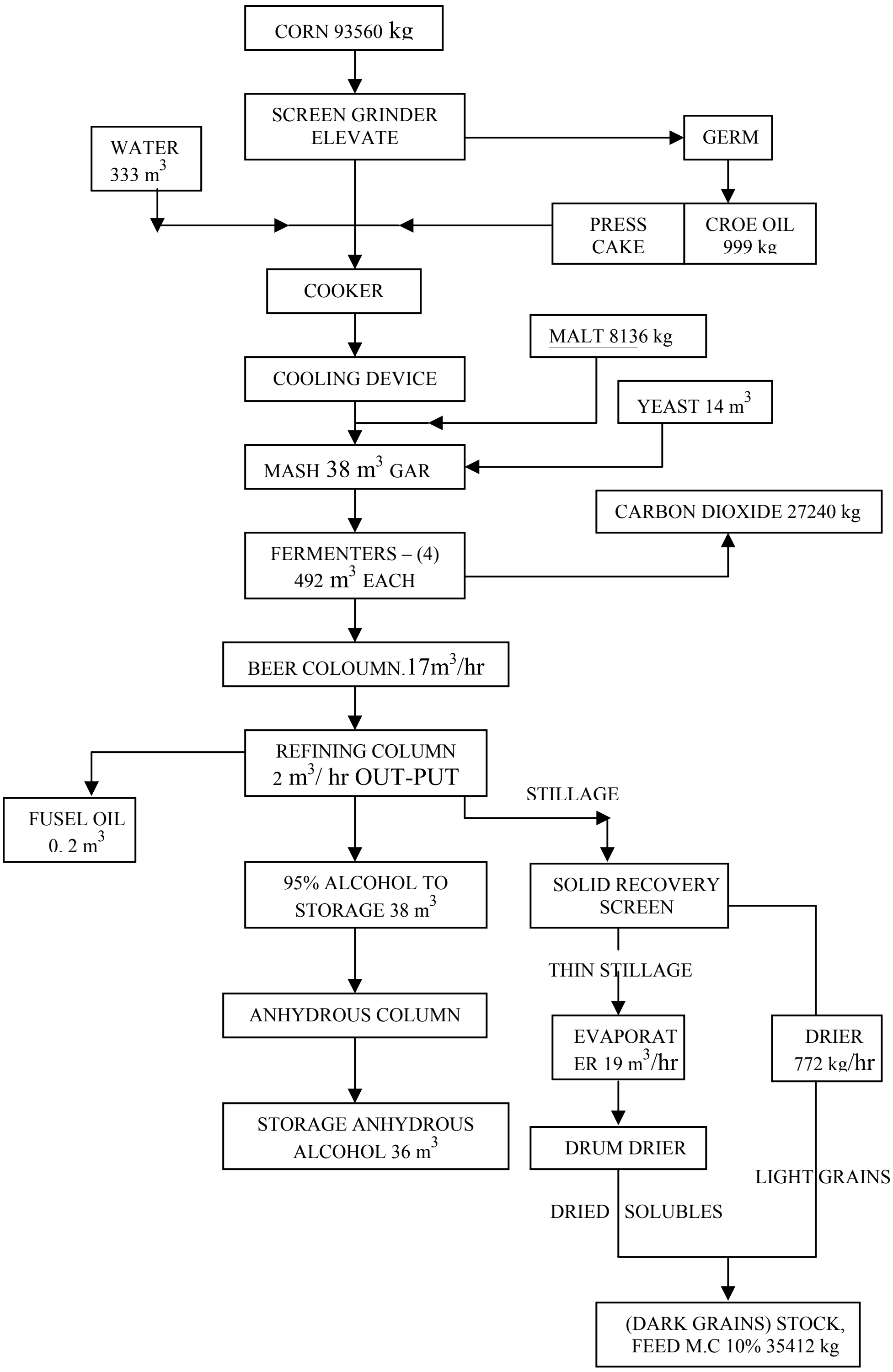
**Molecular sieve:** The ethanol can be dehydrated by using a molecular sieves. The molecular sieves are crystalline metal alumino silicates containing net work of interconnecting pores. The pore size in the molecular sieve can be controlled by crystal formation during manufacturing of the sieve. Separation is based on the selective absorption of molecules into the pore walls of the sieve.

For separation of water from ethanol a sieve with 3-A effective pore diameter is used. Water with molecular diameter of less than 3A is absorbed by the sieve, while ethanol whose molecules are large than 3A can not be absorbed. The component of a mixture for which the sieve has the greatest affinity is removed from the mixture until the sieve is saturated.

