Lecture Note

Renewable Energy and Green Technology

Course Title: Renewable Energy and Green Technology
Course No. Ag. Engg. 4.3   Create Hr : 1+1

Course content

No	Title of topic	Sub topics to be cover
1	Introduction	Classification of energy sources; contribution of these of sources in agricultural sector,
2	Familiarization with biomass utilization for biofuel production and their application	Biomass energy;Biomass characteristics Bio mass resources; Introduction of biofuel: Solid biofuels (wood, straw, animal wastes, and crops etc.); Liquid biofuel (bioalcohol, ethanol, methanol, butanol, biodiesel, and biooils etc.); Gaseous biofuels (bio-methane, and wood gasetc) Application: Direct combustion for heating, Domestic cooking
3-4	Biogas	Anaerobic digestion to methane (Bio Gas) Types of biogas plants: Floating dome type (KVIC);Fixed dome type (Janta, Deenabandu model); Base Pre-requisites of biogas plant installation; Advantages and disadvantages of biogas; Comparison of floating and fixed gas holder type plants; Design steps and numerical
5	Gasifiers,	Gasification; Chemical reactions in gasification; Producer gas; Application of producer gas; Type of Gasifiers (Up draught, Down draught, Cross draught, Fluidized bed)
6	Liquid bio fuel	Production of Bio fuel (Ethanol); Production process of biodiesel; Biooil; Utilization as bioenergy resource,
7	Introduction of solar energy	Introduction;Terminology of solar radiation; Sun earth angle;Solar radiation measurement; Numerical
8-9	Familiarization with solar energy gadgets	Solar cooker (box type concentrated type); solar water heater; natural circulated and forced solar drying; solar pond; solar distillation; Numerical
10	Solar photovoltaic system,	Solar photovoltaic fundamentals;Solar cell;Operation of a PV cell; Solar photovoltaic module; Solar panels; Solar array Application:Solar lantern;Solar street; lights; Solar fencing; Solar water pumping system

11-13	Introduction of wind energy and their application.	Wind power; Calculation of power; Types of wind mills: Vertical axis wind mills (Savonius or S type wind mill Darrius wind mill), Horizontal axis wind mills: (Single blade wind mills Double blade wind mills Multi blade wind mills Bicycle multi-blade type i.e., Sail type.) Comparison of horizontal and vertical axis wind mill, Limitations; Numerical
14	Availability of biomass and their application.	Different type farm biomass; Densification, briquetting; Briquetting machine;

Reference book

R.R. Mahitcha. Non conventional energy sources, Atul Prakashan

R K Partsad, T P Ojha. Non conventional energy sources Jain Brothers

G.D. Rai, Non Conventional Energy Resources, Khanna Publication,

Sanjay Kumar *et al* Fundamentals of Agricultural Engineering, Kalyani Publications, New Delhi

Lecture -1

Energy

Energy is the primary and most universal measure of all kinds of work by human beings and nature. Everything what happens in the world in the expression of flow of energy in one of its forms.

Technical conversion of energy has three different conversion stage namely:

Stage	Definition	Energy source
Primary energy	Original source	*e.g.* crude oil, coal not yet processed, natural uranium, solar, wind etc
Final energy/ secondary	Energy in the form that reaches the end user, hot water or steam	*e.g.,* gas, fuel, oil, petrol, electricity
Effective energy	Energy in form used by the end user	*e.g.,* light, radiation heat, driving force or vehicles

Energy Sources

The energy sources can be classified in a number of ways. The general classification of energy resources is an follows:

A. Based on the usability of energy

1. **Commercial sources of energy:** The energy sources like petroleum products (diesel, petrol and kerosene oil) and electricity, which are capital intensive, exemplify commercial sources of energy. Considering the fact that most of the commercial sources are also non-renewable and to some extent are imported to India, efforts are made to conserve such sources of energy.
2. **Non-commercial sources of energy:** Each and every energy source has some economic value. Some energy sources are available comparatively at low cost whereas others are capital intensive. The energy sources which are available cheaply are called non-commercial sources of energy whereas the ones which are capital intensive are called commercial energy sources. Human labour and bullocks exemplify the category of non-commercial source of energy.

B. Based on traditional use

1. **Conventional :** those energy sources which have been traditional used for many decades *e.g.* fossil fuels, nuclear and hydro
2. **Non-conventional:** Those energy sources which are considered for large scale use of oil crisis of 1973 are called non-conventional energy source *e.g.* solar, wind, biomass etc.

C. Based on long term availability

1. **Non – renewable /Exhaustible:** Those which are finite and do not get replenished after their consumption. Fossil fuels, nuclear, natural gas etc.
2. **Renewable resources:** Those which are renewed by nature again and again and their supply not affected by the rate of their consumption.

D. Base on origin

1. Fossil fuel
2. Wind energy
3. Solar energy
4. Biomass energy
5. Nuclear energy
6. Solar energy
7. Geothermal energy
8. Tidal energy
9. Hydro energy

Introduction to Renewable Energies

Renewable energy refers to energy resources that occur naturally and repeatedly in the environmental and can be harnessed for human benefit. These energy resources are inexhaustible within the time horizon of humanity. Examples of renewable energy systems include solar, wind, and geothermal energy (getting energy from the heat in the earth). We also get renewable energy from trees and plants, rivers, and even garbage. During recent years, due to the increase in fossil fuel prices and the environmental problems caused by the use of conventional fuels, we are reverting back to renewable energy sources such as solar, wind and hydraulic energies. Renewable energies are inexhaustible, clean and they can be used in a decentralized way (they can be used in the same place as they are produced).

Renewable Energy Source	Technology / Application
Solar	Photovoltaic (PV) cells to produce electricity and Solar thermal system for heating water/air
Wind	Wind turbine to pump water, produce electricity or for any other mechanical use
Water	Hydro-electric, wave and tidal systems to produce electricity
Biomass	Direct combustion of gas produced from biomass, or biogas, to generate electricity and/or heat - e.g. wood stoves or larger commercial operations
Geothermal	Using the temperature of the earth to produce

	electricity and/or heat
Ocean energy (wave and Tidal energy)	Ocean to operate a heat engine to produce a work output and generated electricity

Advantages of renewable energy

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

Disadvantages of renewable energy

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

Lecture -2

Biomass energy

The material which has life is called Biomass. Other words, the material contained in the bodies of living organism (plants and animals) is said to be Biomass or plant matter/ organic matter. The energy obtained from organic matter, derived from biological organism is known as biomass energy.

Solar energy → Photosynthesis → Biomass → Energy generation

Biomass include wood, leaves, animal waste, crops, bones, and scales or any other organic matter and Biomass energy is the utilization of energy stored in this organic matter.

The ultimate source of bio mass energy is sun. Plants absorb the energy from the sun in a process called photosynthesis. The chemical energy stored in plants get passed on to animal and human beings that eat them. The average efficiency of photosynthetic conversions of solar energy into biomass energy is estimated to be 0.5 to 1.0 %.

Biomass is a renewable energy source. The organic matters are burned directly to produce heat or they are refined to produce fuel like ethanol or other alcoholic fuels.

Biomass characteristics

The main constituents of any biomass material are (i) lignin (ii) hemicellulose (iii) cellulose (iv) mineral matter (v) ash. Wood is a solid lingocellulose material naturally produced in tree and shrubs, made up 40-50 % cellulose, 20-30 % hemicellulose and 20-30 % lignin. The percentage of the above components of biomass varies from species to species. Evaluation of biomass resource as potential energy feedstocks generally requires information about their composition, heating value, production yields (in the case of energy crops) and bulk density.

Bio mass resources

Biomass resources for energy production are widely available in forest areas, rural farms, urban refuse and organic waste from agro-industries.

Biomass resources fall into three categories:

1. Biomass in its Traditional solid mass (*Wood and Agriculture residue*) To burn the bio mass directly
2. Biomass in its non-traditional solid mass (*converted into liquid fuels*) The biomass is converted into ethanol and methanol to used liquid fuel
3. *To ferment the biomass anaerobically* to obtain a gaseous fuel called biogas

Biomass conversion Routes in produce energy

1.	Physical	➢ Densification of biomass into solid briquettes
2.	Agrochemical	➢ Fuel extraction (solid & liquid) from freshly cut plant
3.	Thermo chemical	➢ Combustion ➢ Carbonization ➢ Pyrolysis ➢ Gasification ➢ Liquefaction ➢ Anaerobic diagestion to methane (Bio Gas)
4.	Biochemical	➢ Ethanol fermentation ➢ Hydrogen formation cell

Direct combustion for heat

Direct combustion is the simplest and most common method of capturing the energy contained within biomass. The technology is well understood and commercially available. Combustion or burning is a *exothermic* chemical reaction between a fuel (usually a hydrocarbon) and an oxidant accompanied by the production of heat or both heat and light. In a complete combustion reaction, a compound reacts with an oxidizing element, such as oxygen and the products are compounds of each element in the fuel with the oxidizing element.

Three things are needed for effective burning:

- High enough temperatures
- Enough air, and
- Enough time for full combustion

If not enough air gets in, combustion is incomplete and the smoke is black from the unburned carbon. If too much air gets in the temperature drops and the gases escape unburned, taking the heat with them. Therefore, the right amount of air is very important to gives the best utilization of fuel. One problem with this method is its very low efficiency (2-5 %). With an open fire most of the heat is wasted and is not used.

A simpler example can be seen in the combustion of hydrogen and oxygen:

$$\mathbf{2H_2 + 0_2 \longrightarrow 2H_20\ (g) + heat}$$ result is water vapour]

Types of combustion:

A. **Rapid:** Rapid combustion is a form of combustion in which large amounts of heat and light energy are released, which often results in a fire. This is used in a form of machinery such as internal combustion engines.
B. **Slow:** Slow combustion is takes place at low temperatures. Cellular respiration is an example of slow combustion

C. **Complete:** In complete combustion, the reactant will burn in oxygen, producing a limited number of products. When a hydrocarbon burns in oxygen, the reaction will only yield carbon dioxide and water. When a hydrocarbon or any fuel burns in air, the combustion products will also include nitrogen. The complete combustion is almost impossible to achieve.

D. **Incomplete:** Incomplete combustion occurs when there isn't enough oxygen to allow the fuel to react completely with the oxygen to produce carbon dioxide and water, also when the combustion is quenched by a heat sink such as a solid surface or flame trap.

Pyrolysis:

Biomass can be converted into gases, liquids and solids through pyrolysis at temperature of 200 to 500 °C by heating in a closed vessel in absence of oxygen. The residue is then the char - more commonly known as charcoal - a fuel which has about twice the energy density of the original and burns at a much higher temperature.

Pyrolysis is most commonly used for organic materials. It occurs spontaneously at high temperatures In general; it produces gas and liquid products and leaves a solid residue richer in carbon content. Pyrolysis is heavily used to produce charcoal, activated carbon, methanol and other chemicals from wood, to convert ethylene dichloride into vinyl chloride to make PVC, to convert biomass into syngas, to turn waste into safely disposable substances, and for the cracking of medium-weight hydrocarbons from oil to produce lighter ones like gasoline.

The products of pyrolysis of wood are nearly

1. charcoal -25 %
2. Wood gas -20 %
3. Pyroligneous acid -40 %
4. Wood oil -15 %

The rate of pyrolysis depends on several factors like

- Composition of material
- Heating rate
- Residence time
- Temperature level

Similarly, another term gasification is also the pyrolysis adopted to produce maximum amount of secondary fuel gases.

Gasification

Biomass gasification is a thermochemical decomposition process in controlled air. It is conversion process of solid, carbonaceous fuel into combustible gas mixture, normally known as **producer gas** (or wood gas, water gas, synthesis gas syngas)

This is done by partially burning and partially heating the biomass (using the heat from the limited burning) in the presence of charcoal (a natural by-product of burning biomass). The gas can be used in internal combustion engines.

Gasification is a process that converts carbonaceous materials, such as coal, petroleum, biofuel, or biomass, into carbon monoxide and hydrogen by reacting the raw material, such as house waste, or compost at high temperatures (>700°C) with a controlled amount of oxygen. Gasification is a method for extracting energy from many different types of organic materials. Almost any type of organic material can be used as the raw material for gasification, such as wood, biomass, or even plastic waste.

The advantage of gasification is that using the syngas is potentially more efficient than direct combustion of the original fuel. Syngas may be burned directly in internal combustion engines or used to produce methanol and hydrogen. Gasification of fossil fuels is currently widely used on industrial scales to generate electricity.

In essence, a limited amount of oxygen or air is introduced into the reactor to allow some of the organic material to be "burned" to produce carbon monoxide and energy, which drives a second reaction that converts further organic material to hydrogen and additional carbon dioxide.

Chemical reactions in gasification

Gasification is quite complex thermochemical process. Splitting of gasifier into strictly separate zone is not realistic, but nevertheless conceptually essential. Four distinct processes take place in a gasifier; drying of the fuel, pyrolysis, combustion and reduction.

Drying zone

Biomass fuels consist of moisture ranging from 5 to 35% at the temperature above 120 °C, the moisture is removed and converted to steam, in the drying, fuels do not experience any kind of decomposition. Depending on the kind of rector, the fuel composition and size of fuel drying may require several minutes to accomplish or may occur almost instantaneously.

Pyrolysis zone

At about 400°C, the complex structure of biomass begins to breakdown with the release of gases, vapours and liquid. Many of these released components are combustible and contribute significantly to the heating value of the product gas from the gasifier. The ratio of products is influenced by the chemical composition of biomass fuels and their operating condition. Reaction times range from milliseconds to minutes. Reaction yields range from mostly liquids to exclusively low molecular weight gases e.g. volatile gases, oil, char and tar.

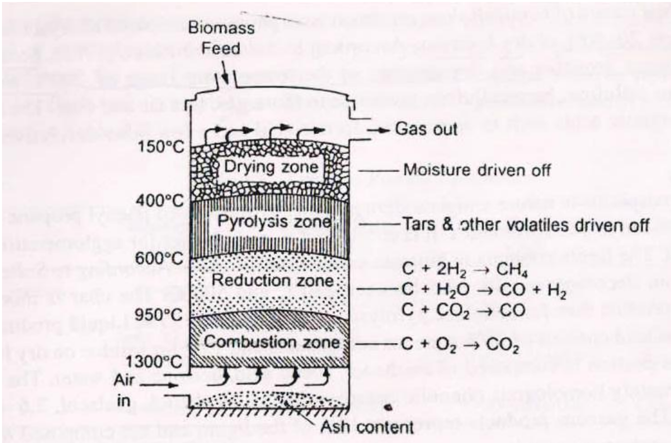
Oxidation/combustion zone

As the temperature approaches 700°C, the char begins to react with oxygen, introduced air in the oxidation zone contains inert gases such as nitrogen and argon besides oxygen and water vapours. The oxidation take place at the temperature of 700 to 1300°C. heterogeneous reaction take place between oxygen in the air and solid char fuel, producing carbon dioxide and water vapour

$$C + O_2 = CO_2 + 393800\ {}^{kJ}/_{kg\ mol}\ (Exothermic\ reaction))$$

Hydrogen in the fuel reacts with oxygen in the air blast, producing steam

$$H_2 + \frac{1}{2}O_2 = H_2O + 242000\ {}^{kJ}/_{kg\ mol}\ (Exothermic\ reaction)$$



Reduction Zone

In reduction zone, a number of high temperature chemical reactions take place in the absence of air. Most of the reactions are endothermic and the heat released during exothermic reaction in oxidation is also utilized in reaction zone. Hence temperature of gas goes down in this zone. The temperature in the zone ranges from 800-1000°C.

$$C + CO_2 = 2\,CO - 172600\frac{kJ}{kg\ mol}\ (Boudouard\ reaction)$$

$$C + H_2O = H_2 + CO - 131000\frac{kJ}{kg\ mol}\ (Water\ gas\ reaction)$$

$$CO + H_2O = CO_2 + H_2 + 42000\frac{kJ}{kg\ mol}\ (Water\ shift\ reaction)$$

$$C + 2H_2 = CH_4 + 75000\frac{kJ}{kg\ mol}\ (Hydrogeneration\ \ reaction)$$

Hence final gas produces in the gasifier is composed of mainly CO and H_2

Producer gas

- Producer gas obtained through gasification is the mixture of combustible and non-combustible gases
- The quantity of constituents of gas depends upon the type of fuel and operation

- Heating value of gas 4.5 to 6 MJ/m^2

Content of producer gas

1. Carbon monoxide -15 to 30 %
2. Hydrogen - 10 to 20 %
3. Methane - less than 4 %
4. Nitrogen -45- 60 % (non combustible)
5. Carbon dioxide - 5 to 15 % (non combustible)

Application of producer gas

Thermal application: cooking, water heating, stem generation, drying etc.

