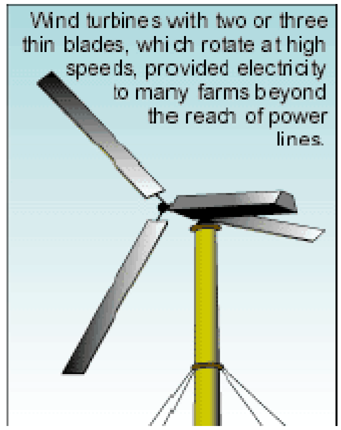
UNIT-III
WIND ENERGY

History of Wind-Mills:

The wind is a by-product of solar energy. Approximately 2% of the sun's energy reaching the earth is converted into wind energy. The surface of the earth heats and coolsunevenly, creating atmospheric pressure zones that make air flow from high- to lowpressureareas.The wind has played an important role in the history of human civilization. The firstknown use of wind dates back 5,000 years to Egypt, where boats used sails to travel fromshore to shore. The first true windmill, a machine with vanes attached to an axis toproduce circular motion, may have been built as early as 2000 B.C. in ancient Babylon.By the 10th century A.D., windmills with wind-catching surfaces having 16 feet lengthand 30 feet height were grinding grain in the areas in eastern Iran and Afghanistan.The earliest written references to working wind machines in western world date from the12th century. These too were used for milling grain. It was not until a few hundred yearslater that windmills were modified to pump water and reclaim much of Holland from thesea.

The multi-vane "farm windmill" of the American Midwest and West was invented in the United States during the latter half of the l9th century. In 1889 there were 77 windmillfactories in the United States, and by the turn of the century, windmills had become amajor American export. Until the diesel engine came along, many transcontinental railroutes in the U.S. depended on large multi-vane windmills to pump water for steamlocomotives.Farm windmills are still being produced and used, though in reduced numbers. They arebest suited for pumping ground water in small quantities to livestock water tanks. In the1930s and 1940s, hundreds of thousands of electricity producing wind turbines were builtin the U.S. They had two or three thin blades which rotated at high speeds to driveelectrical generators. These wind turbines provided electricity to farms beyond the reachof power lines and were typically used to charge storage batteries, operate radio receiversand power a light bulb. By the early 1950s, however, the extension of the central powergrid to nearly every American household, via the Rural Electrification Administration,eliminated the market for these machines. Wind turbine development lay nearly dormantfor the next 20 years.

A typical modern windmill looks as shown in the following figure. The wind-millcontains three blades about a horizontal axis installed on a tower. A turbine connected toa generator is fixed about the horizontal axis.



Like the weather in general, the wind can be unpredictable. It varies from place to place,and from moment to moment. Because it is invisible, it is not easily measured withoutspecial instruments. Wind velocity is affected by the trees, buildings, hills and valleysaround us. Wind is a diffuse energy source that cannot be contained or stored for useelsewhere or at another time.

Classification of Wind-mills:

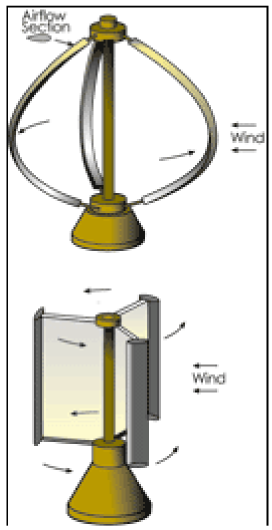
Wind turbines are classified into two general types: Horizontal axis and Vertical axis. Ahorizontal axis machine has its blades rotating on an axis parallel to the ground as shownin the above figure. A vertical axis machine has its blades rotating on an axisperpendicular to the ground. There are a number of available designs for both and eachtype has certain advantages and disadvantages. However, compared with the horizontalaxis type, very few vertical axis machines are available commercially.

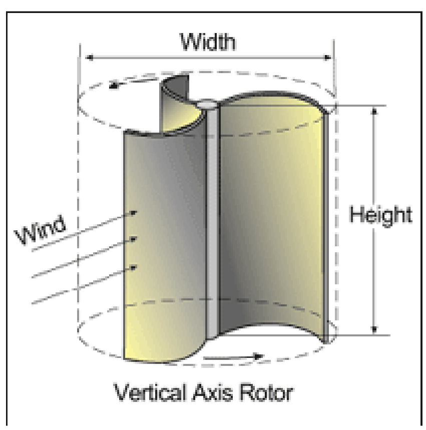
Horizontal Axis:

This is the most common wind turbine design. In addition to being parallel to the ground,the axis of blade rotation is parallel to the wind flow. Some machines are designed to operate in an upwind mode, with the blades upwind of the tower. In this case, a tail vaneis usually used to keep the blades facing into the wind. Other designs operate in adownwind mode so that the wind passes the tower before striking the blades. Without atail vane, the machine rotor naturally tracks the wind in a downwind mode. Some verylarge wind turbines use a motor-driven mechanism that turns the machine in response to awind direction sensor mounted on the tower. Commonly found horizontal axis wind millsare aero-turbine mill with 35% efficiency and farm mills with 15% efficiency.

