

UNIT-IIIWINDENERGY

HistoryofWind-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 cools unevenly, creating atmospheric pressure zones that make air flow from high- to low-pressure areas. The wind has played an important role in the history of human civilization. The first known use of wind dates back 5,000 years to Egypt, where boats used sails to travel from shore to shore. The first true windmill, a machine with vanes attached to an axis to produce 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 length and 30 feet height were grinding grain in the areas in eastern Iran and Afghanistan. The earliest written references to working wind machines in the western world date from the 12th century. These too were used for milling grain. It was not until a few hundred years later that windmills were modified to pump water and reclaim much of Holland from the sea.

The multi-vane "farm windmill" of the American Midwest and West was invented in the United States during the latter half of the 19th century. In 1889 there were 77 windmill factories in the United States, and by the turn of the century, windmills had become a major American export. Until the diesel engine came along, many transcontinental rail routes in the U.S. depended on large multi-vane windmills to pump water for steam locomotives. Farm windmills are still being produced and used, though in reduced numbers. They are best suited for pumping groundwater in small quantities to livestock water tanks.

In the 1930s and 1940s, hundreds of thousands of electricity-producing wind turbines were built in the U.S. They had two or three thin blades which rotated at high speeds to drive electrical generators. These wind turbines provided electricity to farms beyond the reach of power lines and were typically used to charge storage batteries, operate radio receivers, and power a light bulb. By the early 1950s, however, the extension of the central power grid to nearly every American household, via the Rural Electrification Administration, eliminated the market for these machines. Wind turbine development lay nearly dormant for the next 20 years.

A typical modern windmill looks as shown in the following figure. The windmill contains three blades about a horizontal axis installed on a tower. A turbine connected to a 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 without special instruments. Wind velocity is affected by the trees, buildings, hills, and valleys around us. Wind is a diffuse energy source that cannot be contained or stored for use elsewhere or at another time.

Classification of Wind-mills:

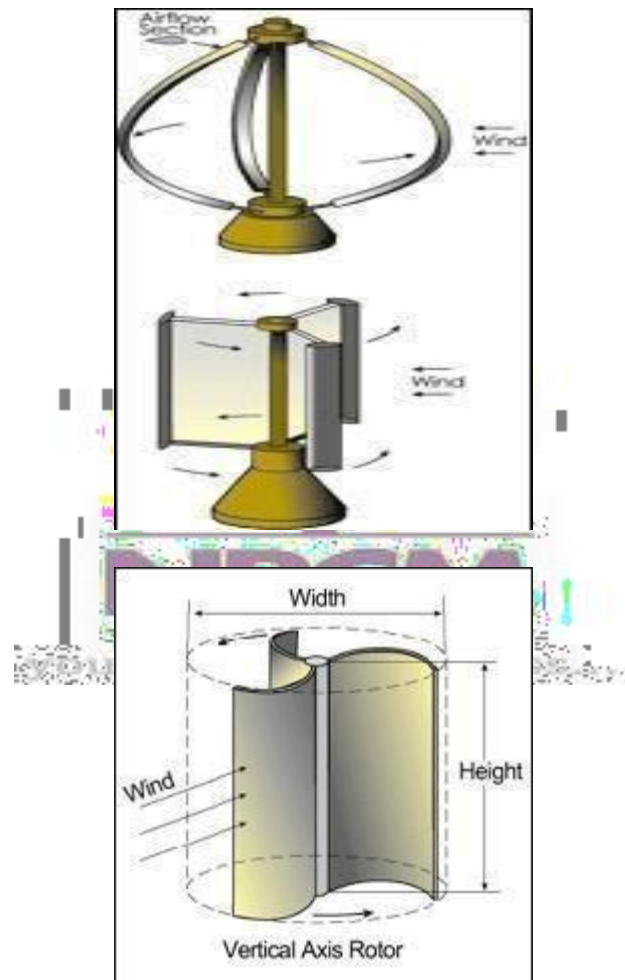
Wind turbines are classified into two general types: Horizontal axis and Vertical axis. A horizontal axis machine has its blades rotating on an axis parallel to the ground as shown in the above figure. A vertical axis machine has its blades rotating on an axis perpendicular to the ground. There are a number of available designs for both and each type has certain advantages and disadvantages. However, compared with the horizontal axis 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 vane is usually used to keep the blades facing into the wind. Other designs operate in a downwind mode so that the wind passes the tower before striking the blades. Without a tail vane, the machine rotor naturally tracks the wind in a downwind mode. Some very large wind turbines use a motor-driven mechanism that turns the machine in response to a wind direction sensor mounted on the tower. Commonly found horizontal axis windmills are aero-turbine mills with 35% efficiency and farm mills with 15% efficiency.