Motive power: I C engine as water pumping

Electricity: I C engine and gas turbine etc.

Type of Gasifiers

Gasifiers are generally classified according to the method of contacting fuel, direction of air / gas movement, type of bed and type of fuel used. The most important classification of gasifier is based on type of bed.

A. Fixed bed
   1. Up draught
   2. Down draught
   3. Cross draught

B. Fluidized bed

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.

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

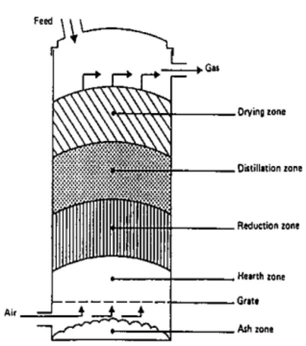


Fig. Updraft Gasifier

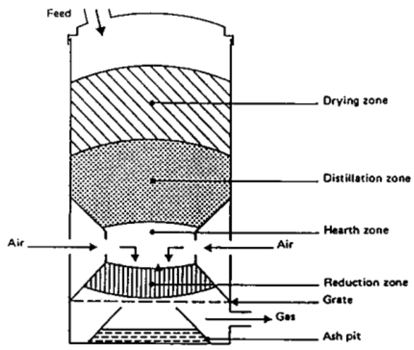


Fig. Down draft Gasifier

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 are 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.

Cross Draft Gasifier: Cross-draught gasifiers, schematically illustrated in Figure 2.9 are an adaptation for the use of charcoal. Charcoal gasification results in very high temperatures (1500 °C and higher) in the oxidation zone which can lead to material problems. In cross draught gasifiers insulation against these high temperatures is provided by the fuel (charcoal) itself.
Advantages of the system lie in the very small scale at which it can be operated. Installations below 10 kW (shaft power) can under certain conditions be economically feasible. The reason is the very simple gas-cleaning train (only a cyclone and a hot filter) which can be employed when using this type of gasifier in conjunction with small engines.
A disadvantage of cross-draught gasifiers is their minimal tar-converting capabilities and the consequent need for high quality (low volatile content) charcoal.
It is because of the uncertainty of charcoal quality that a number of charcoal gasifiers employ the downdraught principle, in order to maintain at least a minimal tar-cracking capability.

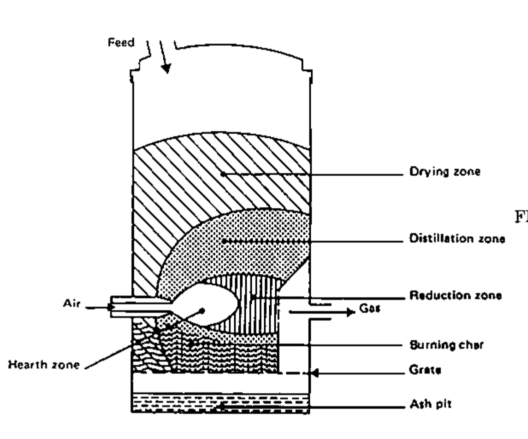


Fig. Cross draft Gasifier

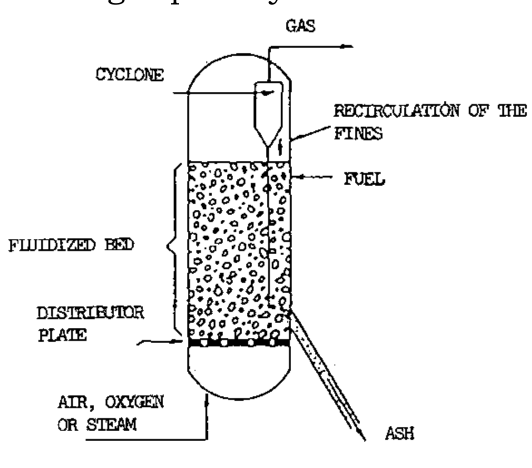


Fig. Fluidized bed gasifier

Fluidized bed gasifier: The operation of both up and downdraught gasifiers is influenced by the morphological, physical and chemical properties of the fuel. Problems commonly encountered are: lack of bunkerflow, slagging and extreme pressure drop over the gasifier. Air is blown through a bed of solid particles at a sufficient velocity to keep these in a state of suspension. The bed is originally externally heated and the feedstock is introduced as soon as a sufficiently high temperature is reached. The fuel particles are introduced at the bottom of the reactor, very quickly mixed with the bed material and almost instantaneously heated up to the bed temperature. As a result of this treatment the fuel is pyrolysed very fast, resulting in a component mix with a relatively large amount of gaseous materials. Further gasification and tar-conversion reactions occur in the gas phase. Most systems are equipped with an internal cyclone in order to minimize char blow-out as much as possible. Ash particles are also carried over the top of the reactor and have to be removed from the gas stream if the gas is used in engine applications.

The major advantages of fluidized bed gasifiers, and others, stem from their feedstock flexibility resulting from easy control of temperature, which can be kept below the melting or fusion point of the ash (rice husks), and their ability to deal with fluffy and fine grained materials (sawdust etc.) without the need of pre-processing. Problems with feeding, instability of the bed and fly-ash sintering in the gas channels can occur with some biomass fuels.

Other drawbacks of the fluidized bed gasifier lie in the rather high tar content of the product gas (up to 500 mg/m^3 gas), the incomplete carbon burn-out, and poor response to load changes.

Particularly because of the control equipment needed to cater for the latter difficulty, very small fluidized bed gasifiers are not foreseen and the application range must be tentatively set at above 500 kW (shaft power).

Lecture -3

Anaerobic diagestion to methane (Bio Gas)

Anaerobic digestion is the decomposition of organic waste to gaseous fuel by bacteria in an oxygen free environment. The process occurs in stages to successively break down the organic matter in to simpler organic compounds. The final product, known as biogas is a mixture of methane, carbon dioxide and some trace gases. Biogas is also known as the swamp gas, sewer gas, fuel gas, marsh gas, wet gas and in Indian more commonly as gobar gas.

Composition of biogas

Sr. No	Constituents	Formulae	Proportion in percentage
1	Methane gas	CH_4	50-65
2	Carbon dioxide	CO_2	30-45
3	Hydrogen	H_2	1- 3
3	Nitrogen	N_2	0-5
4	Oxygen	0_2	0.01
5	Hydrogen sulphide	M_2 S	1-2

Basics of anaerobic digestion

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

Anaerobic digestion consists of the following three phase.

(i) Hydrolysis phase,
(ii) Acid formation phase
(iii) Methane formation phase

Hydrolysis

Large molecules are breakdown into smaller size by enzymes which in turn are decomposable by bacteria. The organic substances such as polysaccharide, protein and lipid are converted into mono-saccharide, peptide, amino acids, and fatty acids. Then they are further converted into organic acids (acetate, propionate and butyrate). Cellulytica bacteria help to reduce chains and branches. Cellulytica bacteria is of two types mesophilic (30°- 40°) and thermophilic (50°- 60°).

Acid formation

Acid phase which simple organic materials are converted into simpler acids such as volatile fatty acids. Acetic acid is one common by-product of digestion of fats, starch and proteins. Methane bacteria are strictly anaerobic and can produce methane either by fermenting acetic acid to from methane and carbon dioxide, or by reducing carbon dioxide to methane using hydrogen gas. Acetic acid is to react with methaogenic bacteria resulting in methane formation. Acetic acid accounts for 70 % of methane produced.

Methane formation

Methanogenic bacteria react with acetic acid, ethyanol, carbon dioxide and hydrogen to produce methane. Methane forming bacteria slowly, in about 14 days at 25 °C complete the digestion. The remaining indigestible matter is referred as "slurry".

Cellulose + Nutrients

Extracellular Enzymes
Step-I (Hydrolysis)

$$(C_6H_{10}O_5)_n + nH_2O \xrightarrow{Hydrolysis} n(C_6H_{12}O_6)$$

Soluble glucose+ Nutrients

Acid Producing Bacteria
Step-II (Acid Phase)

$$C_6H_{12}O_6 = 2CH_3.CHOH.COOH$$

Lactic Acid

$$C_6H_{12}O_6 = CH_3CH_2.CH_2.COOH + 2CO_2 + 2H_2$$

Butyric Acid

$$C_6H_{12}O_6 = 2CH_3CH_2.OH + 2CO_2$$

Ethyl alcohol

$$+ \begin{bmatrix} Volatile \\ fatty\ acid \end{bmatrix} + CO_2 + H_2 + \begin{bmatrix} Other\ products \\ alcohols, lactate.etc \end{bmatrix}$$

Methane Producing Bacteria
Step-III (Methane Phase)

$$4H_2 + CO_2 = CH_4 + H_2O$$

$$2CH_3.CH_2.OH + CO_2 = 2CH_3.COOH + CH_4$$

$$CH_3.COOH = CH_4 + CO_2$$

$$2CH_3.CH_2.CH_2.COOH + 2H_2 + CO_2 = 4CH_3.COOH + CH_4$$

$$CH_4 + CO_2$$

Details of biochemistry of anaerobic digestion process

Optimum conditions for biogas production

Parameters	**Optimum value**
Temperature	30-35 °C
pH	6.8-7.5
C/N Ratio	20-30:1
Solid content	8-10 %
Retention time	20-50

Feedstock for biogas plants

- ✓ Animal wastes:
- ✓ Human wastes
- ✓ Kitchen wastes
- ✓ Agriculture Wastes
- ✓ Aquatic plants
- ✓ Municipal wastes
- ✓ Industrial wastes
- ✓ Hens and ducks droppings

The calorific values of different fuels

Commonly used fuels	Calorific values in K.Cal.
Bio-gas	4713/M^3
Dung cake	2093/Kg
Firewood	4978/Kg
Diesel (HSD)	10550/Kg
Kerosene	10850/Kg
Petrol	11100/Kg

Factors involved in biogas production

Biogas production involves different physical, chemical and biological process for conversion of biodegradable organic materials to energy rich gas.

C/N ratio

The ratio of carbon to nitrogen present in the feed material is called C:N ratio. It is a crucial factor in maintaining perfect environment for digestion. Carbon is used for energy and nitrogen for building the cell structure. Optimum condition for anaerobic digestion to take place ranges from 20 to 30:1. This means the bacteria use up carbon about 20 to 30 times faster than they use up nitrogen.

When there is too much carbon in the raw astes, nitrogen will be used up first and carbon left over. This will make the digestion slow down and eventually stops. On the other hand if there is too much nitrogen, the carbon soon becomes exhausted and fermentation stops. The nitrogen left over will combine with hydrogen to form ammonia. This can kill or inhibit the growth of bacteria specially the methane producers.

Temperature:

Temperature affects the rate of reaction happening inside the digester. Increase in the ambient temperature increases the rate of reaction thus increasing the biogas production as well. Methane bacteria work best at a temperature of 35° - 38° C. The fall in gas production starts at 20°C and stops at a temperature of 10°C. Studies hawed that 2.25 m^3 of gas was produced from 4.25m^3 of cattle dung everyday when the digester temperature was 25°C. When the temperature rose to 28.3°C the gas production was increased by 50 per cent to 3.75 m° per day.

Retention time:

It is the theoretical time that particular volume of feedstock remains in the digester. In other words, retention time describes the length of time the material is subjected to the anaerobic reaction. It is calculated as the volume of digester divided by the feedstock added per day and it is expressed in days. Under anaerobic condition, the decomposition of the organic substances is slow and hence need to keep for long time to complete the digestion. In case of Indian digesters, where the feed stock is diluted with equal composition, so demarcation prevails between solid and liquid. In this case, biomass in the form of bacteria is washed out; hence the solid retention time (SRT) is equal to hydraulic retention time (HRT).

Loading rate

Loading rate is defined as the amount of raw material fed to the digester per day per unit volume. If the reactor is overloaded, acid accumulation will be more obviously affecting daily gas production. On the other hand, under loading of digester have negative impact in designed gas production.

Toxicity:

Though small quantities of mineral ions like sodium, potassium stimulates the growth of bacteria, the high concentration of heavy metals and detergents have negative impact in gas production rate. Detergents like soap, antibiotics, and organic solvents are toxic to the growth of microbes inside the digester. Addition of these substances along with the feed stock should be avoided.

pH or hydrogen ion concentration

To maintain a constant supply of gas, it is necessary to maintain a suitable pH range in the digester. pH of the slurry changes at various stages of the digestion. In the initial acid formation stage in the fermentation process, the pH is around 6 or less and much of CO_2 is given off. In the letter 2-3 weeks times, the pH increase as the volatile acid and N_2 compounds are digested and CH_4 is produced. The digester is usually buffered if the pH is maintained between 6.5 and 7.5. In this pH range, the micro – organisms will be very active and digestion will be very efficient. If the pH range is between 4 and 6 it is called acidic. If it is between 9 and 10 it is called alkaline. Both these are detrimental to the methanogenic (Methane production) organisms.

Total solid content

The raw cow dung contains 80-82% of moisture. The balance 18-20% is termed as total solids. The cow dung is mixed usually in the proportion of 1:1 in order to bring the total solid content to 8-10%. This adjustment of total solid content helps in digesting the materials at the faster rate and also in deciding the mixing of the various crop residues as feed stocks in biogas digester.

Feed rate

One of the prerequisites of good digestion is the uniform feeding of the digester so that the micro – organisms are kept in relatively constant organic solids concentration at all times. Therefore the digester must be fed at the same time every day with a balanced feed on the same quality and quantity.

Diameter to depth ratio

Studies reveal that 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. One reason may be that because in a simple unstirred single stage digester the temperature varies at different depths. The most activity digesting sludge is in the lower half of the digester and this is less affected by changes in night and day temperature.

Nutrients

The major nutrients required by the digester are, C, H_2, O_2 N_2 P and S, of these nutrients N_2 and P are always in short supply and therefore to maintain proper balance of nutrients and extra raw material rich in phosphorus (night soil, chopped leguminous plants) should be added along with the cow dung to obtain maximum production of gas.

Degree of mixing

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. It is found that slight mixing improves the fermentation; however a violent slurry agitation retards the digestion.

Type of feed stocks

All plant and animal wastes may be used as the feed materials for a digester. When feed stock is woody or contains more of lignin, then digestion becomes difficult. To obtain as efficient digestion, these feed stocks are combined in proportions, Pre-digestion and finely chopping will be helpful in the case of some materials. Animal wastes are pre-digested. Plant wastes do not need pre-digestion. Excessive plant material may choke the digester.