Vertical Axis:

Although vertical axis wind turbines have existed for centuries, they are not as commonas their horizontal counterparts. The main reason for this is that they do not takeadvantage of the higher wind speeds at higher elevations above the ground as well ashorizontal axis turbines. The basic vertical axis designs are the Darrieus, which hascurved blades and efficiency of 35%, the Giromill, which has straight blades, andefficiency of 35%, and the Savonius, which uses scoops to catch the wind and theefficiency of 30%. A vertical axis machine need not be oriented with respect to winddirection. Because the shaft is vertical, the transmission and generator can be mounted atground level allowing easier servicing and a lighter weight, lower cost tower. Althoughvertical axis wind turbines have these advantages, their designs are not as efficient atcollecting energy from the wind as are the horizontal machine designs. The followingfigures show all the above mentioned mills.

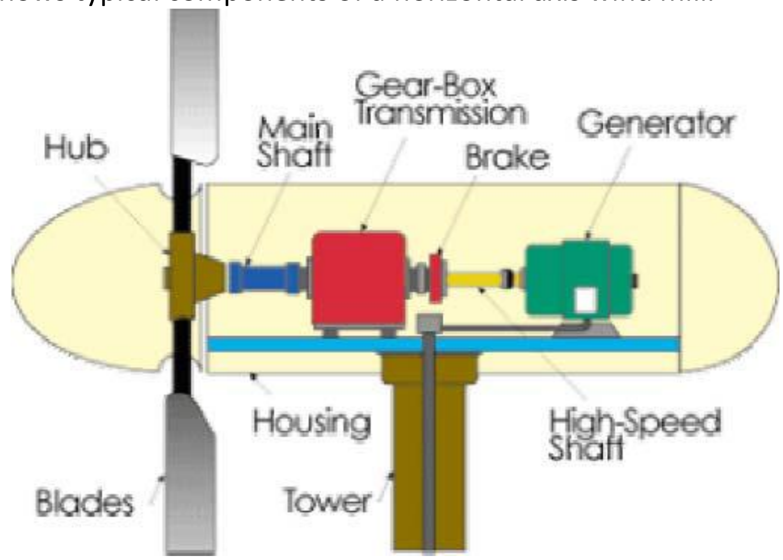




There is one more type of wind-mill called Cyclo-gyro wind-mill with very highefficiency of about 60%. However, it is not very stable and is very sensitive to winddirection. It is also very complex to build.

Main Components of a wind-mill :

Following figure shows typical components of a horizontal axis wind mill.



Rotor:

The portion of the wind turbine that collects energy from the wind is called the rotor. Therotor usually consists of two or more wooden, fiberglass or metal blades which rotateabout an axis (horizontal or vertical) at a rate determined by the wind speed and the shapeof the blades. The blades are attached to the hub, which in turn is attached to the mainshaft.

Drag Design:

Blade designs operate on either the principle of drag or lift. For the drag design, the windliterally pushes the blades out of the way. Drag powered wind turbines are characterized by slower rotational speeds and high torque capabilities. They are useful for the pumping,sawing or grinding work. For example, a farm-type windmill must develop high torque atstart-up in order to pump, or lift, water from a deep well.

Lift Design:

The lift blade design employs the same principle that enables airplanes, kites and birds tofly. The blade is essentially an airfoil, or wing. When air flows past the blade, a windspeed and pressure differential is created between the upper and lower blade surfaces.The pressure at the lower surface is greater and thus acts to "lift" the blade. When bladesare attached to a central axis, like a wind turbine rotor, the lift is translated into rotationalmotion. Lift-powered wind turbines have much higher rotational speeds than drag typesand therefore well suited for electricity generation.

Tip Speed Ratio:

The tip-speed is the ratio of the rotational speed of the blade to the wind speed. The largerthis ratio, the faster the rotation of the wind turbine rotor at a given wind speed.Electricity generation requires high rotational speeds. Lift-type wind turbines havemaximum tip-speed ratios of around 10, while drag-type ratios are approximately 1.Given the high rotational speed requirements of electrical generators, it is clear that thelift-type wind turbine is most practical for this application.

The number of blades that make up a rotor and the total area they cover affect windturbine performance. For a lift-type rotor to function effectively, the wind must flowsmoothly over the blades. To avoid turbulence, spacing between blades should be greatenough so that one blade will not encounter the disturbed, weaker air flow caused by theblade which passed before it. It is because of this requirement that most wind turbineshave only two or three blades on their rotors.

Generator:

The generator is what converts the turning motion of a wind turbine's blades intoelectricity. Inside this component, coils of wire are rotated in a magnetic field to produceelectricity. Different generator designs produce either alternating current (AC) or directcurrent (DC), and they are available in a large range of output power ratings. Thegenerator's rating, or size, is dependent on the length of the wind turbine's blades becausemore energy is captured by longer blades.

It is important to select the right type of generator to match intended use. Most home andoffice appliances operate on 240 volt, 50 cycles AC. Some appliances can operate oneither AC or DC, such as light bulbs and resistance heaters, and many others can beadapted to run on DC. Storage systems using batteries store DC and usually areconfigured at voltages of between 12 volts and 120 volts.

Generators that produce AC are generally equipped with features to produce the correctvoltage of 240 V and constant frequency 50 cycles of electricity, even when the windspeed is fluctuating.

DC generators are normally used in battery charging applications and for operating DC appliances and machinery. They also can be used to produce AC electricity with the useof an inverter, which converts DC to AC.