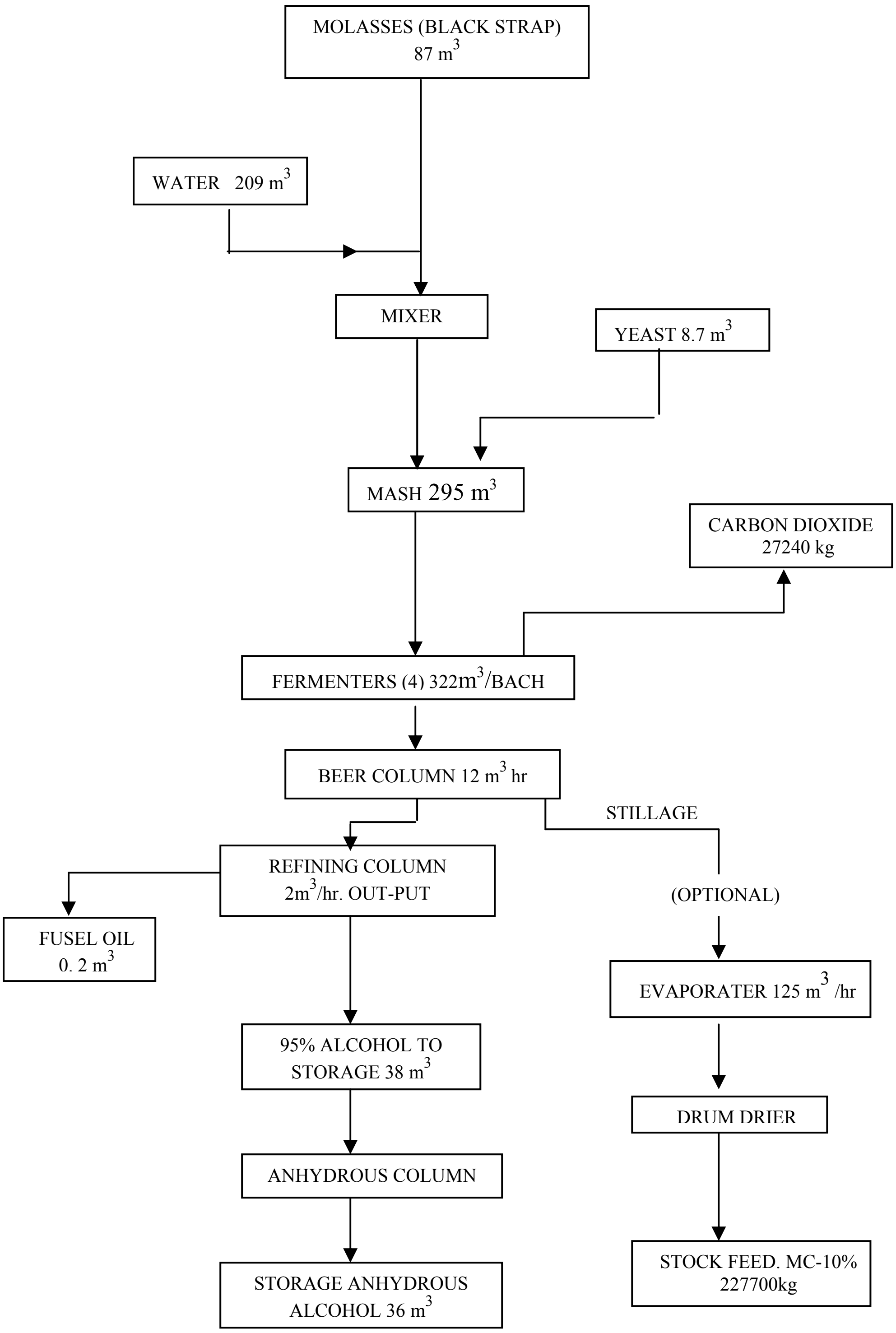
**Denaturing: -** Ethanol that will be used for fuel is then denatured with a small amount of (2-5%) some product like gasoline to make it unfit for human consumption.

**Uses of ethyl alcohol :**

| Sl. No | General uses | Specific use/product |
|---|---|---|
| 1 | Fuel | a) Light<br>b) Power<br>c) Heat |
| 2 | Raw material in chemical processes | a) Ethylene<br>b) Ether<br>c) Esters |
| 3 | General utility | a) Hospital<br>b) Chemical laboratory<br>c) Home |
| 4 | Solvent | a) Dyes<br>b) Nitrocellulose<br>c) Oils and waxes<br>d) Drugs and chemicals<br>e) Preparation of tinctures |
| 5 | Miscellaneous | a) Carbon remover<br>b) Preservative<br>c) Antiseptic |




Flow diagram of alcoholic fermentation of corn
(Prescott & Dunn, 1959)




Flow diagram of alcoholic fermentation of molasses
(Prescott & Dunn, 1959)