Lecture -4

Types of biogas plants:

Biogas plants basically are two types

1. Floating dome type
   Eg. KVIC-type (KVIC- Khadi Village Industries Commission)
2. Fixed dome type
   E.g. Deenabandu model

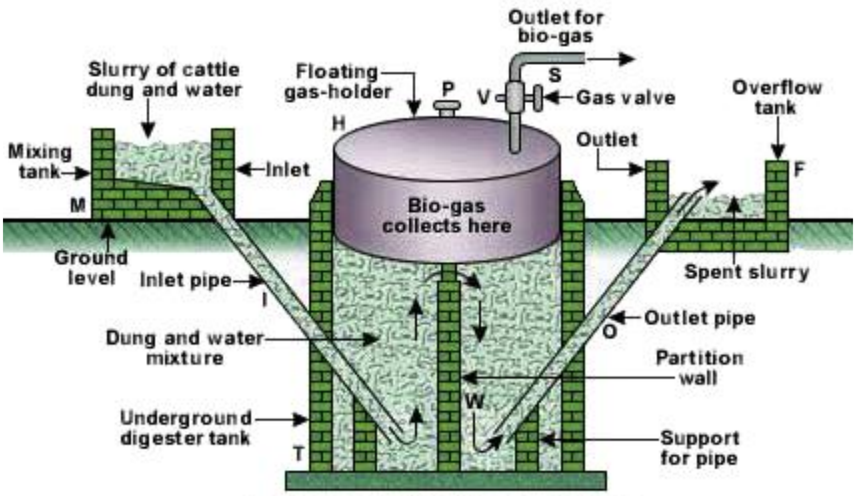
Base Pre-requisites of Biogas Plant Installation:

- The land should be leveled and at a higher elevation than the surroundings to avoid runoff water and soil should not be too loose of the area.
- The plant should be nearer to the place of gas use and to the cattle shed/ stable for easy handling of raw materials.
- The ground water table should not be very high.
- Adequate supply of water should be there at the plant site.
- The plant should get clear sunshine during most part of the day and the plant site should be well ventilated as methane mixed with oxygen is very explosive.
- A minimum distance of 1.5m should be kept between the plant and any wall or foundation or any source of drinking water purpose.
- It should be away from any tree to make it free from failure due to root interference.
- There should be adequate space for construction of slurry pits.
- Mechanical agitation of the scum layer and slight stirring of slurry improves gas production.
- The solid content in the slurry should be maintained between 7.5 to 10 per cent for optimum gas production.
- A carbon to nitrogen ratio of 20: 1 to 30: 1 is found to be optimum for bio-gas production. The CN ratio of cattle dung if approximate 25:1.

KVIC type biogas plant

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

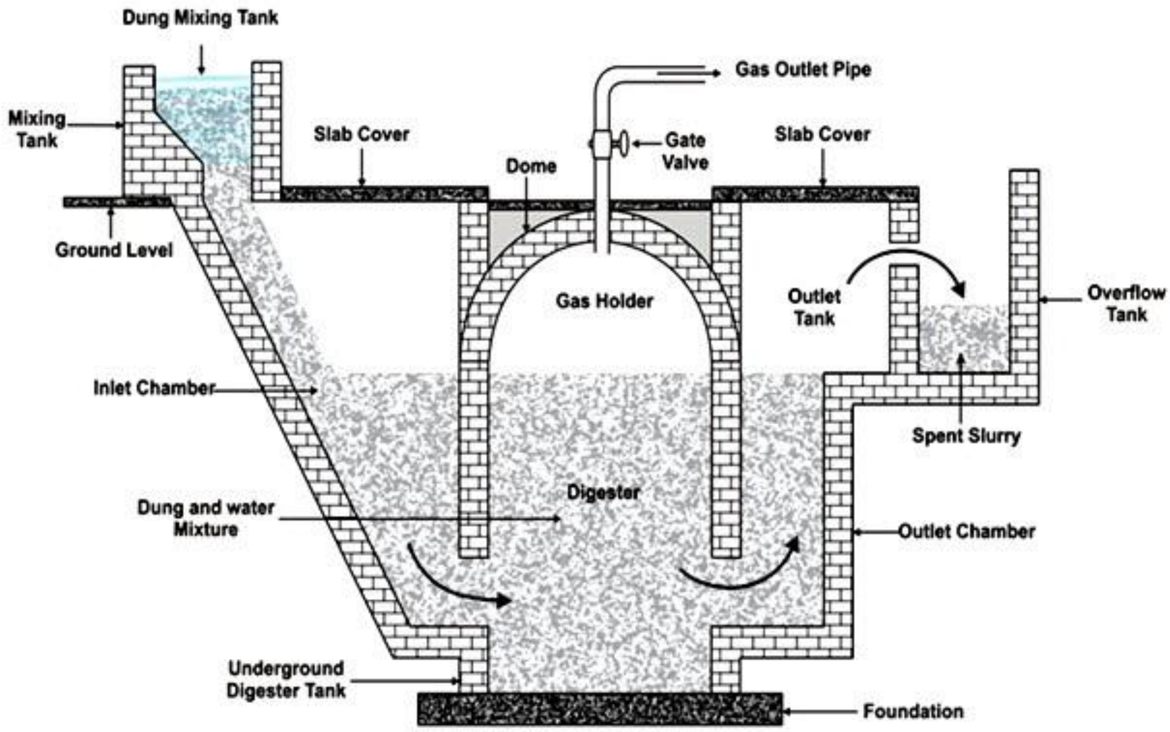
Gas holder: The gas holder is a dum constructed of mild steel sheets. This is cylindrical in shape with concave. The top is supported radically with angular iron. The holder fits into the digester like a stopper. It sinks into the slurry due to its own weight and rests upon the ring constructed for this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



Floating gas-holder type bio-gas plant.

Janata type biogas plant:

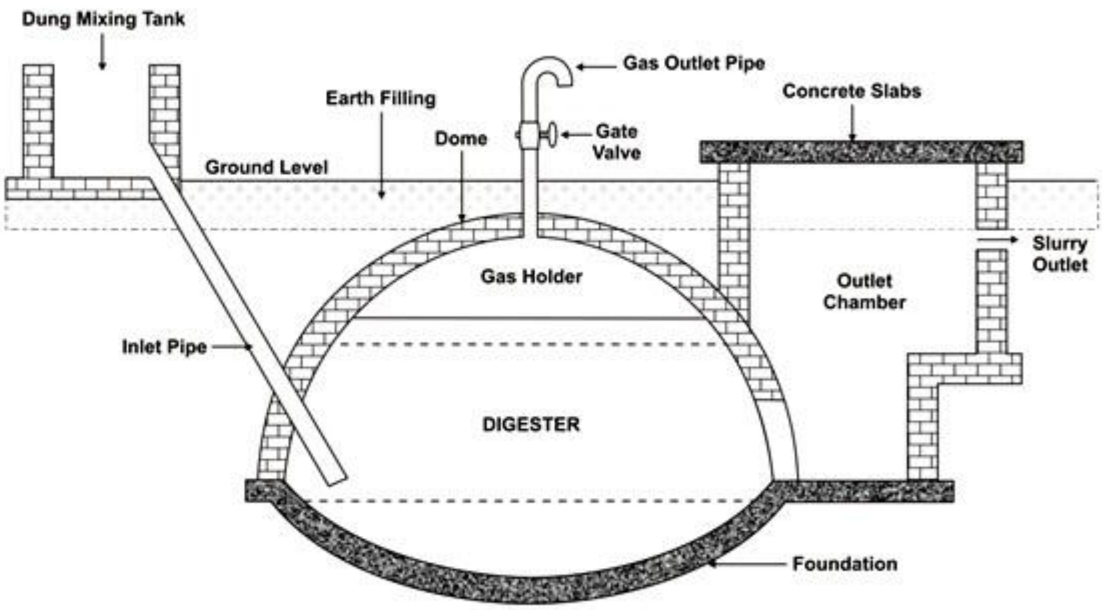
The design of this plant is of Chinese origin but it has been introduced under the name "Janata biogas plant" by Gobar Gas Research Station, Ajitmal in view of its reduced cost. This is a plant where no steel is used, there is no moving part n it and maintenance cost is low. The plant can be constructed by village mason taking some pre-explained precautions and using all the indigenously available building materials. Good quality of bricks and cement should be used to avoid the afterward structural problems like cracking of the dome and leakage of gas. This model have a higher capacity when compared with KVIC model, hence it can be used as a community biogas plant. This design has longer life than KVIC models. Substrates other than cattle dung such as municipal waste and plant residues can also be used in janata type plants. The plant consists of an underground well sort of digester made of bricks and cement having a dome shaped roof which remains below the ground level is shown in figure. At almost middle of the digester, there are two rectangular openings facing each other and coming up to a little above the ground level, act as an inlet and outlet of the plant. Dome shaped roof is fitted with a pipe at its top which is the gas outlet of the plant. The principle of gas production is same as that of KVIC model. The biogas is collected in the restricted space of the fixed dome; hence the pressure of gas is much higher, which is around 90cm of water column.



Janta model biogas plant

Deenbandhu biogas plant:

Deenbandhu model was developed in 1984, by Action for Food Production (AFPRO), a voluntary organization based in New Delhi. Schematic diagram of a Deenbandhu biogas plant entire biogas programme of India as it reduced the cost of the plant half of that of KVIC model and brought biogas technology within the reach of even the poorer sections of the population. The cost reduction has been achieved by minimizing the surface area through joining the segments of two spheres of different diameters at their bases. The Deenbandu biogas plant has a hemispherical fixed-dome type of gas holder, unlike the floating dome of the KVIC-design is shown. The dome is made from pre-fabricated ferrocement or reinforced concerete and attached to the digester, which has a curved bottom. The slurry is fed from a mixing tank through an inlet pipe connected to the digester. After fermentation, the biogas collects in the space under the dome. It is taken out for use through a pipe connected to the top of the dome, while the sludge, which is a by-product, comes out through an opening in the side of the digester. About 90 precent of the biogas plants in India are of the Deenbandhu type.



Deenbandhu model biogas plant

Comparison of floating and fixed gas holder type plants:

Floating gas holder type biogas plant		**fixed gas holder type plants**	
1	Initial cost of plant is high.	1	Initial cost, of plant is low
2	Floating gas holder is made up iron plate and has tendency of rusting and corrosion	2	No such problems of rusting and corrosion as there is no floating gas holder.
3	Maintenance expenditures are high.	3	Maintenance expenditures are low.
4	Life of plant is lower due to floating lias holder which may last, few years.	4	Life of plant is higher.
5	Plant, is not underground due floating gas holder hence land occupied by plant cannot be used for any other purposes.	5	Plant is under ground the upper land can be used for other purposes.
6	Its performance is very much affected by temperature variations.	6	Its performance is not much affected by temperature variations.
7	Other forms of biomass cannot be used except gobar and human excretes	7	Other forms biomass such as agro waste and municipal wastes can be used with some

			modifications.
8	Pressure of gas remains constant	8	Pressure of gas increases with increased gas production decrease with gas consumption.
9	Gas holder lank is needed to be fabricated in workshop and transported to the site	9	Separate gas holder is not required.
10	Fault finding and repairs are easy	10	Fault finding and repairs arc not easy
11	Higher depth of plant requires deeper excavation of land.	11	Lower depth of excavation reduces the cost of construction.

Gas consumption

Gas is used as cooking fuel but it is not yet used in lighting or power generation purposes in the developing country. Hence the size of biogas plant is decided on the basis number of persons in the family, types of food habit, types of utensils used in cooking etc. Daily need of gas per person varies from 0.28 to 0.42 cubic meter.

Following table shows the gas requirements for different applications.

Sr.	Applications	Requirement	Gas consumption in m^3/hr
1	Cooking	One person per day	0.24
2	Gas lighting	40 candle power	0.07
3	Mental lamp	100 candle power	0.13
4	Gas engine	Per one HP	0.45
5	Petrol engine	Per one liter petrol	1.4
6	Diesel engine	Per one liter diesel	1.6
7	Electric appliances	Per kwh or unit of electricity	0.60

Advantages and disadvantages of biogas:

Advantages:

1. Cost of equipments used for making biogas is less and equipments used are very simple.
2. Waste product obtained from digester is best quality of fertilizer and gives best yields.
3. Biogas can be used for lighting, running the engines, farms machines and cooking gas in the kitchen.
4. Distribution of gas has no problems of any gas leakages and fire.
5. Biogas is a best medium for cooking food.

6. Organic feed stocks used in the plants are easily available at all places..
7 Biogas plant gives efficiency as much as 60.

Disadvantages:

1 Biogas produced from biogas plant has to be used at nearby places only. It cannot be transported over long distances.
2 Biogas cannot be filled in the bottles.
3 Biogas plants require more area.
4 It cannot be established in urban area where availability of land is limited.

Gas production in different feed stocks

Different types of feed stocks give different rate of gas production. The size of digester can be determined by the types of biomass feed stocks. Following table shows rate of gas production from varieties of feed stocks:

Sr. No	**Type of biomass**	**Nos of catties**	**Gas produced per kg of biomass in m³**	**Daily gas availability in m³**
1	Cow dung	10	0.36	0.36
2	Buffalo dung	10	0.36	0.36
3	Morse dung	15	0.36	0.54
4	Pig dung	02	0.078	0.18
5	Chicken droppings	018	0.062	0.011
6	Human excrete	0.40	0.072	0.028

Plant size, feed stock, and gas consumption in cooking:

Sr.	**Plant size in m³**	**Daily biomass in kg**	**No. of cattle**	**No Cross breed cattle**	**Cooking needs in no. of persons**
1	1	25	2	1	Up to 4
2	2	50	4	2	48
3	3	75	6	3	8 12
4	4	100	8	4	12 16
5	6	150	12	6	20 24
6	8	200	16	8	30 34
7	10	250	20	10	40 45
8	15	375	30	15	50 55
9	20	500	40	20	80 85

Lecture -5

Design of digester

The energy available from a biogas digester is given by

$$E = \eta H_b V_b$$

Where, η is the combustion efficiency of burner, boiler etc. (~60 %) H_b the heat of combustion per unit volume of biogas and V_b the volume of biogas.

$$E = \eta H_m f_m V_b$$

Where, Hm is the heat of combustion of methane and fm the fraction of methane in the biogas

The volume of biogas is given by

$$V_b = CM_0$$

Where, C is the biogas yield per unit dry mass of whole input dry mass of whole input and M_0 is the mas of dry input.

The volume of fluid in the digester is given by

$$V_f = \frac{M_0}{\rho_m}$$

Where, ρ_m is the density of dry matter in the fluid

The volume of the digester is given by

$$V_d = V_f t_r$$

V_f is the flow rate of the digester fluid (water) and t_r is the retention time in the digester.