Transmission:

The number of revolutions per minute (rpm) of a wind turbine rotor can range between 40 rpm and 400 rpm, depending on the model and the wind speed. Generators typicallyrequire rpm's of 1,200 to 1,800. As a result, most wind turbines require a gear-boxtransmission to increase the rotation of the generator to the speeds necessary for efficientelectricity production. Some DC-type wind turbines do not use transmissions. Instead,they have a direct link between the rotor and generator. These are known as direct drivesystems. Without a transmission, wind turbine complexity and maintenance requirementsare reduced, but a much larger generator is required to deliver the same power output asthe AC-type wind turbines.

Tower:

The tower on which a wind turbine is mounted is not just a support structure. It alsoraises the wind turbine so that its blades safely clear the ground and so it can reach thestronger winds at higher elevations. Maximum tower height is optional in most cases,except where zoning restrictions apply. The decision of what height tower to use will bebased on the cost of taller towers versus the value of the increase in energy productionresulting from their use. Studies have shown that the added cost of increasing towerheight is often justified by the added power generated from the stronger winds. Largerwind turbines are usually mounted on towers ranging from 40 to 70 meters tall.

Towers for small wind systems are generally "guyed" designs. This means that there are guy wires anchored to the ground on three or four sides of the tower to hold it erect.These towers cost less than freestanding towers, but require more land area to anchor theguy wires. Some of these guyed towers are erected by tilting them up. This operation canbe quickly accomplished using only a winch, with the turbine already mounted to thetower top. This simplifies not only installation, but maintenance as well. Towers can beconstructed of a simple tube, a wooden pole or a lattice of tubes, rods, and angle iron.Large wind turbines may be mounted on lattice towers, tube towers or guyed tilt-uptowers.

Towers must be strong enough to support the wind turbine and to sustain vibration, windloading and the overall weather elements for the lifetime of the wind turbine. Their costs will vary widely as a function of design and height.

Operating Characteristics of wind mills:

All wind machines share certain operating characteristics, such as cut-in, rated and cutout wind speeds.

Cut-in Speed:

Cut-in speed is the minimum wind speed at which the blades will turn and generate usable power. This wind speed is typically between 10 and 16 kmph.

Rated Speed:

The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. For example, a "10 kilowatt" wind turbine may not generate 10kilowatts until wind speeds reach 40 kmph. Rated speed for most machines is in the rangeof 40 to 55 kmph. At wind speeds between cut-in and rated, the power output from awind turbine increases as the wind increases. The output of most machines levels offabove the rated speed. Most manufacturers provide graphs, called "power curves,"showing how their wind turbine output varies with wind speed.

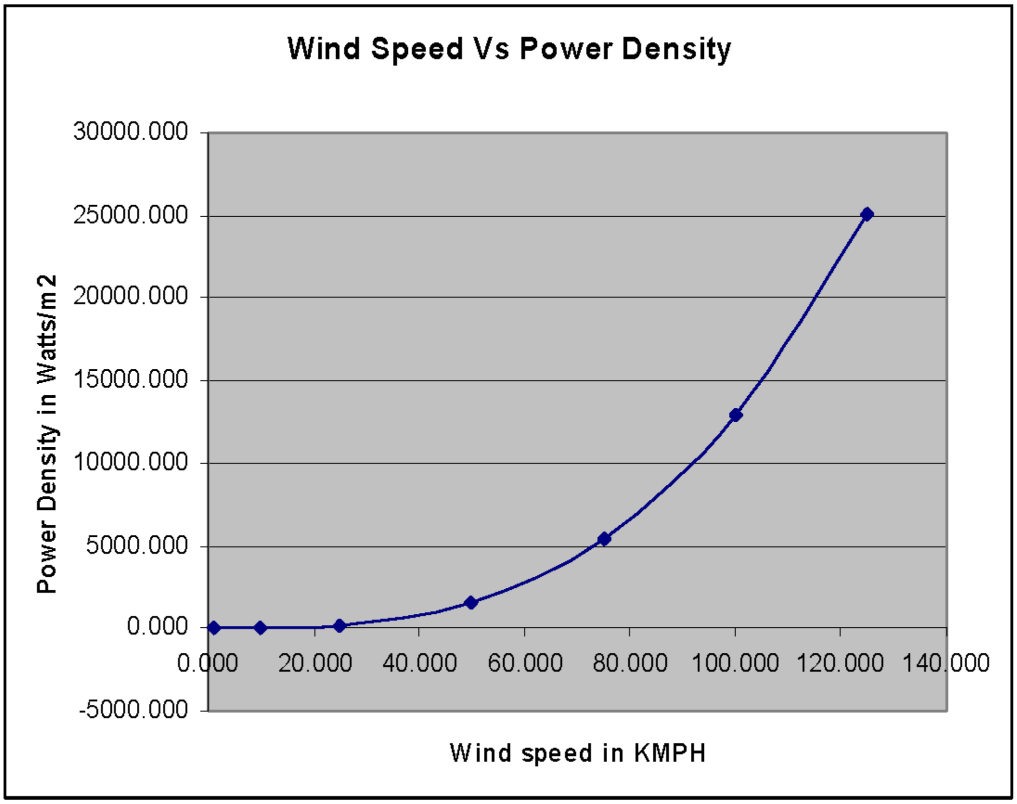
Cut-out Speed:

At very high wind speeds, typically between 72 and 128 kmph, most wind turbines cease power generation and shut down. The wind speed at which shut down occurs is called thecut-out speed. Having a cut-out speed is a safety feature which protects the wind turbinefrom damage. Shut down may occur in one of several ways. In some machines anautomatic brake is activated by a wind speed sensor. Some machines twist or "pitch" theblades to spill the wind. Still others use "spoilers," drag flaps mounted on the blades orthe hub which are automatically activated by high rotor rpm's, or mechanically activatedby a spring loaded device which turns the machine sideways to the wind stream. Normalwind turbine operation usually resumes when the wind drops back to a safe level.