Vertical Axis:

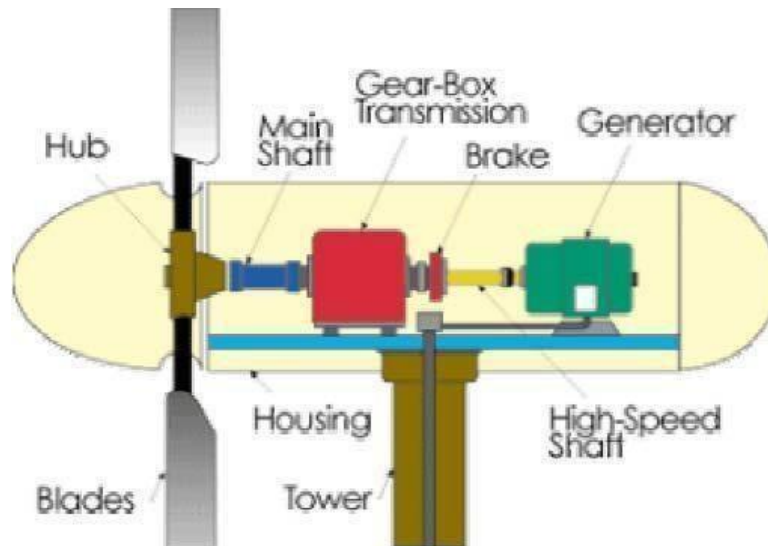
Although vertical axis wind turbines have existed for centuries, they are not as common as their horizontal counterparts. The main reason for this is that they do not take advantage of the higher wind speeds at higher elevations above the ground as well as horizontal axis turbines. The basic vertical axis designs are the Darrieus, which has curved blades and efficiency of 35%; the Giromill, which has straight blades and efficiency of 35%; and the Savonius, which uses scoops to catch the wind and has an efficiency of 30%. A vertical axis machine need not be oriented with respect to wind direction. Because the shaft is vertical, the transmission and generator can be mounted at ground level, allowing easier servicing and a lighter weight, lower-cost tower. Although vertical axis wind turbines have these advantages, their designs are not as efficient at collecting energy from the wind as are the horizontal machine designs. The following figures show all the above-mentioned mills.



There is one more type of windmill called the Cyclo-gyro windmill, with very high efficiency of about 60%. However, it is not very stable and is very sensitive to wind direction. It is also very complex to build.

Main Components of a wind-mill:

Following figure shows typical components of a horizontal axis windmill.



Rotor:

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

Drag Design:

Blade designs operate on either the principle of drag or lift. For the drag design, the wind literally 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 pumping, sawing, or grinding work. For example, a farm-type windmill must develop high torque at start-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 to fly. The blade is essentially an air foil, or wing. When air flows past the blade, a wind speed 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 blades are attached to a central axis, like a wind turbine rotor, the lift is translated into rotational motion. Lift-powered wind turbines have much higher rotational speeds than drag types and are therefore well suited for electricity generation.

TipSpeedRatio:

The tip-speed is the ratio of the rotational speed of the blade to the wind speed. The larger this 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 have maximum 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 the lift-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 wind turbine performance. For a lift-type rotor to function effectively, the wind must flow smoothly over the blades. To avoid turbulence, spacing between blades should be great enough so that one blade will not encounter the disturbed, weaker airflow caused by the blade which passed before it. It is because of this requirement that most wind turbines have only two or three blades on their rotors.

Generator:

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

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

Generators that produce AC are generally equipped with features to produce the correct voltage of 240V and constant frequency of 50 cycles of electricity, even when the wind speed 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 use of 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 typically require rpm's of 1,200 to 1,800. As a result, most wind turbines require a gear-box transmission to increase the rotation of the generator to the speeds necessary for efficient electricity 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 drive systems. Without a transmission, wind turbine complexity and maintenance requirements are reduced, but a much larger generator is required to deliver the same power output as the AC-type wind turbines.

Tower:

The tower on which a wind turbine is mounted is not just a support structure. It also raises the wind turbine so that its blades safely clear the ground and so it can reach the stronger 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 be based on the cost of taller towers versus the value of the increase in energy production resulting from their use. Studies have shown that the added cost of increasing tower height is often justified by the added power generated from the stronger winds. Larger wind 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 the guy wires. Some of these guyed towers are erected by tilting them up. This operation can be quickly accomplished using only a winch, with the turbine already mounted to the tower top. This simplifies not only installation, but maintenance as well. Towers can be constructed 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-up towers.

Towers must be strong enough to support the wind turbine and to sustain vibration, wind loading, 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 windmills:

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

RatedSpeed:

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 10 kilowatts until wind speeds reach 40 kmph. Rated speed for most machines is in the range of 40 to 55 kmph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases. The output of most machines' levels off above the rated speed. Most manufacturers provide graphs, called "power curves," showing how their wind turbine performs.