Exampal:1. Design an appropriate size of biogas plant for a family of 8 members owing two bullocks, one buffalo and 2 calves. The gas is required for cooking food and lighting one lamp of 100 candle power for 2h daily (As same density of slurry (p) = 1090 kg/m³)

Solution: Bullock dung = 2 x 15 = 30 kg

Buffalo dung = 1 x 15 = 15 kg

Calves dung = 5 x 2 = 10 kg

Total dung = 55 kg

We know that

1 kg dung produces 0.036 m^3 gas

Total gas produced = 55 x 0.036 m^3/day

=1.98 m^3/day

1 day cooking required 0.24 m^3/person

Gas required for cooking = 0.24 x 8

= 1.92 m^3/person per hour

For lighting purpose = 0.13 m^3/hour

For 2 hours = 0.13 x 2

= 0.26 m^3/person

Total gas required = 1.92 + 0.26

= 2.18 m^3/daily use

Density of slurry = 10.99 kg/m^3

Wt of total charge = 55 + 55 = 110 kg/day

Volume of charge = 110/1090 = 0.1009 m^3

Digester volume = volume of daily charge x Re

= 0.1109 x 30 days

= 3.027 m^3

10 % extra is taken for digester volume

= 1.1 x 3.027

Digester volume = 3.33 m^3

$\pi/4 \times D^2 \times h = 3.33\ m^3$

Where d = diameter of digester

h = height of digester, D = 0.6 h

Or $\pi/4 \times (0.6h)^2 \times h = 3.33$

$h^3 = 3.33 \times \pi/4 \times 1/(0.6)^2$

$h^3 = 11.78\ m^3$

h = 2.275

And D = 0.6 x 2.275 = 0.6 x 2.275. = 1.365

Example:2. Calculate the theoretical power available of an ORP – 12 PV 500 wind mill at 12 mph wind speed

Power = ½ ρ V^3 A

Where, P = power of the wind mill watts

ρ = Air density 1.2 kg/m^3 at sea level

V = Wind velocity m/s

A = Frontal area of wind mill m^2 Rotor diameter = 5m

V = 12 x 1000/ 60 x 60 = 10/3 = 3.3 m/s

$P = ½ \times 1.2 \times (10/3)^3 \times (\pi/4) \times 5^2$

= 430 Watts

Example:3 Calculate the power of above wind mill at 24 km/h speed

Solution: We know that $P \propto V^3$

P_1 = 430 watts V_1 = 12 km/h

P_2 = ? V_2 = 24 km/h

$P_2 = P_1 (V_1/V_2)^3$

$= 430 (24/12)^3$

= 430 x 8

= 3440 watts

= 3.44 KW

Example:3 Calculate the power generation of a standalone wind energy generator of 50 m diameter at 40 km/h speed. The overall conversion efficiency of the machine is 40 % (percent)

$P = \frac{1}{2} \rho n V^3 A$ Watts

$V = 40 \times 1000/ 60 \times 60$

$= 109/9$ m/s

$A = \pi/4 D^2$

$= 3.14/4 \times 50 \times 50$

$= 1962 m^2$

Calculation of size of biogas plant:

Example: A farmer family has 7 members and 2 cows, 2 baby cows an d 1 buffalo. Calculate the size of biogas for this family.

- 1 cow gives 10 kg gobar and 0.36 m^3 gas
- 1 baby cow gives 5 kg gobar and 0.27 m^3 gas
- 1 buffalo gives 15 kg gobar and 0.54 m^3 gas

(1) Availability of biomass:

On the basis of we can calculate the daily biomass availability and essential gas production

2 cows give	20 kg gobar	0.72 m^3 gas
2 baby cows give	10 kg gobar	0.72 m^3 gas
1 buffalo give	10 kg gobar	0.54 m^3 gas

Total availability of gas 1.58 m^3 gas

(2) Gas consumption for the family:

6 members of the family shall consume	1.44 m^3 gas
100 candle lamp for 3 hours shall need	0.26 m^3 gas
Totally daily gas required	1.70 m^3 gas

Availability of gas on biomass availability is 1.58 m^3 gas while requirement of gas is 1.70 m^3 gas daily. Hence it is necessary to set up biogas plant of daily production capacity 2.00 m^3 gas to suffice the family need for energy. Of course family shall need to obtain additional biomass to run the plant at full capacity and to satisfy entire needs.

On the basis of gas consumption

Gas is used as cooking fuel but it is not yet used in lighting or power generation purposes in the developing country. Hence the size of biogas plant is decided on the basis number of persons in the family, types of food habit, types of utensils used cooking etc. Daily need of gas per person varies from 0.28 to 0.42 cubic meters. Following table shows the gas requirements for different applications.

Sr.	**Applications**	**Requirements**	**Gas consumption in m^3/hr**
1	Cooking	One person per day	0.24
2	Gas lighting	40 candle power	0.07

3	Mental lamp	100 candle power	0.13
4	Gas engine	Per one HP	0.45
5	Petrol engine	Per one liter petrol	1.4
6	Diesel engine	Per one liter diesel	1.6
7	Electric appliances	Per kwh or unit of electricity	0.60

On the basis of type of biomass:

Different types of feed stocks give different rate of gas production. The size digester can be determined by the types of biomass feed stocks. Following table shows rate of gas production from varieties of feed stocks.

Sr.	Type of biomass	Normal manual Kg/day	Gas produced per kg of biomass in m³/kg	Daily gas availability in m³
1	Cow dung	10	0.036	0.36
2	Buffalo dung	15	0.036	0.36
3	Pig dung	02	0.078	0.18
4	Chicken droppings	0.18	0.062	0.011
5	Human excrete	0.40	0.072	0.028

Example: Calculate (i) the volume of a biogas digester suitable for the output of six cows and (ii) the power available from the digester. The retention time is 14 days, temperature, 30°C; dry matter consumed 2.5 kg/day biogas yield, 0.24 m^3/kg, burner efficiency, 0.6; methane proportion 0.7; density of dry matter, 50 kg/m^3.

Solution: The mas of dry input (M_o) = 2.5 ×6 =15 kg/day

Fluid volume

$$V_f = \frac{M_0}{\rho_m}$$

ρ_m is the density of dry matter in the fluid

$$= \frac{15}{50} = 0.3\ m^3/day$$

The volume of the digester is given by

$$V_d = V_f t_r$$

V_f is the flow rate of the digester fluid (water) and t_r is the retention time in the digester.

$$= 0.3 \times 14 = 4.2\ m^3$$

The volume of biogas is given by

$$V_b = CM_0$$

Where, C is the biogas yield per unit dry mass of whole input dry mass of whole input and M_0 is the mas of dry input.

$$=0.24\times15=3.6$$

Energy available from a biogas digester

$$E = \eta H_m f_m V_b$$

Where, H_m is the heat of combustion of methane and f_m the fraction of methane in the biogas

$$E= 0.6\times28\times0.7\times3.6= 42.336 \text{ MJ/day}= 11.76 \text{kWh/day}$$

Lacture-6

Bio fuels

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

Advantages of biodiesel

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

Production methods:

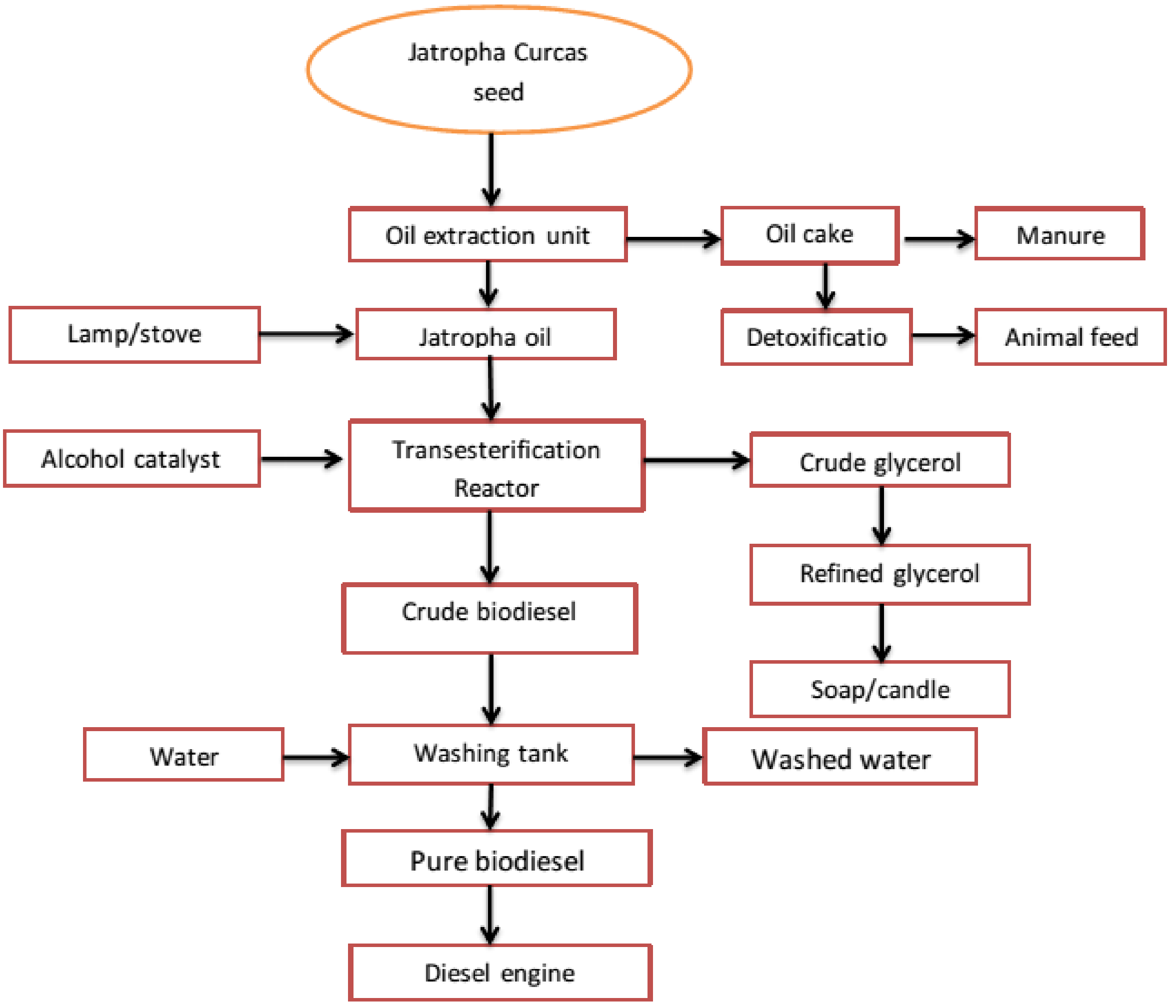
1. Preparation: care must be taken to monitor the amount of water and free fatty acids in the incoming biolipid (oil or fat). If the free fatty acid level or water level is too high it may cause problems with soap formation and the separation of the glycerin by-product downstream.
2. Catalyst is dissolved in the alcohol using a standard agitator or mixer.
3. The alcohol/catalyst mix is then charged into a closed reaction vessel and the biolipid (vegetable or animal oil or fat) is added. The system from here on is totally closed to the atmosphere to prevent the loss of alcohol.
4. The reaction mix is kept just above the boiling point of the alcohol (around 70 °C) to speed up the reaction. Some systems recommend the reaction take place anywhere from room temperature to 55 °C for safety reasons. Recommended reaction time varies from 1 to 8 hours; under normal conditions the reaction rate will double with every 10

°C increase in reaction temperature. Excess alcohol is normally used to ensure total conversion of the fat or oil to its esters.

5. The glycerin phase is much denser than biodiesel phase and the two can be gravity separated with glycerin simply drawn off the bottom of the settling vessel. In some cases, a centrifuge is used to separate the two materials faster.
6. Once the glycerin and biodiesel phases have been separated, the excess alcohol in each phase is removed with a flash evaporation process or by distillation. Care must be taken to ensure no water accumulates in the recovered alcohol stream.
7. The by-product (i.e., glycerin) contains unused catalyst and soaps, which are neutralized with an acid and sent to storage as crude glycerin.
8. Once separated from the glycerin, the biodiesel is sometimes purified by washing gently with warm water to remove residual catalyst or soaps, dried, and sent to storage.
9. Reduce expenditure on oil imports
10. Nontoxic, biodegradable and safety to handle

Biodiesel production

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



Ethanol from agricultural produce (Sugar cane and corn)

Non-petroleum fuels liquid fuels find use when petroleum fuels are scarce or costly. The scientists have been in search of new fuels to replace conventional fuels that are used in IC engines. Among all the fuels, alcohols, which can be produced from sugarcane waste and many other agricultural products, are considered the most promising fuels for the future. There are two types of alcohols: methanol (CH_3OH) and ethanol (C_2H_5OH). Ethanol has attracted a lot of attention as a transport fuel because it is relatively cheap non- petroleum-based fuel. Also, the emissions from the combustion of ethanol are much less than for fossile fuels. Ethanol, being a pure compound, has a fixed set of physical as well as chemical properties. This is in contrast to petrol and diesel, which are mixtures of hydrocarbons. But in countries like India, ethanol is a strong candidate since they posses the agricultural resources for it production. It is a more attractive fuel for India because the productive capacity from sugarcane crops is high, of the order of 1345 l/ha. Earlier, this fuel was not used in automobiles due to low energy density, high production cost and corrosion. The current shortage of gasoline has made it necessary to substitute ethanol as fuel in SI engines. At present, Brazil is the only country that produces fuel alcohol on a large scale from agricultural products (mainly sugarcane). Brazil was the first and biggest producer of cheapest bio-ethanol in the world. Second cheapest bio-ethanol is made from corn in the USA. Properties of ethanol and methanol are similar, with difference of only 5 -10%. Ethanol is superior to methanol as it has wider ignition limit (3.5 -17) than methanol (2.15 -12.8). Ethanol calorific value (26,880 kJ/kg) is considerably higher than methanol (19,740 kJ/kg). Ethanol is a much more superior fuel for diesel engines as its cetane number is compared to the cetane number of 3 for methanol. Ethanol is used in racing cars due to its very high heat of vaporization.

Manufacture of ethanol

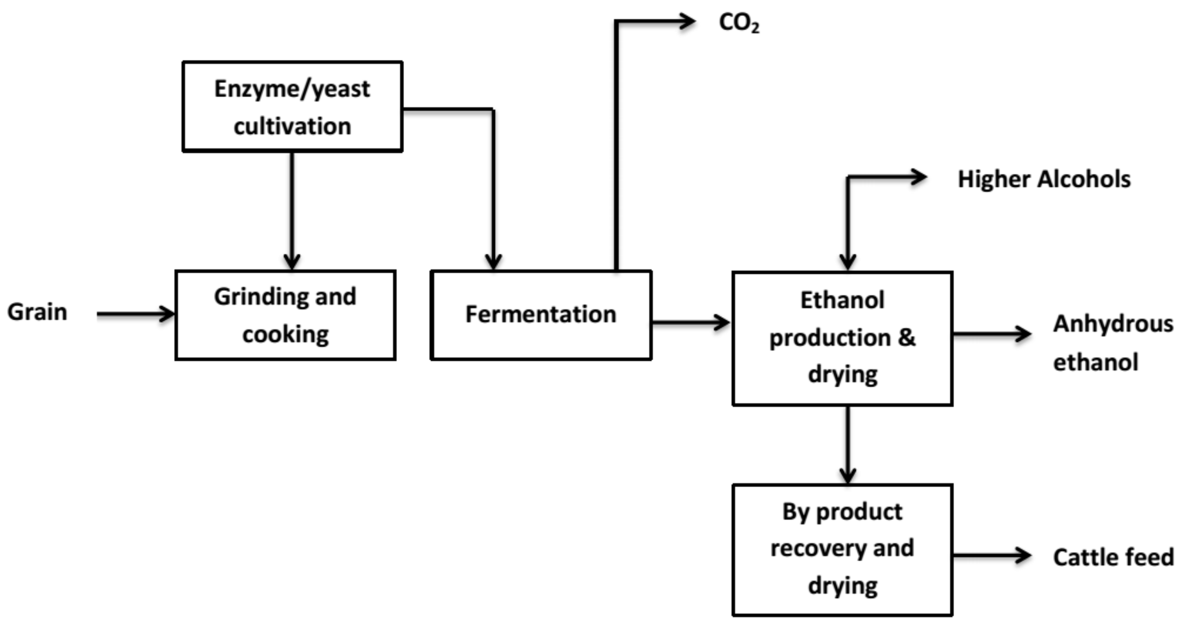
Three different feed stocks are available for ethanol production such as, sugar feed stock i.e., sugarcane and sugar beet; starch feed stock i.e., cereal grains and potato and cellulose feed stock i.e., forest products and agricultural residues.