Betz Limit:

It is the flow of air over the blades and through the rotor area that makes a wind turbine function. The wind turbine extracts energy by slowing the wind down. The theoreticalmaximum amount of energy in the wind that can be collected by a wind turbine's rotor isapproximately 59%. This value is known as the Betz limit. If the blades were 100%efficient, a wind turbine would not work because the air, having given up all its energy,would entirely stop. In practice, the collection efficiency of a rotor is not as high as 59%.A more typical efficiency is 35% to 45%. A complete wind energy system, includingrotor, transmission, generator, storage and other devices, which all have less than perfectefficiencies, will deliver between 10% and 30% of the original energy available in thewind.

The following plot gives the relationship between wind speed in KMPH and the powerdensity.



In the last column of the table, we have calculated the output of the turbine assuming thatthe efficiency of the turbine is 30%. However, we need to remember that the efficiency ofthe turbine is a function of wind speed. *It varies with wind speed*.

Now, let us try to calculate the wind speed required to generate power equivalent to 1square meter PV panel with 12% efficiency. We know that solar insolation available atthe PV panel is 1000 watts/m2at standard condition. Hence the output of the PV panelwith 12% efficiency would be 120 watts. Now the speed required to generate this powerby the turbine with 30% efficiency can be calculated as follows:
Turbine output required = 120 Watts/m^2

Power Density at the blades = 120/ (0.3) = 400 watts/m^2

BIOMASS:

Introduction:

Biomass is the term used to describe all the organic matter, produced by photosynthesis that exists on the earth's surface. The source of all energy in biomass is the sun, the biomass acting as a kind of chemical energy store. Biomass is constantly undergoing a complex series of physical and chemical transformations and being regenerated while giving off energy in the form of heat to the atmosphere. To make use of biomass for our own energy needs we can simply tap into this energy source, in its simplest form we know, this is a basic open fire used to provide heat for cooking, warming water or warming the air in our home. More sophisticated technologies exist for extracting this energy and converting it into useful heat or power in an efficient way.

The exploitation of energy from biomass has played a key role in the evolution of mankind. Until relatively recently it was the only form of energy which was usefully exploited by humans and is still the main source of energy for more than half the world's population for domestic energy needs. Traditionally the extraction of energy from biomass is split into 3 distinct categories:

Solid biomass - the use of trees, crop residues, animal and human waste (all though not strictly a solid biomass source, it is often included in this category for the sake of convenience), household or industrial residues for direct combustion to provide heat. Often the solid biomass will undergo physical processing such as cutting, chipping, briquetting, etc. but retains its solid form.

Biogas - biogas is obtained by anaerobically (in an air free environment) digesting organic material to produce a combustible gas known as methane. Animal waste and municipal waste are two common feed stocks for anaerobic digestion.

Liquid Biofuels - are obtained by subjecting organic materials to one of various chemical or physical processes to produce a usable, combustible, liquid fuel. Biofuels such as vegetable oils or ethanol are often processed from industrial or commercial residues such as bagasse (sugarcane residue remaining after the sugar is extracted) or from energy crops grown specifically for **Micro-organisms** , like all living things, **require food for growth** . Biological sewage treatment consists of a step-by-step, continuous, sequenced attack on the organic compounds found in wastewater and upon which the microbes feed.

Aerobic Digestion

Aerobic digestion of waste is the natural biological degradation and purification process in which bacteria that thrive in oxygen-rich environments break down and digest the waste.

During oxidation process, pollutants are broken down into carbon dioxide (CO_2), water (H_2O), nitrates, sulphates and biomass (microorganisms). By operating the oxygen supply with **aerators,** the process can be significantly accelerated. Of all the biological treatment methods, aerobic digestion is the most widespread process that is used throughout the world.

Biological and chemical oxygen demand

Aerobic bacteria demand oxygen to decompose dissolved pollutants. Large amounts of pollutants require large quantities of bacteria; therefore the demand for oxygen will be high.

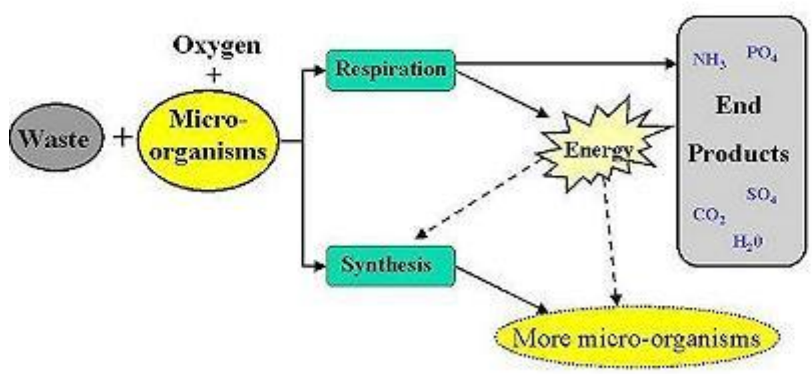
The Biological Oxygen Demand (BOD) is a measure of the quantity of dissolved organic pollutants that can be removed in biological oxidation by the bacteria. It is expressed in **mg/l.**

The Chemical Oxygen Demand (COD) measures the quantity of dissolved organic pollutants than can be removed in chemical oxidation, by adding strong acids. It is expressed in **mg/l.**

The **BOD/COD** gives an indication of the fraction of pollutants in the wastewater that is biodegradable.