Ethanol from starchy feed stock (grains

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

a) Milling of grains
b) Hydrolysis of starch to sugar units
c) Fermentation by yeas
d) Distillation
e) Removal of water from ethanol

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

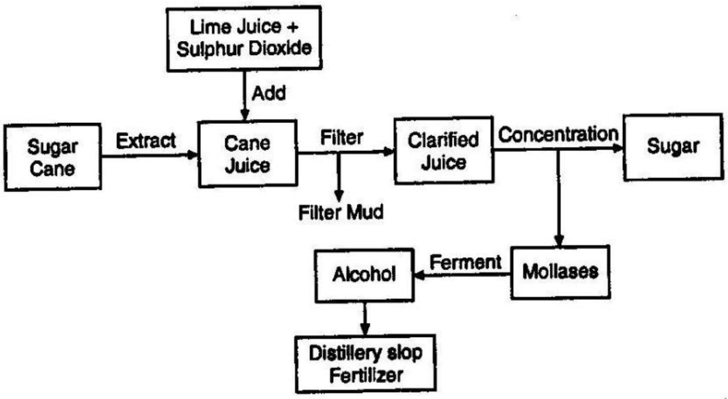


Process flow chart for the production of ethanol from corn

Ethanol production from sugar cane:

Ethanol production from sugarcane is one of the easiest and most efficient processes since sugarcane contains about 15% sucrose. The glycosidic bond in the disaccharide can be broken down into two sugar units, which are free and readily available for fermentation.

The cane is cut and the juice is extracted by maceration. After clarification, the juice is concentrated by boiling. The concentrated juice is fermented with yeast to produce raw ethanol. A series of distillation steps including a final extractive distillation with benzene are used to obtain anhydrous ethanol. The normal yield of ethanol is about 8.73 litres of alcohol per tonne of cane. The potential of ethanol production in India is about 475 litres per year. The process flow chart for production of ethanol from sugarcane is shown in fig.


Lime Juice +
Sulphur Dioxide
Add
Sugar Cane
Extract
Cane Juice
Filter
Filter Mud
Clarified Juice
Concentration
Sugar
Mollases
Ferment
Alcohol
Distillery slop Fertilizer

Lacture-7

Biomass Briquetting – A Value Adding Technology for Agro Residues

Biomass plays a major part in fulfilling the energy needs of the developing countries. According to the world's energy topics, it is widely accepted that fossil fuel shortage, fuel increasing price, global warming including other environmental problems are critical issues. Therefore, biomass energy has been attracting attention as an energy source since zero net carbon dioxide accumulation in the atmosphere from biomass production and utilization can be achieved. The carbon dioxide released during combustion process is compensated by the carbon dioxide consumption in photosynthesis. Among several kinds of biomass, agro residues have become one of most promising choices. They are available as a free or almost free, indigenous and abundant energy source. But it is generally difficult to handle them because of its bulky nature, low combustion characteristics and copious liberation of smoke. The direct burning of these agro residues in domestic and industrial applications is inefficient and associated with wide scale air pollution. In order to achieve more efficient usage of agro residues, it is essential to densify them to compact pieces of definite shape and high thermal value. Briquetting is one of the several compaction technologies in the category of densification. The process of briquetting consists of applying pressure to a mass of particles with or without a binder and converting it into a compact product of high bulk density, low moisture content, uniform size and shape and good burning characteristics. Briquettes can be produced with the density of 1.2 to 1.4 g/cm3 from loose agro residues with a bulk density of 0.1 to 0.2 g/cm3.

Raw materials for briquetting

Almost all agro residues can be briquetted. Agro residues such as saw dust, rice husk, tapioca waste, groundnut shell, cotton stalks, pigeon pea stalks, soybean stalks, coir pith, mustard stalks, sugar cane bagasse, wood chips, tamarind pod, castor husk, coffee husk, dried tapioca stick, coconut shell powder are the commonly used raw materials for briquetting in India. All these residues can be briquetted individually and in combination with or without using binders. The factors that mainly influence on the selection of raw materials are moisture content, ash content, flow characteristics, flow characteristics, particle size and availability in the locality. Moisture content in the range of 10-15% is preferred because high moisture content will pose problems in grinding and more energy is required for drying. The ash content of biomass affects its slagging behaviour together with the operating conditions and mineral composition of ash. Biomass feedstock having up to 4% of ash content is preferred for briquetting. The granular homogeneous materials which can flow easily in conveyers, bunkers and storage silos are suitable for briquetting.

Briquetting Process

The series of steps involved in the briquetting process are

1. Collection of raw materials
2. Preparation of raw materials
3. Compaction
4. Cooling and Storage.

Collection of raw materials

In general, any material that will burn, but is not in a convenient shape, size or form to be readily usable as fuel is a good candidate for briquetting.

Preparation of raw materials

The preparation of raw materials includes drying, size reduction, mixing of raw materials in correct proportion, mixing of raw materials with binder etc.

Drying

The raw materials are available in higher moisture contents than what required for briquetting. Drying can be done in open air (sun), in solar driers, with a heater or with hot air.


Size reduction

The raw material is first reduced in size by shredding, chopping, crushing, breaking, rolling, hammering, milling, grinding, cutting etc. until it reaches a suitably small and uniform size (1to10 mm). For some materials which are available in the size range of 1 to 10 mm need not be size reduced. Since thesize reduction process consumes a good deal of energy, this should be as short as possible.

Shredding machine

Raw material mixing

It is desirable to make briquettes of more than one raw material. Mixing will be done in proper proportion in such a way that the product should have good compaction and high calorific value.

Compaction

Compaction process takes place inside the briquetting machine. The process depends on the briquetting technology adopted.

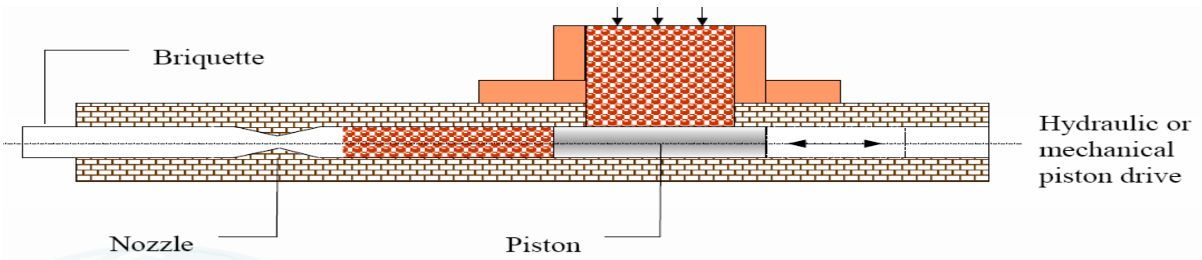
Briquetting Technologies

Briquetting technologies used in the briquetting of the agro residues are divided into three categories. They are (i) high pressure or high compaction technology, (ii) Medium pressure technology and (iii) low pressure technology. In high pressure briquetting machines, the pressure reaches the value of 100 MPa. This type is suitable for the residues of high lignin content. At this high pressure the temperature rises to about 200 – 250 °C, which is sufficient to fuse the lignin content of the residue, which acts as a binder and so, no need of any additional binding material. In medium pressure type of machines, the pressure developed will be in the range of 5 MPa and 100MPa which results in lower heat generation. This type of machines requires additional heating to melt the lignin content of the agro residues which eliminates the use of an additional binder material. The third type of machine called the low pressure machines works at a pressure less than 5 MPa and room temperature. This type of machines requires addition of binding materials. This type of machines is applicable for the carbonized materials due to the lack of the lignin material.

The high pressure compaction technology for briquetting of agro residues can be differentiated in to two types (i) hydraulic piston press type and (ii) screw press type. Among these two technologies hydraulic piston press type was predominantly used to produce briquettes in India, particularly in Tamil Nadu all the briquette producing firms' uses hydraulic piston press technology for briquetting. Mostly cylindrical shaped briquettes with 30 mm to 90 mm diameter were produced. All the commercial firms involved in briquette making produces 60 mm and 90 mm diameter briquettes.

A scheme of a hydraulic piston press briquetting technology

Feedstock



Cooling and Storage of briquettes

Briquettes extruding out of the machines are hot with temperatures exceeding 100oC. They have to be cooled and stored in dry place.

Uses for Briquettes

The most frequent applications for this type of fuel are of both a domestic and industrial nature; from fireplaces or stoves to boilers generating hot water and steam. Tea industries, wine distilleries, textile industries, and farms are the major sectors using briquettes. Briquettes are also used in gasification process for electricity production.

Advantages of agro residual briquettes:

- The process increase the net calorific value of material per unit volume
- End product is easy to transport and store
- The fuel produced is uniform in size and quality
- Helps solve the problem of residue disposal
- Helps to reduce deforestation by providing a substitute for fuel wood.
- The process reduce/eliminates the possibility of spontaneous combustion waste
- The process reduces biodegradation of residues

Necessary requirements to start a briquette production unit

1. Land requirement: Land area of minimum 1 acre is required for starting a briquette production unit to store the raw materials for briquetting and produced briquettes.

2. Raw materials: Continuous availability of raw materials is a major factor for profitable briquette production.

3. Drying facility to dry raw materials: The raw materials which are commonly available are with higher moisture content. So, any of the drying technologies such as solar driers/ heater/ hot air generator system is required to bring down the moisture content to an desirable level for briquetting.

4. Shredding machine: A shredding machine with minimum of 5 hp motor is required to powder the agro residues for briquetting.

5. Briquetting machine: A high pressure hydraulic piston press type briquetting machine powered by minimum of 50 hp motor is required to produce binderless briquettes from agro residues.

Lacture-8

SOLAR ENERGY

Sun is the largest source of energy. Energy radiated from the sun is electromagnetic waves reaching the plant earth in three separated region,

1. Ultraviolet - 6.4 % ($\lambda<0.38\mu m$)
2. Visible -48 % ($0.38\ \mu m <\lambda<0.78\mu m$)
3. Infrared -15.6 % ($\lambda>0.78\mu m$

When solar radiation (solar energy) is absorbed by a body it increases its energy. It provides the energy needed to sustain life in the solar system. It is a clean inexhaustible, abundantly and universally available energy and is the ultimate source of other various sources of energy.

The heat generation is mainly due to various kinds of fusion reactions , the most of energy is released in which hydrogen combine to helium.

$4(1H^1) \rightarrow 2He^4 + 26.3$ MeV

An effective black body temperature of sun is 5777K

Use of direct solar energy

- Solar thermal power plant
- Photolysis systems for fuel production
- Solar collector for water heating
- Passive solar heating system
- Photovoltaic, solar cell for electricity generation.

Use of indirect solar energy

- Evaporation, precipitation, water flow
- Melting of snow
- Wave movements
- Ocean current
- Biomass production
- Heating of earth surface
- Wind

Solar Constant*:* The rate at which solar energy arrives at the top of the atmosphere is called solar constant I_{sc}

Standard value of 1353 W/m² was adopted in 1953, but 1367 W/m², adopted by the world radiation center is known commonly used.

Extra-terrestrial solar radiation:

Solar radiation received on outer atmosphere of earth.

$$I_{ext} = I_{sc}\left[1.0 + 0.033\ \cos\left(\frac{360\ n}{365}\right)\right]$$

Where, n^{th} day of the year

Terrestrial solar radiation: The solar radiation reaches earth surface after passing through the atmosphere is known as terrestrial solar radiation or global radiation.

Direct or Beam radiation: It is the solar radiation propagating along the line joining the sum and the receiving object.

Diffuse radiation: It is the solar radiation scattered by aerosols, dust and molecules. It does have a unique direction.

Total radiation or Global radiation: The sum of beam and diffuse radiation is referred as total radiation.

Irradiance: the rate at which radiant energy is incident per unit area of the surface. The unit of Irradiance is W/m^2. It is used for beam and diffused radiation.

Radiant exposure (irradiation): the incident energy per unit area on a surface is found by integration of irradiance over a specified time usually an hour or a day. Its unit is J/m^2.

Radiant existence (Radiosity): The rate at which radiant energy (W/m^2) leaves a surface per unit area, by the combination of emission reflection and transmission.

Emissive power: The rate at which radiant energy (W/m^2) leaves a surface per unit area, by emission only.

Albedo: The energy reflected back to the space by reflection from clouds, scattered by the atmospheric gases and dust particles and by reflection from earth surface is called albedo of earth atmospheric system. 30 % of the incoming solar radiation back to extraterrestrial region through atmosphere from earth

Solar time

Zenith: the point directly over head is called zenith.

Air mass ratio: Air mass is defined as the ratio of the path length of radiation through the atmosphere, considering the vertical path at sea level as unity.

$$Air\ mass(m) = \frac{Path\ length\ traversed\ by\ beam\ radiation}{Vertical\ path\ length\ of\ atmosphere}$$

$$\boldsymbol{m = \sec\theta_z}$$

$$\boldsymbol{= \mathrm{cosec}\,\alpha}$$

$$(\alpha + \theta_z = 90°)$$

where, α is inclination angle and θ_z is zenith angle

Latitude (ϕ): the latitude of a location on earth surface is angle made by the radial line joining the given location to the center of the earth with its projection on the equator plane.

Declination (δ): It may be defined as the angular distance of the sun ray from the plane of earth equator.

$$\delta = 23.45 \times \sin\left[\frac{360}{365}(284 + n)\right]$$

where, n =day of year counted from 1st of January.

Solar radiation measurement

Solar radiation measuring instruments are following type

Pyranometer: used to measure global radiation

Pyrheliometer: used to measure beam radiation

Pyranometer: It is used to measure total hemispherical radiation-beam plus diffuse on a horizontal surface. If shaded, a pyranometer measures diffuse radiation. Most of solar resource data come from pyranometers. The total irradiance (W/m^2) measured on a horizontal surface by a pyranometer is expressed as follows:

$I_{total} = I_{beam} \cos\theta + I_{diffuse}$

where, θ is the zenith angle (i.e., angle between the incident ray and the normal to the horizontal instrument plane.

Pyrheliometer: The pyrheliometer is a broadband instrument that measures the direct beam radiation. Consequently, the instrument should be permanently pointed toward the Sun. A two-axis Sun tracking mechanism is most often used for this purpose. The detector is a multi-junction thermopile placed at the bottom of a collimating tube provided with a quartz window to protect the instrument. The detector is coated with optical black. Its temperature is compensated to minimize sensitivity of ambient temperature fluctuations. The pyrheliometer aperture angle is 5°. Consequently, radiation is received from the Sun and a limited circumsolar region, but all diffuse radiation from the rest of the sky is excluded. A readout device is used to give the instant value of the direct beam irradiance. Its scale is adapted to the sensitivity of the particular instrument in order to display the value in SI units, Wm^{-2}.

Utilization of solar energy by technological processes

Heliochemical: By the process of photosynthesis, plants absorb the solar energy which maintains life the earth by productions of various types of foods. The energy is absorbed by the chemical reaction hence the process is called Heliochemical.

Helioelectrical: The solar energy is input to photovoltaic converters and power is output from it which is used for spacecraft etc.

Heliothermal: This process can be used for water heating of building etc.

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 distillations
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

Lacture-9

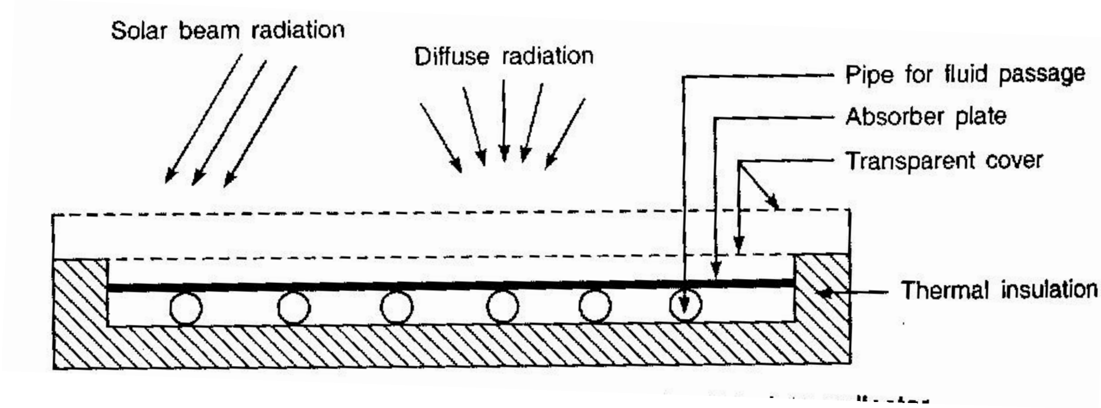
Application of solar energy

Solar Thermal Energy Collector

Solar Thermal Energy Collector: Solar thermal energy collector is equipment in which solar energy is collected by absorbing the radiation in an absorber and then transferring to a fluid. There are two type of collectors;

Flat Plate solar Collector:

This is the most common type of solar thermal collector. It is designed for operation in the low temperature range (ambient 60^{0}C) or in the medium temperature range (100 ^{0}C). It has no optical concentrator. Here the collector area and the absorber area are numerically same.



The flat plate collector consists of five major parts as given below:

A metallic flat absorber plate: It is made of copper, steel or aluminium (having high thermal conductivity) and having black surface. The thickness of the metal sheet ranges from 0.5 to 1.0 mm.

Tubes or channels: they are soldered to the absorber plate. Water flowing through these tubes takes away the heat from the absorber plate. The diameter of tubes is around 1.25 cm, while that of the header pipe which leads water in and out of the collector and distributes it to absorber tubes is 2.5 cm.

A transparent toughened glass sheet: of 5 mm thickness is provided as the cover plate. It reduces convection heat losses through a stagnant air layer between the absorber plate and the glass. Radiation loss are also reduced as the spectral transmissivity of glass is such that it transparent to short wave radiation and nearly opaque to long wave thermal radiation emitted by interior collector walls and absorbing plate.

Fiber glass insulation: Fiber glass of 2.5 to 8.0 cm thickness is provided at the bottom and on the sides in order to minimize the heat loss.

Encloses container: The commercially available collector have a face area of 2 m^2. The whole assembly is fixed on a supporting structure that is installed on a tilted position at a suitable angle facing south in northern hemisphere. For the whole year, the optimum tilt angle of collector is equal to the latitude of its location. During winter the tilt angle is kept $10\text{-}15^0$ more than the latitude of the location, while in summer it should be $10\text{-}15^0$ less than the latitude.

Working of solar flat plate collector:

The solar flat plate collector is provided with inlet through which water from the outside tank enters from downside header pipe. The water passes through the number of distributor pipe line. The water gets heated up while passing through these pipes. The heated water is collected in the upper header pipe and flows back to the side tank. IN this way water gets circulating through the collector where it absorb heat energy.

Water is circulating inside the collector due to thermosyphon effect in which heated water has tendency to move up. This is a natural circulation of water. In some collector the circulating pump is provided the pump circulates the water inside the collector system. Such type of circulation is called forced or pressurized water circulation system. It has better efficiency.

Advantages of flat plate collector:

1. They absorb heat from beam and diffused radiations.
2. They are passive heating system without any moving component.
3. They are simple in design and construction.
4. They can be easily fabricated using locally available materials.
5. Maintance is simple and without any expenders.
6. They are providing with water tank which can serve as tank to store daily requirements of water.
7. They can be easily installed unused spaces like roof top, balcony, window shades etc.

Solar flat plate collectors have following disadvantages:

1. They are bulky and difficult in transportation.
2. Their efficiency is around 60 percentage and less.
3. Pipe lines may get scale formation on inside surface. It reduces its heat transfer efficiency.
4. They cannot be used in the applications like power generation where very high temperatures are required.

Applications of flat plate collector:

The flat plate solar collectors are widely used now a days as they are gaining popularity with improved design.

1. They are used for water heating in homes, hotels, hospitals and industries etc.
2. They used for space and air heating.
3. They are used for making distilled water.
4. They are used for drying agricultural produce.
5. They are used for wood seasoning.

Concentrating Type solar Collector:

Here the receiving area of solar radiation is several times greater than the absorber area and the efficiency is high. Mirrors and lenses are used to concentrate sun rays on the absorber. The temperature of working fluid can be raised only up to 500 ^{0}C. For better performance, the collector is mounted on a tracking equipment to always face the sun with its changing position.

Advantages:

1. Reflecting surfaces required material and are structurally simpler than flat plate collectors.
2. The absorber area of a concentrator system is smaller than other.
3. Due to less area of heat loss and better insolation intensity.
4. Concentrating type collectors can be used for electric power generation.
5. Heat storage cost less.
6. Higher efficiency.
7. No-anti freeze required to protect the absorber.

Disadvantage:

1. Non-uniform flux on the absorber
2. High initial cost
3. Additional optical losses such as reflectance loss and the intercept loss
4. Out of the beam and diffuse solar radiation components, only beam component is collected in case of focusing collectors because diffuse components cannot be reflected and thus lost.

Solar cooking:

Solar cooker is a device in which food is cooked by the heat received from solar radiations.

Varieties of solar cookers have been designed using different materials and they are used by the people all over the world. Some of the types are given below.

Box type solar cooker:

This is simple flat plate solar cooker in the shape of box or suit case which can move anywhere we like to use. It is made up of double wall wooden or aluminum sheet metal box with operable glass lid. In between the wall, insulating materials like thermocol or glass wool is filled up. Inside surface of solar cooker is painted with non-shining black paint so that it can efficiently absorb the heat from solar radiations. There are following components of the box type solar cooker:

Outer box : It is made up from sheet metal and painted with black color which work as absorber plate to receive heat energy.

Inner box: It is also made from sheet metal and painted with black color which works as absorber plate to receive heat energy.

Insulation: In the space between the outer box and inner box insulating materials like glass wool or thermocol is filled up to prevent the loss of heat energy from the cooker.
Double glass lid: A lid which can close or open is provided over the empty space where food material is kept for cooking. It is double glass cover to prevent the radiation losses from the cooker, Ii permits the solar rays to enter the cooker but prevents to go out from the cooker.
***Mirror paneled outer lid*:** This is sheet metal cover to close or open the box of cooker. Inside surface of the cover is provided with flat reflecting mirror.
Cooking containers: The aluminum containers are kept in the space provided in the cooker. They are also painted with black color on outer surface to absorb the heat energy. The food stuff is kept inside these containers.

Working of solar cooker:

The solar cooker is placed on the stand in the sunlight where direct beam radiations are falling. Its mirror cover lid is open and adjusted in such a way that the reflection of sun rays fall on the transparent double glass lid. The food materials like rice, vegetables for boiling or dry roasting are kept in the containers. Depending upon the intensity of sun rays the food gets cooked within one to three hours. In clear day with good sunshine it is possible to get food cooked in an hour.

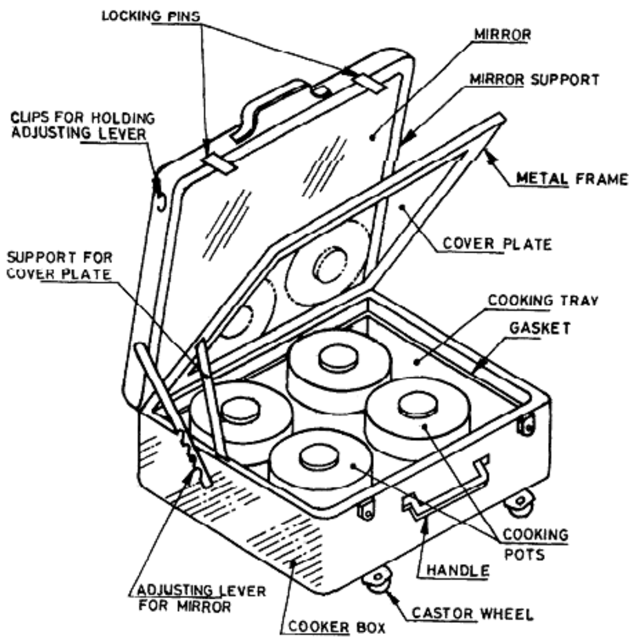


Fig. Construction of solar cooker

Concentrating collector solar cooker

In the concentrating solar cookers, the cooking pot is placed at the focus of a concentrating mirror. Concentrating type solar cooker is working on one or two axis tracking with a concentration ratio up to 50 and temperature up to 300°C, which is suitable for cooking. Concentrating cookers utilize multifaceted mirrors, Fresnel lenses or parabolic concentrators to attain higher temperatures. The concentrating type of solar cookers is further subdivided into parabolic dish/trough, cylindrical, spherical, and Fresnel. This type of cookers usually employs mirrors/reflectors to concentrate the total solar energy incident on the collector surface, so the collector surface is usually very wide and the temperature achieved is very high. Parabolic dish cooker has the highest efficiency in terms of the utilization of the reflector area because in fully steerable dish system there are no losses due to aperture projection effects. Also radiation losses are small because of the small area of the absorber at the focus. Additional advantages include higher cooking temperatures, as virtually any type of food can be cooked and short heat-up times.

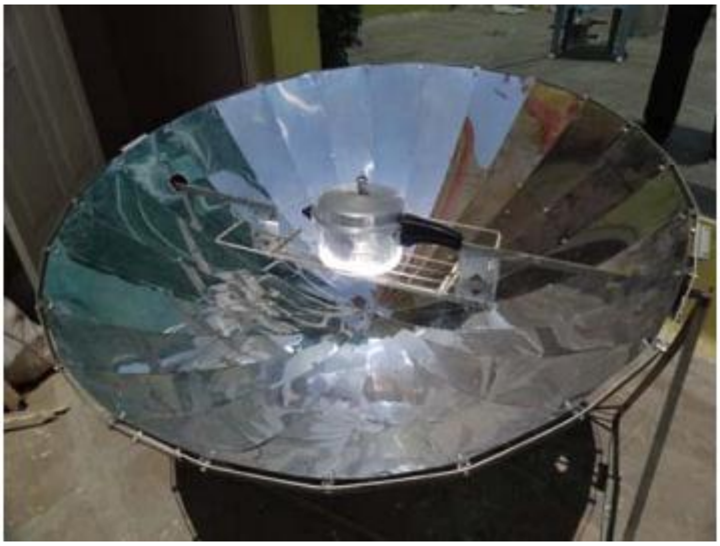


Fig Solar cooker

Solar dryer

Conventional method of drying is to spread the material in a thin layer on ground and let it exposed to the sun. Such a method has various disadvantages like,

- ❖ Accumulation of dust and harms due to insects
- ❖ Wastage of material due to birds
- ❖ Non uniform drying due to varying intensity of sun
- ❖ Larger area required for drying

All these difficulties are removed by using solar drier. There are two types of solar driers.

Natural convection solar drier:

Natural air-drying is an in bin drying system with the following typical characteristics:

- ❖ Drying process is slow, generally requiring 4 to 8 weeks.
- ❖ Initial moisture content is normally limited to 22 to 24%.

- ❖ Drying results from forcing unheated air through grain at airflow rates of 1 to 2 cfm/bu.
- ❖ Drying and storage occur in the same bin, minimizing grain handling.
- ❖ Bin is equipped with a full-perforated floor, one or more high capacity fans, a grain distributor and stairs
- ❖ Cleaning equipment is used to remove broken kernels and fines.

Description of Cabinet drier

It can be of fixed type and also of portable type. Generally it has an area of about 3 x 5 m^2 glass sheet fixed at the top at an angle of about 0 to 30^0. Holes are provided at the bottom and at the topsides for airflow by natural convection. Wire meshed black tray is provided to the material to be dried.

Forced convection solar dryer (Hot air system)

In these, the collectors are provided with duct. Generally, a duct of 2.5 cm depth is provided. It is made out of two plates welded together lengthwise. Cold air is blown through a blower into the collectors, which gets heated during the passage through it. The hot air thus available is then used for drying the products kept on the shelves of driers. This hot air takes away the moisture of the products and is let out through a properly located outlet.

1. Absorber with ducting
2. Blower with motor and
3. Drying bin

Description: This drier has three main components viz., flat plate collector, blower and drying bin. The area of the collector is 8 m^2. It is divided into 4 tray each having 2m x 1m absorber area. The absorber is made out of corrugated G.I. sheet and is painted with dull black color. Another plain G.I. sheet placed 5 cm below the absorber plate creates air space for heating. This sheet is insulated at the bottom with glass wool and is supported at the bottom with another plain G.I. sheet. The absorber is covered at the top with two layers of 3 mm thick plain glass. The unit is supported on all sides with wooden scantling and is placed at 11^0 to the horizontal facing south. Baffle plates are provided in the air space. The air space is open at the bottom to suck atmospheric air and at the top it is connected to a duct leading to suction side of the blower. The blower is of 80 m^3 / min, capacity run by 3HP electric motor. The delivery side of the blower is connected to the plenum chamber of a circular grain

Forced Convection Solar Drier for Drying of Grains

For drying high moisture paddy the solar drier can be used. The different components of the drier are air heater, air ducts and blower and grain drying chamber. The flat plate collector used for heating the air has an efficiency of 60% and rise in ambient air temperature is 13 ˚C. Freshly harvested paddy can be dried and it may take about 7-8 hours to bring the moisture content from 30% to 16% (d.b.). After drying the grains, the milling quality can be tested. The use of solar air heater for drying of grains indicates that 10-15 °C rise in the temperature of the air is enough to reduce the relative humidity of the air to 60% or less which is quite useful for drying of cereal grains. To the level consists of safe moisture content for storage 500 kg of paddy could be dried from 30 to 40 % moisture content in a period of 6 hours on bright sunny day by using air flow rate 4 m^3/min, with temperature rise 8-10°C. Solar drier consists of air heater, blower drying chamber, air distribution system and thermal storage system. The heated air is blown to drying chamber by blowers of the centrifugal type to handle large quantity of air. Batch type or continuous flow type drying chamber artificially creates the necessary radiation to reduce moisture. Hot air from the collector is sucked by a blower through the inlet pipe and is being forced into the drying chamber. An auxiliary heating system to supplement heat requirement may be arranged. This type of auxiliary systems and thermal storage systems for collecting extra energy during daytime, take care of the night operations.

Solar Pond:

A solar pond is large-scale solar thermal energy collector with integral heat storage for supplying thermal energy. A solar pond can be used for various applications, such as process heating, desalination, refrigeration, drying and solar power generation.

Solar pond is simply a pool of salt water which collects and stores solar thermal energy. The saltwater naturally forms a vertical salinity gradient also known as a "Halocline", in which low- salinity water floats on top of high-salinity water. The layers of salt solutions increase in concentration (and therefore density) with depth. Below a certain depth, the solution has a uniformly high salt concentration.

When solar energy is absorbed in the water, its temperature increases, causing thermal expansion and reduces density. If the water is fresh, the low-density warm water would float to the surface, causing convection current. The temperature gradient alone causes a density gradient that decreases with depth. However the salinity gradient forms a density gradient that increases with depth, and this counteracts the temperature gradient, thus preventing heat in the lower layers from moving upwards by convection and leaving the pond. This means that the temperature at the bottom of the pond will rise to over 90 °C while the temperature at the top of the pond is usually around 30°C.

There are 3 distinct layers of water in the pond:

- The top layer, which has a low salt content.
- An intermediate insulating layer with a salt gradient, which establishes a density gradient that prevents heat exchange by natural convection.
- The bottom layer, which has a high salt content.