Advantages of Aerobic Digestion

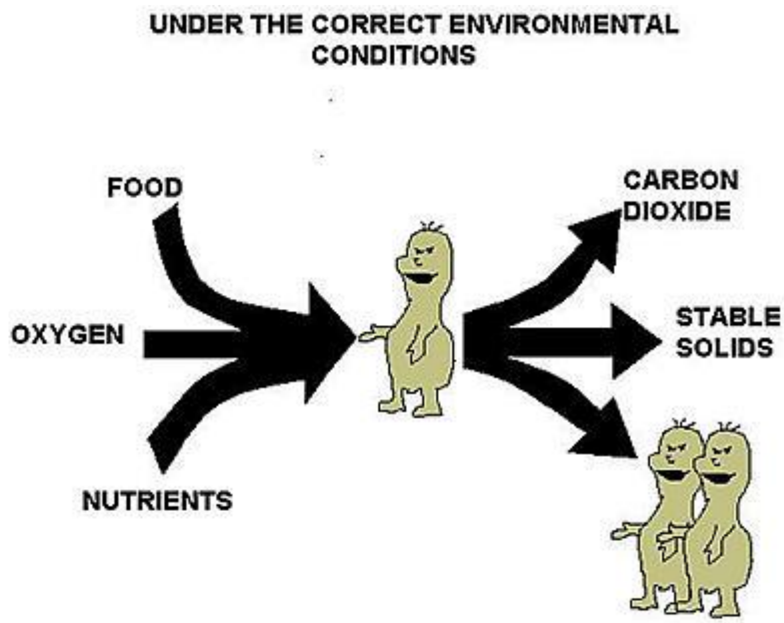
Aerobic bacteria are very efficient in breaking down waste products. The result of this is; aerobic treatment usually yields better effluent quality that that obtained in anaerobic processes. The aerobic pathway also releases a substantial amount of energy. A portion is used by the microorganisms for synthesis and growth of new microorganisms.



Path of Aerobic Digestion

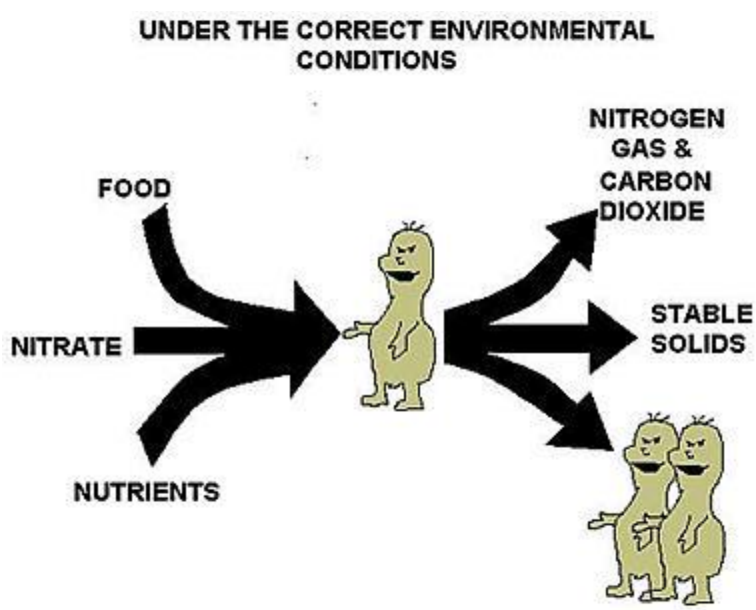
Aerobic Decomposition

A biological process, in which, organisms use available organic matter to support biological activity. The process uses organic matter, nutrients, and dissolved oxygen, and produces stable solids, carbondioxide, and more organisms. The microorganisms which can only survive in aerobic conditions are known as aerobic organisms. In sewer lines the sewage becomes anoxic if left for a few hours and becomes anaerobic if left for more than 1 1/2 days. Anoxic organisms work well with aerobic and anaerobic organisms. Facultative and anoxic are basically the same concept.



Anoxic Decomposition

A biological process in which a certain group of microorganisms use chemically combined oxygen such as that found in nitrite and nitrate. These organisms consume organic matter to support life functions. They use organic matter, combined oxygen from nitrate, and nutrients to produce nitrogen gas, carbon dioxide, stable solids and more organisms.



Anaerobic Digestion

Anaerobic digestion is a complex biochemical reaction carried out in a number of steps by several types of microorganisms that require little or no oxygen to live. During this process, a gas that is mainly composed of methane and carbon dioxide, also referred to as biogas, is produced. The amount of gas produced varies with the amount of organic waste fed to the digester and temperature influences the rate of decomposition and gas production.

Anaerobic digestion occurs in four steps:

- **Hydrolysis** : Complex organic matter is decomposed into simple soluble organic molecules using water to split the chemical bonds between the substances.