The top layer is cold and has relatively little salt content. The bottom layer is hot- up to100°C (212°F) - and is very salty. Separating these two layers is the important gradient zone. Here salt content increases with depth. Water in the gradient cannot rise because the water above it has less salt content and is therefore lighter. The water below it has a higher salt content and is heavier. Thus, the stable gradient zone suppresses convection and acts as a transparent insulator, permitting sunlight to be trapped in the hot bottom layer from which useful heat may be withdrawn or stored for later use. The heat trapped in the salty bottom layer can be used for many different purposes, such as the heating of buildings or industrial hot water or for generating electricity.

The Bhuj (Gujarat) solar pond is first-ever solar pond in India to have connected itself to an end-user- supplying industrial process heat to the Kutch Dairy. The pond covers an area of 6000 square metres. Avoiding use of imported membrane lining, the project developed a cost-effective, indigenous lining scheme, using locally mined clay and plastics. While the pond attained a record 99.8 °C under stagnation, stability of the salinity gradient was maintained even at such elevated temperatures.

Solar still/ solar desalination

The basic principle behind solar distillation is simple and replicates the natural process of water purification. A solar still is an air tight basin that contains saline or contaminated water (i.e. feed water). It is enclosed by a transparent top cover, usually of glass or plastic, which allows incident solar radiation to pass through. The inner surface of the basin is usually blackened to increase the efficiency of the system by absorbing more of the incident solar radiation. The feed water heats up, then starts to evaporate and subsequently condenses on the inside of the top cover, which is at a lower temperature as it is in contact with the ambient air. The condensed water (i.e. the distillate) trickles down the cover and is collected in an interior trough and then stored in a separate basin. This system is also known as passive solar still, as it operates solely on sun`s radiation. The amount of solar radiation that is absorbed is a function of the absorptivity and depth of the water. The remaining energy eventually reaches the blackened basin liner, where it is mostly absorbed and converted into thermal energy. At this stage, the water heats up, resulting in an increase of the temperature difference between the cover and the water itself. Heat transfer takes then place as radiation, convection and evaporation from the water surface to the inner part of the cover. The evaporated water condenses and releases latent heat. This last one is then lost through convection and radiation together with the remaining convective and radiative heat.

Solar Still Operation

Water to be cleaned is poured into the still to partially fill the basin. The glass cover allows the solar radiation to pass into the still, which is mostly absorbed by the blackened base. This interior surface uses a blackened material to improve absorption of the sunrays. The water begins to heat up and the moisture content of the air trapped between the water surface and the glass cover increases. The heated water vapor evaporates from the basin and condenses on the inside of the glass cover. In this process, the salts and microbes that were in the original water are left behind. Condensed water trickles down the inclined glass cover to an interior collection trough and out to a storage bottle. Feed water should be added each day that roughly exceeds the distillate production to provide proper flushing of the basin water and to clean out excess salts left behind during the evaporation process. If the still produced 3 litres of water, 9 litres of make-up water should be added, of which 6 litres leaves the still as excess to flush the basin.

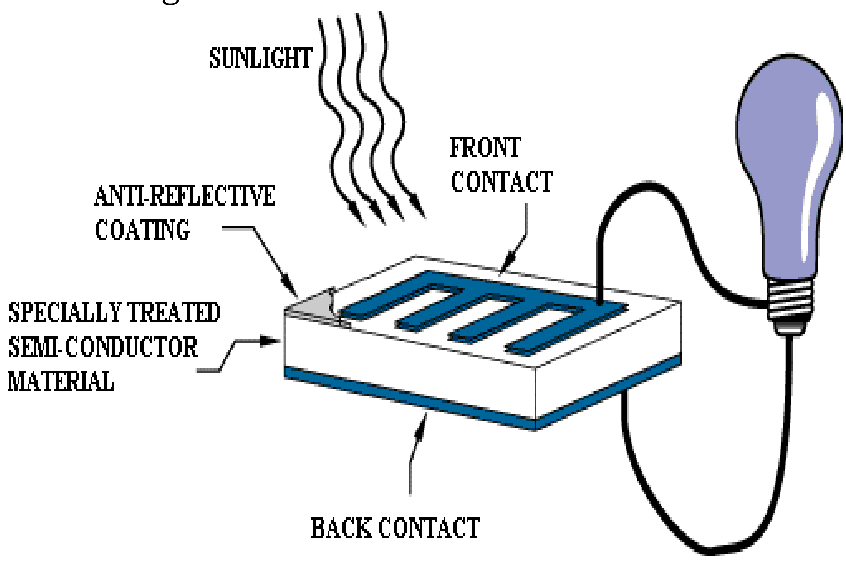
Lacture-10

Solar Photovoltaic System

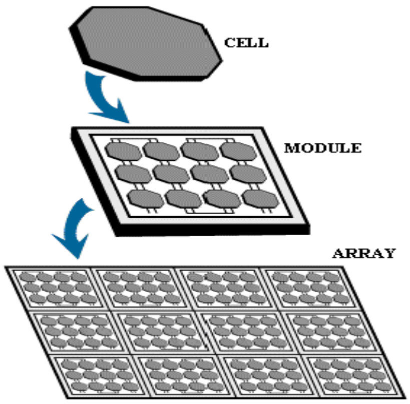
Photovoltaic system (PV) is the technology of solar cells for energy by converting solar energy (sunlight, including ultra violet radiation) directly into electricity. A *solar cell* or *photovoltaic cell* is a device that converts light directly into electricity by the photovoltaic effect. Combination of cells are used to make solar panels, it is called *solar modules, or photovoltaic arrays*. The photovoltaic effect refers to photons of light knocking electrons into a higher state of energy to create electricity. Solar cells produce direct current electricity from light, which can be used to power equipment or to recharge a battery. An inverter is required to convert the DC to AC.

How do Photovoltaics Work?

Solar cells are made of the some kinds of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive side (p-type) and negative side (n-type), forming an electrical circuit, the electrons can be captured in the form of an electric current-that is, electricity. This electricity can then be used to power a load, such as a light or a tool.



These devices have theoretical efficiency of the order of 25 %. Actual operation efficiency is less than half this value and decrease fairly rapidly with increasing temperature. Large number of cells has been manufactured with area 2 × 2 cm, efficiency approaching 10 % and operating at 28°C. The efficiency is the power developed per unit area of array divided by the solar energy flux in the free space (1.353 kW/m^2)



Operation of a PV cell

Due to the low voltage of an individual solar cell (typically 0.5V), several cells are combined into photovoltaic modules, which are in turn connected together into an array. The electricity generated can be either stored, used directly or fed into a large electricity grid powered by central generation plants (grid-connected/grid-tied plant) or combined with one or many domestic electricity generators to feed into a small grid.

Multiple cells can be clubbed together to form a Module and multiple modules can be wired together to form an Array. In general, the larger the area of a module or array, the more electricity will be produced. Photovoltaic modules and arrays produce direct- current (dc) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

Application of PV system

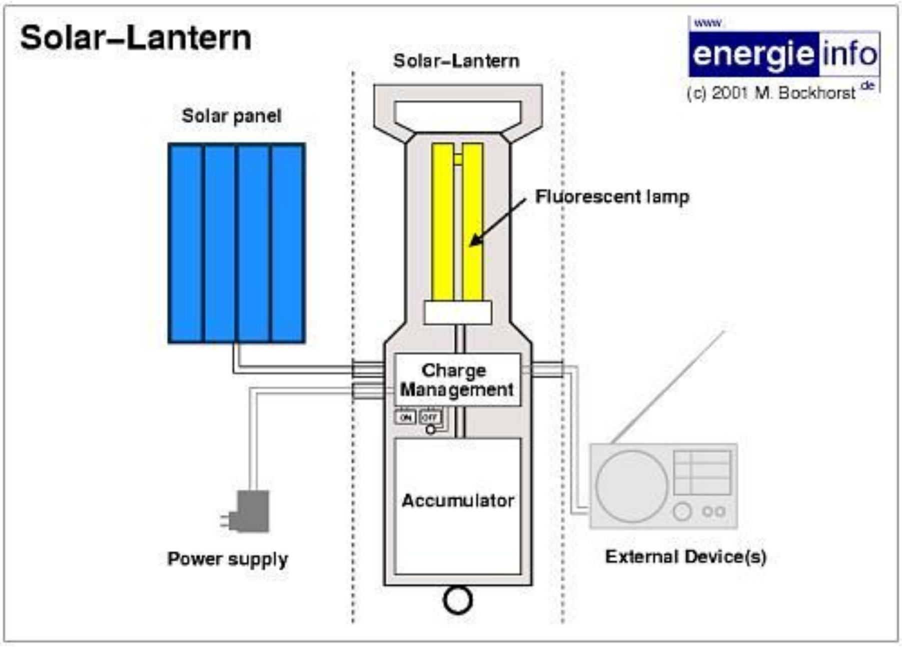
Solar Lantern:

The lantern is basically a portable lighting device suitable for either indoor or outdoor lighting, covering a full range of 360 degrees. A solar Lantern is made of three main components - the solar PV panel, the storage battery and the lamp. 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 3-6 hours.

Advantages:

- Charges from the sun
- Up to 6 hours of light
- Zero running cost
- Extremely Bright light (equivalent to 60Watt tungsten light)
- Very solid, durable design
- Portable, easy to carry anywhere
- Long life, maintenance free battery
- Wall mounting option

- Versatile; charge it suing Solar, AC charger or Car Charger
- Emergency function: Lights on automatically in power cuts



A LED based solar lantern system aims at providing solar electricity for operating LED lights for specified hours of operation per day. Light Emitting Diode (LED) is a device which emits light when an electric current passes through it. A Solar lantern is a lighting system consisting of a lamp, battery and electronics, all placed in a suitable housing, made of metal, plastic or fiber glass, and a PV module. The battery is charged by electricity generated through the PV module.

System Description

PV Module	12 V, 10 Wp
Battery	Sealed and Maintenance free type
Lamp	Compact Fluorescent Lamp (CFL), 7/ 9 W or LED
Working Time	3-6 hrs
Charging Time	6-8 hours / day
Warranty	10 Years for PV module, 1 year for electronics battery

Solar Street Lights:

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

The solar street light system comprise of:

- Solar PV Module
- 12 V, 75 Ah Tubular plate battery with battery box
- Charge Controller cum inverter (20-35 kHz)
- 11 Watt CFL Lamp with fixtures
- 4 metre mild steel lamp post above ground level with weather proof paint and mounting hardware.

The SPV modules are reported to have a service life of 15-20 years. Tubular Batteries (Sealed and Maintenance free type) provided with the solar street lighting system require lower maintenance; have longer life and give better performance as compared to pasted plate batteries used earlier. The systems electronic provide for over-charge and over-discharge cut-off essential for preventing battery and luminaries damages.

Power Consumption	28W(For LED consumption only, the system with power supply is about 36W)
Working Voltage	85-264VAC, 12 or 24VDC
Luminous Flux	2,100lm (equal to 75w HPS Lamp on 7m height pole or 150w HPS lamp on

Solar Fencing:

Solar Power Fencing system is safe, effective and reliable perimeter solutions. The systems utilize the latest solar power fence technology. Deterrence is provided through an electric pulse which is sent around the fence line every 1.2 seconds. The pulse delivers a SAFE, SHORT, yet SHARP SHOCK. Importantly, should someone attempt to breach the fence, the system reports the zone under attack. An alarm is sent to the monitoring center so they can dispatch a security guard ensuring the site is secure day and night.

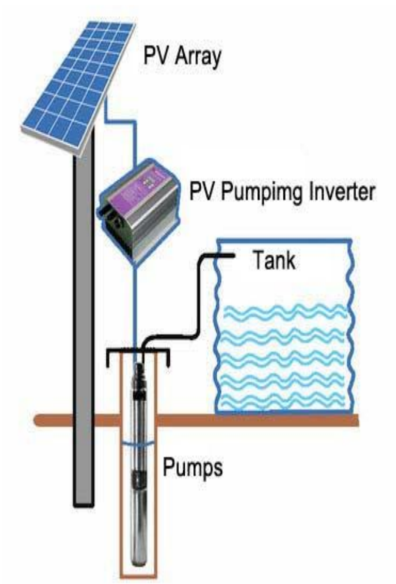
Solar Power Fencing systems can be standalone or linked with other security systems. It can be designed to meet the rigorous requirements of high-risk security installations, such as military installations and prisons, through to small commercial applications such as self storage facilities and vehicle sales yards.

Why go for solar power fencing?

- Growing, rationing of crops and pastures can be improved during slow growth periods.
- Keep animals, including wild and vermin, away.
- Separate various types and classes of animals.
- Fence off trees, rivers, eroding areas and roads.
- Substantial increase in the pasture production.
- The return of valuable animal manure more evenly over the grazing area than having it concentrated in specific areas.

Features:

- Easy Construction.
- Power fence can be erected to target species only.
- Low maintenance.
- Long lasting because of minimal physical pressure.
- All domestic and wild animals can be controlled economically.
- Modification of system to control a variety of animals is very easy.
- Discourages trespassers and predators.
- Not harmful. It gives a short, sharp but safe shock to the intruder.
- Perimeter protection
- Substantially reduces crop damage
- Environment friendly
- Uses solar energy and therefore non dependent on grid power
- Significantly reduces man-animal conflicts
- Effective wildlife management tool for use by park managers
- Cost effective and return on investment starts from day one.
- Works 24/7



Applications of electric Fence systems

Electric fence systems have varied application in Agriculture, Industrial and Forestry *or* Plantation sectors. With increasing crime in urban areas, this proven technology has now been adapted for domestic security applications, too.

Industrial: Security Electric Fence systems provide 100% protections against theft, Pilferage, arson, sabotage. The fence systems can also be integrated with other security devices like sirens, flood lights etc., making it impenetrable.

Domestic: The wall top system for residential applications is sleek, aesthetic and ideal for compounds, rooftops, farm houses and apartments.

Solar Water Pumping System:

The solar water pumping system is a stand-alone system operating on power generated using solar PV (photovoltaic) system. The power generated by solar cells is used for operating DC surface centrifugal mono-block pump set for lifting water from bore / open well or water reservoir for minor irrigation and drinking water purpose.

Advantages of solar pump sets:

- No fuel cost-uses abundantly available free sun light
- No conventional grid electricity required
- Long operating life
- Highly reliable and durable- free performance
- Easy to operate and maintain
- Eco-friendly
- Saving of conventional diesel fuel

Salient Features:

- Automatic start and shut off as per solar intensity
- Dry run protection (automatic switch off)
- Single phase 50 Hz AC input operating voltage range of 100-270 Volts
- Visual indication of faults through flickering LED displays
- Will not restart automatically for faults like dry run, phase imbalance, output short circuit; unless attended
- Controller is designed to accept DC voltages

Applications:

- Remote Villages, Homes, Cabins and Hunting Lodges
- Irrigation for remote orchards, gardens, and greenhouses
- Wildlife watering at wild game parks and farms
- Fish pond water level maintenance and aeration
- Surface water pumping for landscaping streams and waterfalls
- Cattle, Livestock and wildlife watering systems.

Parts of the solar water pumping system:

- Solar PV panel
- Motor-pump sets compatible with the photovoltaic array:

- Surface mounted centrifugal pump set or submersible pump set Pipe fittings

Lacture-11

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 x 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 is the conversion of wind energy into a useful form of energy, such as electricity, using wind turbines.

Wind Mill: A wind turbine is a rotating machine which converts the kinetic energy of wind into mechanical energy. If the mechanical energy is used directly by machinery, such as a pump or grinding stones, the machine is usually called a windmill.