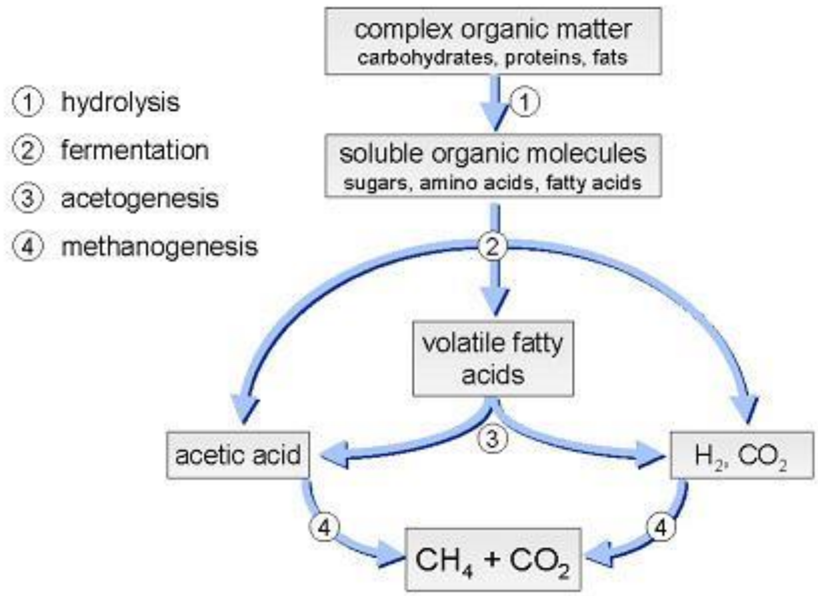
- **Fermentation or Acidogenesis:** The chemical decomposition of carbohydrates by enzymes, bacteria, yeasts, or molds in the absence of oxygen.

- **Acetogenesis:** The fermentation products are converted into acetate, hydrogen and carbon dioxide by what are known as acetogenic bacteria.

- **Methanogenesis:** Is formed from acetate and hydrogen/carbon dioxide by methanogenic bacteria.

The acetogenic bacteria grow in close association with the methanogenic bacteria during the fourth stage of the process. The reason for this is that the conversion of the fermentation products by the acetogens is thermodynamically only if the hydrogen concentration is kept sufficiently low. This requires a close relationship between both classes of bacteria.

The anaerobic process only takes place under strict anaerobic conditions. It requires specific adapted bio-solids and particular process conditions, which are considerably different from those needed for aerobic treatment.



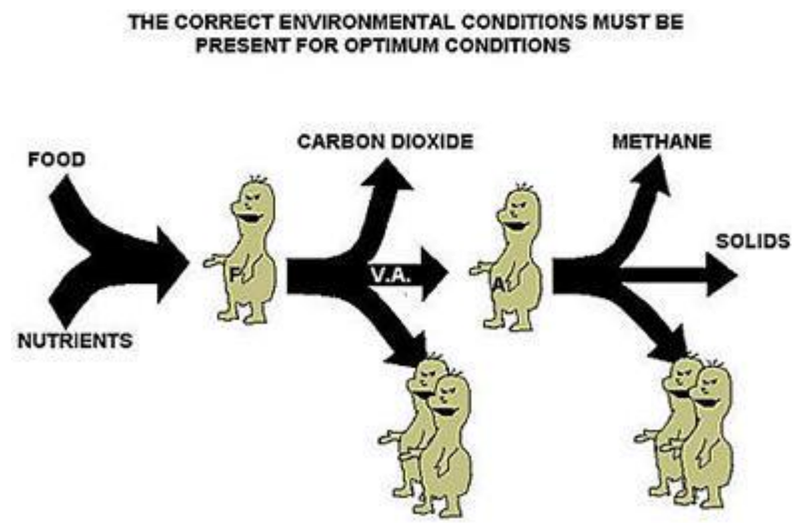
Path of Anaerobic Digestion

Advantages of Anaerobic Digestion

Wastewater pollutants are transformed into methane, carbon dioxide and smaller amount of bio-solids. The biomass growth is much lower compared to those in the aerobic processes. They are also much more compact than the aerobic bio-solids.

Anaerobic Decomposition

A biological process, in which, decomposition of organic matter occurs without oxygen. Two processes occur during anaerobic decomposition. First, facultative acid forming bacteria use organic matter as a food source and produce volatile (organic) acids, gases such as carbon dioxide and hydrogen sulfide, stable solids and more facultative organisms. Second, anaerobic methane formers use the volatile acids as a food source and produce methane gas, stable solids and more anaerobic methane formers. The methane gas produced by the process is usable as a fuel. The methane former works slower than the acid former, therefore the pH has to stay constant consistently, slightly basic, to optimize the creation of methane. You need to constantly feed it sodium bicarbonate to keep it basic.



Biogas - Digester types

In this chapter, the most important types of biogas plants are described:

· Fixed-dome plants
· Floating-drum plants
· Balloon plants
· Horizontal plants
· Earth-pit plants
· Ferrocement plants

Of these, the two most familiar types in developing countries are the **fixed-dome plants** and the **floating-drum** plants. Typical designs in industrialized countries and appropriate design selection criteria have also been considered.

Fixed-dome plants

The costs of a fixed-dome biogas plant are relatively low. It is simple as no moving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected. The plant is constructed underground, protecting it from physical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons, sunshine and warm seasons take longer to heat up the digester. No day/night fluctuations of temperature in the digester positively influence the bacteriological processes.

The construction of fixed dome plants is labor-intensive, thus creating local employment.
Fixed-dome plants are not easy to build. They should only be built where construction can be supervised by experienced biogas technicians. Otherwise plants may not be gas-tight(porosity and cracks).
The basic elements of a fixed dome plant (here the **Nicarao Design**) are shown in the figure below.

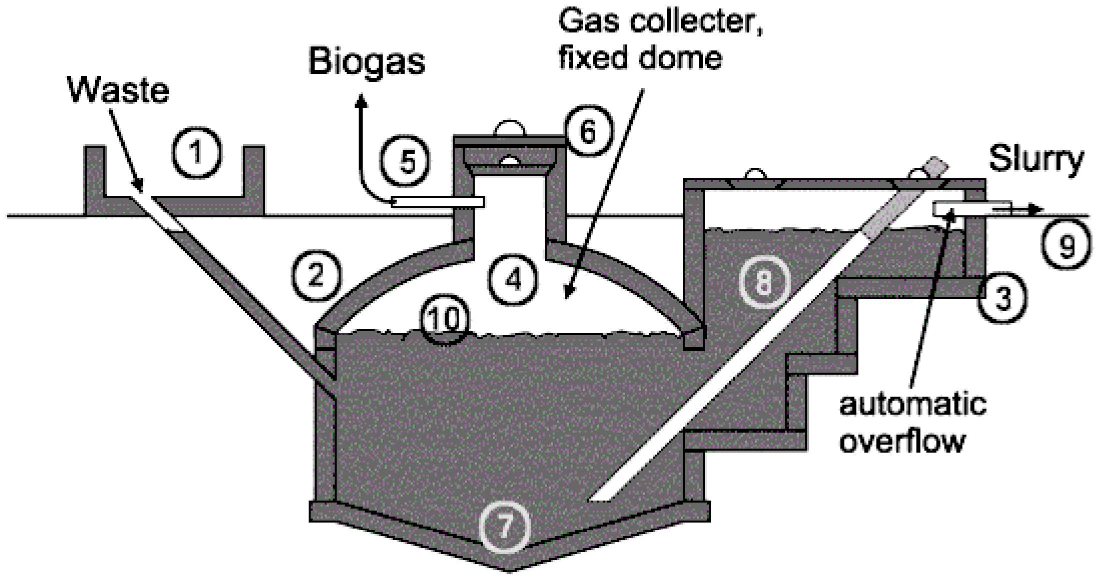


Figure 1: Fixed dome plant Nicarao design: 1. Mixing tank with inlet pipe and sand trap.2. Digester. 3. Compensation and removal tank. 4. Gasholder. 5. Gaspipe. 6. Entry hatch, with gastight seal. 7. Accumulation of thick sludge. 8. Outlet pipe. 9. Reference level. 10.Supernatant scum, broken up by varying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

Function

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

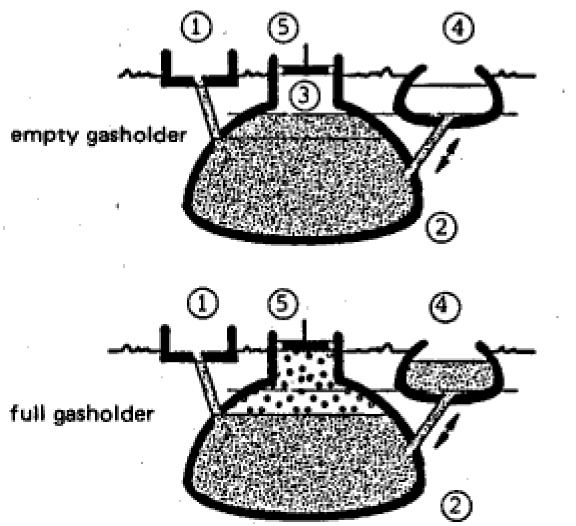


Figure 2: Basic function of a fixed-dome biogas plant, 1 Mixing pit, 2 Digester, 3 Gasholder, 4 Displacement pit, 5 Gas pipe

Digester:

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

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

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

Gas-Holder:

Figure 3: Fixed-dome plant in Tunesia. The final layers of the masonry structure are being fixed.

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

Types of fixed-dome plants

· **Chinese fixed-dome plant** is the archetype of all fixed dome plants. Several million have been constructed in China. The digester consists of a cylinder with round bottom and top.

· **Janata model** was the first fixed-dome design in India, as a response to the Chinese fixed dome plant. It is not constructed anymore. The mode of construction lead to cracks in the gasholder - very few of these plant had been gas-tight.

· **Deenbandhu** the successor of the Janata plant in India, with improved design, was more crack-proof and consumed less building material than the Janata plant. with a hemisphere digester

· **CAMARTEC model** has a simplified structure of a hemispherical dome shell based on a rigid foundation ring only and a calculated joint of fraction, the so-called weak / strong ring. It was developed in the late 80s in Tanzania.