Wind Turbine: If the mechanical energy is instead converted to electricity, the machine is called a wind generator, wind turbine, wind power unit (WPU), wind energy converter (WEC), or Aerogenerator

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 Kinetic energy (KE) of the wind into mechanical energy. Power is equal to energy per unit time

$$KE = \frac{1}{2}mv^2$$

$[\therefore m = \rho A v]$

$$KE = \frac{1}{2}\rho A v^3$$

where,

ρ = Air density (1.225 kg/m^3 at sea level and changes by 10% with altitude Area swept by the rotor)

$$A = \frac{\pi}{4}D^2$$

v = wind velocity

We can convert the expression for KE into power

$$P = \frac{1}{2}\rho A v^3$$

The term P/A is the wind power potential

$$\boldsymbol{\frac{P}{A} = \frac{1}{2}\rho v^3}$$

Power equation also written

$$P = \boldsymbol{\frac{1}{8}\pi D^2 \rho v^3}$$

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

Wind machine intended for generating substantial amounts of power should have large rotors and be located in areas of high wind speed.

Power coefficient

The fraction of the free flow wind power that can be extracted by a rotor is called power coefficient. It is also called ideal or maximum, theoretical efficiency (η_{max}) of a wind turbine.

It is the ratio maximum power obtained from the wind, to the total power available in the wind.

$$Power\ coefficient(C_p) = \eta_{max} = \frac{Power\ output\ from\ wind\ machine}{Power\ available\ in\ wind}$$

The maximum theoretical power coefficient is equal to 16/27 or 0.593 for a horizontal axis wind machine. The factor 0.593 is known as the Betz coefficient.

Maximum power

The maximum power for ideal wind machine, with horizontal axis wind machine

$$P_{max} = \frac{8}{27\, g_c}\rho A v^3$$

$$= \frac{16}{27 g_c}\frac{1}{2}\rho A v^3 = \boldsymbol{0.593(\frac{1}{2}.\frac{\rho A v^3}{g_c})}$$

than

$$\boldsymbol{P_{max} = 0.595\, P_{total}}$$

Forces on the blades and thrust on turbines

There are two types of forces which are acting on the blades. One is circumferential force acting in the direction of wheel rotation that provides torque and other is the axial force acting thrust that must be counteracted by proper machine design.

The circumferential force or torque

$$T = \frac{P}{\pi\, DN}$$

where,

T= torque kgf or newton
P= Power
D= diameter of turbine wheel
N= wheel revelations per unit time

$$P = \eta\, P_{total} = \eta . \frac{1}{2} . \frac{\rho A v^3}{g_c}$$

$$T = \eta . \frac{1}{2 g_c} . \frac{\rho A v^3}{\pi D N}$$

Or

$$\boldsymbol{T = \eta . \frac{1}{8 g_c} . \frac{\rho D v^3}{N}}$$

At maximum efficiency

$$\boldsymbol{T_{max} = \frac{12}{27 g_c} . \frac{\rho D v^3}{N}}$$

The axial force or thrust

$$F_x = \frac{1}{2 g_c} \rho A (v_i^2 - v_e^2)$$

$$\boldsymbol{F_x = \frac{\pi}{8 g_c} \rho D^2 (v_i^2 - v_e^2)}$$

The axial force on a turbine wheel operating at maximum efficiency where $v_e = 1/3\ v_i$

$$\boldsymbol{F_{x\,max} = \frac{\pi}{9 g_c} \rho D^2 v_i^2}$$

We see that axial force is proportional to the square of the diameter of the turbine wheel, this limits turbine wheel diameter of large size.

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

Lacture-12

Types of wind mills

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

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

Parts of Common Wind Turbines

The main parts of the systems that comprise these wind turbines are:

1. The tower: Since velocities close to the ground are very low and there must be good clearance between the lower part of the blades and the ground, the wind turbines are placed on top of a tower at a significant height above the ground. The height of the tower depends on the diameter of the blade and is of the order of magnitude of the blade diameter, D, allowing a clearance of D/2, between the ground and the lower part of the blade. Thus, towers are between 30 and 100 m high. The tower is a simple structural element, usually made of reinforced concrete, which is designed to withstand the axial force and resulting moment generated by the wind turbine. It is typically thicker at the lower part and is usually designed as a hollow structure to allow easy access to the top for engine repairs at the turbine hub. Some older (and shorter) towers were designed as trusses made of metal.

2. The yaw bearings and yaw break: Because the wind turbine must rotate to face the instantaneous direction of the wind, the entire electricity producing system is pivoted on strong bearings that allow the rotation of the system around a vertical axis. The drag force on a downstream rotating vane or a simple rudder provides the force for this rotation. In order to avoid overshooting in the rotation of the electricity generating system and unnecessary power fluctuations, the yaw break system slows the rotational motion by providing damping.

3. The rotor blades*:* They are the most important part of the generating system, where the wind energy is imparted to the engine. They are very long, typically 30–100 m in diameter. The rotor blades are designed aerodynamically with pitch angles that vary with the distance from the hub and they are made of low weight and strong materials. Low density woven composites are now typically used for the turbine blades, which are typically hollow. The blades are connected to the hub, which extends to a horizontal metal shaft that becomes the prime mover of the engine. The shaft is supported by a series of bearings. In the more advanced and better optimized engines, a mechanism is put in place that changes the pitch of the blades to produce maximum power at the instantaneous wind velocity. These mechanisms are made of sensors and actuators, which measure the magnitude of the instantaneous wind velocity, adjust the position of the base of the blades inside the hub and, thus change the pitch of the entire blade. The actuator mechanisms are attached to the blades, rotate with them and are supported by their own pitch-control bearings.

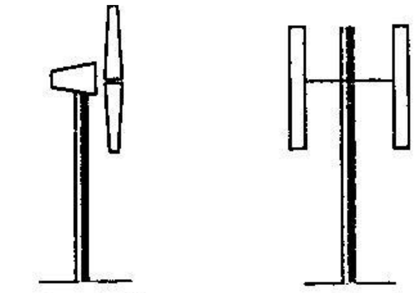
4. The gear box: In order to minimize the centrifugal stresses, the rotational speed of the blades at operating conditions is fairly low, typically of the order of 100 rpm. A gearbox steps up the rotational speed of the prime mover to reach a range 2,000–3,000 rpm and transmits the power to a secondary high rpm shaft, which is connected to the generator. A small fraction of the blade power is dissipated in the gear box by friction. For this reason, larger wind power engines may require a cooling system for their gearbox.

***5. The generator**:* Both permanent magnet generators and generators with electromagnets (exciters) are used for the conversion of the mechanical power to electricity. The generators of the more modern and larger engines are rated in MW (typically 1–3 MW) and include power electronics, such as Variable Speed Constant Frequency devices (VSCF), which convert the variable frequency of the secondary shaft to a constant frequency. Any power spikes in the system are usually absorbed by the inertia of the rotor. One of the salient characteristics of wind power systems is that very high power fluctuations occur with relatively low wind velocity changes. For example, an increase of the wind velocity from 8 to 10 m/s (or 25%) would cause a power increase of almost 100%. Frequent power variations of this magnitude are undesirable because they are associated with high stresses on the blades, on the prime mover and gear as well as with strong power fluctuations on the electric grid. These types of problems are minimized by designing the wind turbines to produce almost constant power.

Vertical axis type wind mills

Vertical axis machines are of simple design as compared to the horizontal axis. The axis of rotation of vertical axis wind turbine is vertical to the ground and almost perpendicular to the wind direction. These turbines can receive wind from any direction. Hence complicated yaw devices can be eliminated. The generator and the gearbox of such systems can be housed at the ground level, which makes the tower design simple and more economical. Moreover, the maintenance of these turbines can be done at the ground level.

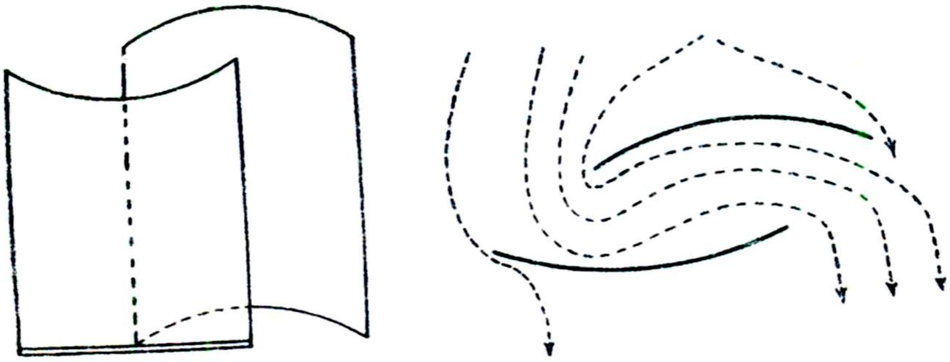
The major disadvantage of vertical axis machines are that, these turbines usually not self starting. Additional mechanism may be required to push and start the turbine, once it is stopped.



Schematic diagram horizontal and vertical axis wind mill

Savonius wind mill

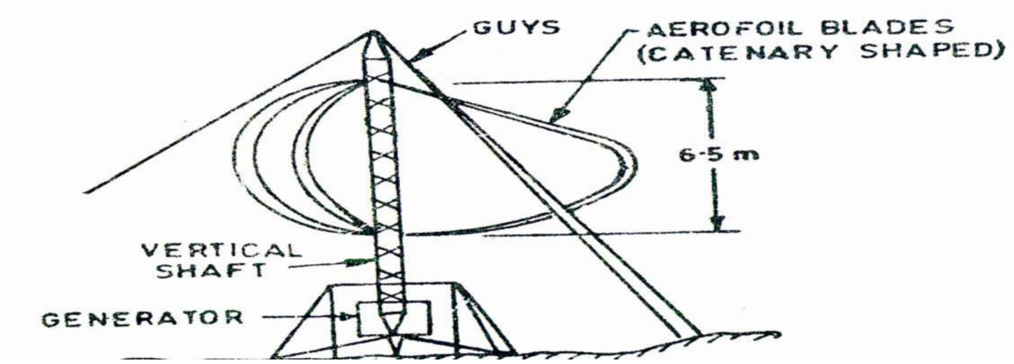
It works on the principle of cup anemometer. This was invented by S.J. Savonius in the year 1920. This machine has become popular, since it requires low wind velocity for operation. It consists of two half cylinders, which are mounted on a vertical axis perpendicular to the direction of wind, with a gap at the axis between the two cylinders (Fig.29). Two half cylinders facing each other forming a 's' shaped cross-section. Irrespective of the wind direction, the rotor rotates such as to make the convex sides of the buckets head into the wind. From the rotor shaft, we can tap power for our use like water pumping, battery charging, grain winnowing etc. The main action of the wind is very simple, the force of the wind is greater on the cupped face than on rounded face. A low pressure is created on the convex sides of drums. Torque is produced by the 5 pressure difference between the two sides of the half cylinders facing the wind. This design is efficient but requires a large surface area. A savonius wind energy conversion system has vertical axes which eliminate the expensive power transmission system from the rotor to the axis. Since it is a vertical axis machine it does not matters much about the wind direction. The machine performs even at lower wind velocity ranges (i.e., 8 kmph).



Schematic diagram of savonius wind mill

Darrieus wind mill

It has two are three thin, curved blades with airfoils cross section and constant chord length. Both ends of blades 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 experiences. The blades can thus be made lighter than propeller type.



Schematic diagram of darrieus wind mill

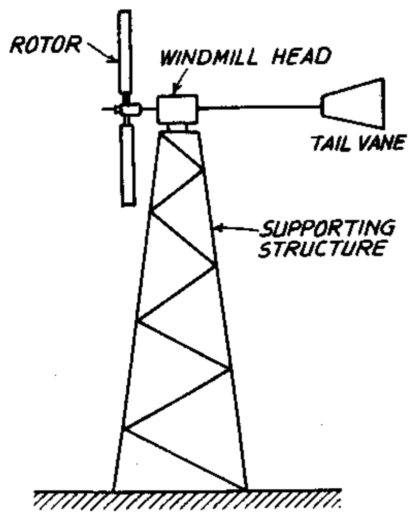
Lacture-12

Horizontal axis type wind mills

Horizontal axis wind turbines have their axis of rotation horizontal to the ground and almost parallel to the wind stream. Most of the commercial wind turbines fall under this category.

Horizontal axis machines have some distinct disadvantages such as low cut-in speed and easy furling. In general, they show relatively high power coefficient. However, the generator and gearbox of these machines are to be placed over the tower which makes its design more complex and expensive. Depending on the number of blades, horizontal axis wind turbines are further classified as single bladed, two bladed, three bladed and multi bladed. Single blade turbines are cheaper due to savings on blade materials. The drag losses are also minimum for these turbines. However, to balance the blade, a counter weight has to be placed opposite to the hub. Single bladed designs are not very popular due to problems in balancing and visual acceptability. Most of the present commercial turbines used for electricity generation have three blades.

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



Schematic diagram of horizontal axis wind mill

Horizontal axis propeller type wind mill with single blade

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

- The blade is designed such that the tip of the blades makes a small angle with the plane of rotation and almost at right angles to the direction of wind.
- The generator and gearbox of these machines are to be placed over the tower which makes its design more complex and expensive.
- In a modern wind turbine, the velocity of blades is six times the wind velocity. Ideally, the blade should be twisted, but because of construction difficulties this is not always achieved.
- The horizontal axis wind mills generally have better performance. These are mainly used for electric power generation and pumping water.

Horizontal axis - two blade wind mill

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

Horizontal axis-multi blade type wind mill: This type of design for multi blades is shown in fig.34, made from sheet metal or aluminum. The rotors have high strength to weight ratios and are strong enough to with stand a wind speed of 60 Kmph. This type of wind mills have good power coefficient, high starting torque, simple and are low in cost.

Sail type wind mill: It is recent development in wind mills. The blades are made by stretching out triangular pieces of canvas cloth or nylon or plastics. There is also variation in the number of sails used. It runs at 60 to 80 rpm. The horizontal axis types generally have better performance. They have been used for various applications but two major areas of interest are electric power generation, and pumping water.

COMPARISON OF HORIZONTAL AND VERTICAL AXIS WIND MILL

	Horizontal axis wind mill		Vertical axis wind mill
1.	Shaft of the rotor of wind mill as horizontal and is not very long.	1.	Shaft of the rotor of wind mill is vertical and it is very long and heavy.
2.	Wind mill tower is required to support rotor and generator.	2.	No such tower is needed and generator is kept at ground level.
3.	Its starting torque is less.	3.	Its starting torque is high.
4.	Tip to wind speed ratio is more and it gives more power.	4.	Tip to wind speed ratio is less and it gives less power.
5.	Rotor head changes the direction when wind direction is changed.	5.	Vertical shaft rotor does not require to change its directions. It runs by the winds coming from any directions.
6.	Wind mill support system has to bear total weight of rotor, blades and generator.	6.	Wind mill support system is made up of guy bars which does not require to bear the weight of rote and generator.
7.	Wind force on the rotor produces stress on every parts of the wind mill such as rotor, bearings and structures.	7.	Wind force on the rotor does not produce stress on all parts of the wind mill.
8.	The support structures required is very strong.	8.	Strong support structures are not very strong.
9.	The wind mills are very popular for power generation.	9.	The wind mills are not very popular for power generation.
10	Propeller type and multi blade American type are examples of horizontal axis wind mills	10	Savonius rotor and Darricus wind mills are vertical type wind mills.

Limitations:

1. Wind machines must be located where strong, dependable winds are available most of the time.
2. Because winds do not blow strongly enough to produce power all the time, energy from wind machines is considered "intermittent," that is, it comes and goes. Therefore, electricity from wind machines must have a back-up supply from another source.
3. As wind power is "intermittent," utility companies can use it for only part of their total energy needs.
4. Wind towers and turbine blades are subject to damage from high winds and lighting. Rotating parts, which are located high off the ground can be difficult and expensive to repair.
5. Electricity produced by wind power sometimes fluctuates in voltage and power factor, which can cause difficulties in linking its power to a utility system.

6. The noise made by rotating wind machine blades can be annoying to nearby neighbors.
7. People have complained about aesthetics of and avian mortality from wind machines.