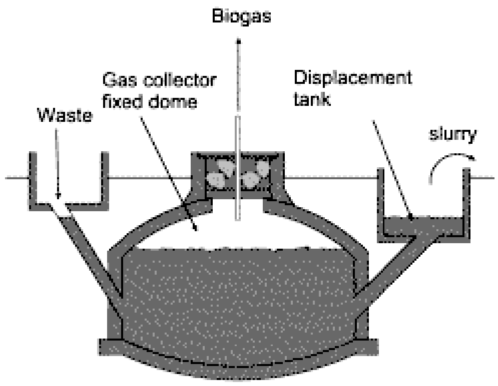


Figure 4: Chinese fixed dome plant

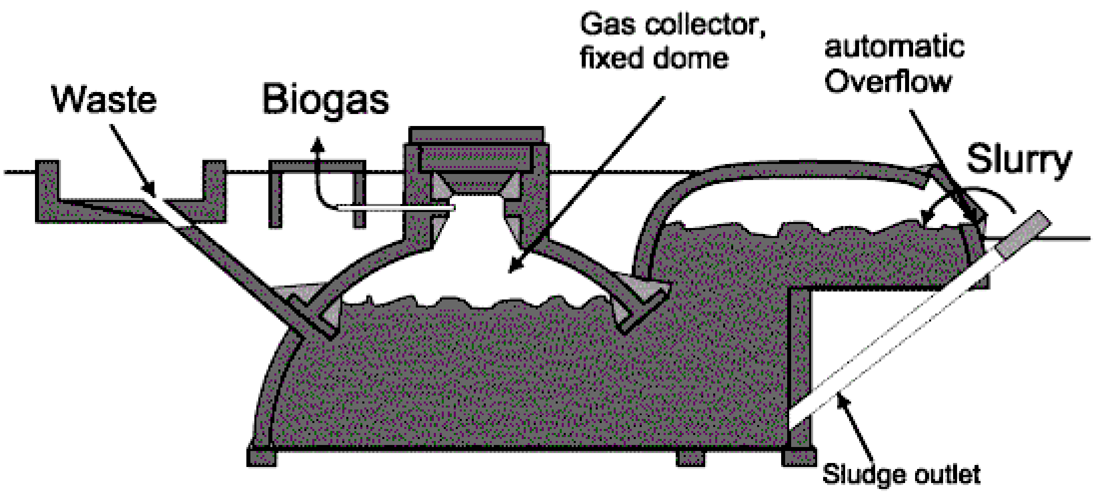


Figure 5: Fixed dome plant CAMARTEC design

Climate and size

Fixed-dome plants must be covered with earth up to the top of the gas-filled space to counteract the internal pressure (up to 0,15 bar). The earth cover insulation and the option for internal heating makes them suitable for colder climates. Due to economic parameters, the recommended minimum size of a fixed-dome plant is 5 m3. Digester volumes up to 200m3 are known and possible.

Advantages: Low initial costs and long useful life-span; no moving or rusting parts involved; basic design is compact, saves space and is well insulated; construction creates local employment.

Disadvantages: Masonry gas-holders require special sealants and high technical skills for gas-tight construction; gas leaks occur quite frequently; fluctuating gas pressure complicates gas utilization; amount of gas produced is not immediately visible, plant operation not readily understandable; fixed dome plants need exact planning of levels; excavation can be difficult and expensive in bedrock.

Fixed dome plants can be recommended only where construction can be supervised by experienced biogas technicians.

Figure 6: Installation of a Shanghai fixed-dome system near Shanghai, PR China Floating-drum plants

Floating – drum plants

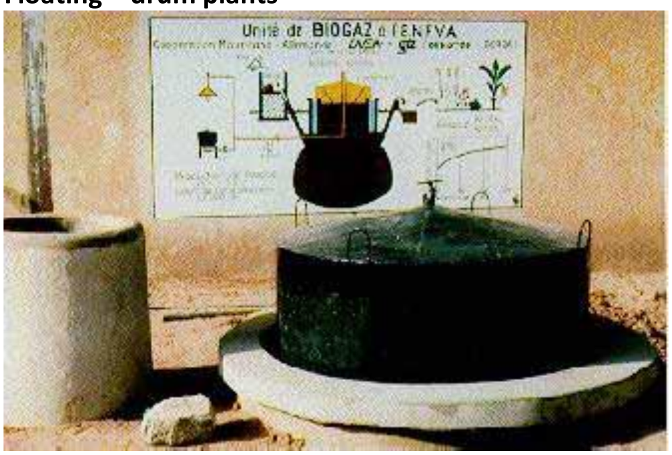


Figure 7: Floating-drum plant in Mauretania

The drum

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

Size

Floating-drum plants are used chiefly for digesting animal and human feces on a continuous feed mode of operation, i.e. with daily input. They are used most frequently by small- to middle-sized farms (digester size: 5-15m3) or in institutions and larger agro-industrial estates(digester size: 20-100m3).

Advantages: Floating-drum plants are easy to understand and operate. They provide gas at a constant pressure, and the stored gas-volume is immediately recognizable by the position of the drum. Gas-tightness is no problem, provided the gasholder is de-rusted and painted regularly.

Disadvantages: The steel drum is relatively expensive and maintenance-intensive. Removing rust and painting has to be carried out regularly. The life-time of the drum is short (up to 15 years; in tropical coastal regions about five years). If fibrous substrates are used, the gas-holder shows a tendency to get "stuck" in the resultant floating scum.

Types of floating-drum plants

There are different types of floating-drum plants (see drawings under Construction):

· **KVIC model** with a cylindrical digester, the oldest and most widespread floating drum biogas plant from India.

· **Pragati model** with a hemisphere digester

· **Ganesh model** made of angular steel and plastic foil floating-drum plant made of pre-fabricated reinforced concrete compound units floating-drum plant made of fibre-glass reinforced polyester

· **BORDA model:** The BORDA-plant combines the static advantages of hemispherical digester with the process-stability of the floating-drum and the longer life span of a water jacket plant.