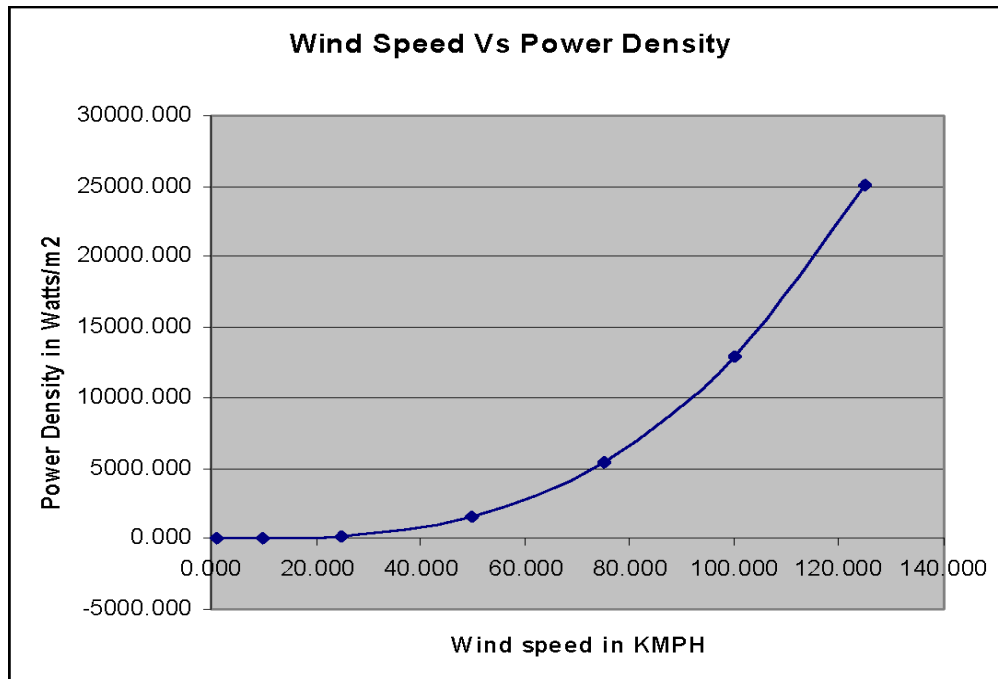
Cut-outSpeed:

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 shutdown occurs is called the cut-out speed. Having a cut-out speed is a safety feature which protects the wind turbine from damage. Shutdown may occur in one of several ways. In some machines an automatic brake is activated by a wind speed sensor. Some machines twist or "pitch" the blades to spill the wind. Still others use "spoilers," drag flaps mounted on the blades or the hub which are automatically activated by high rotor rpms, or mechanically activated by a spring-loaded device which turns the machine sideways to the wind stream. Normal wind turbine operation usually resumes when the wind drops back to a safe level.

BetzLimit:

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 theoretical maximum amount of energy in the wind that can be collected by a wind turbine's rotor is approximately 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, including rotor, transmission, generator, storage, and other devices, which all have less than perfect efficiencies, will deliver between 10% and 30% of the original energy available in the wind.

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



In the last column of the table, we have calculated the output of the turbine assuming that the efficiency of the turbine is 30%. However, we need to remember that the efficiency of the 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 1 square meter PV panel with 12% efficiency. We know that solar insolation available at the PV panel is 1000 watts/m² at standard condition. Hence the output of the PV panel with 12% efficiency would be 120 watts. Now the speed required to generate this power by the turbine with 30% efficiency can be calculated as follows:

$$\text{Turbine output required} = 120 \text{ watts/m}^2 \text{ Power density at the blades} = 120 / (0.3) = 400 \text{ watts/m}^2$$

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 as 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 three distinct categories:

Solid biomass-The use of trees, crop residues, animal and human waste (although 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 feedstocks for anaerobic digestion.

Liquid Biofuels-

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 this purpose.

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 the oxidation process, pollutants are broken down into carbon dioxide (CO₂), water (H₂O), 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.

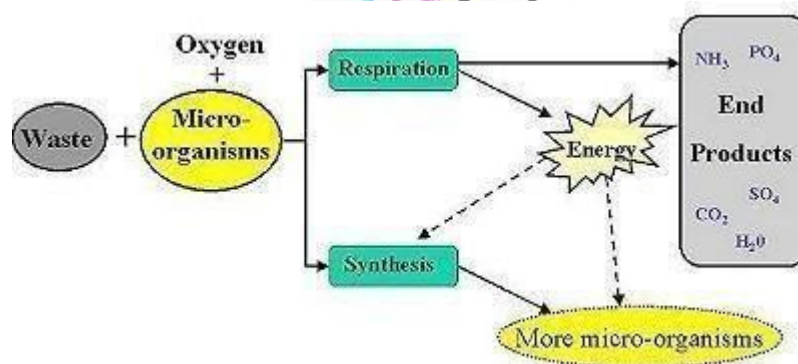
The Biological Oxygen Demand (BOD) is a measure of the quantity of dissolved organic pollutants that can be removed in biological oxidation by the bacteria. It is expressed in mg/l.

The Chemical Oxygen Demand (COD) measures the quantity of dissolved organic pollutants that 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

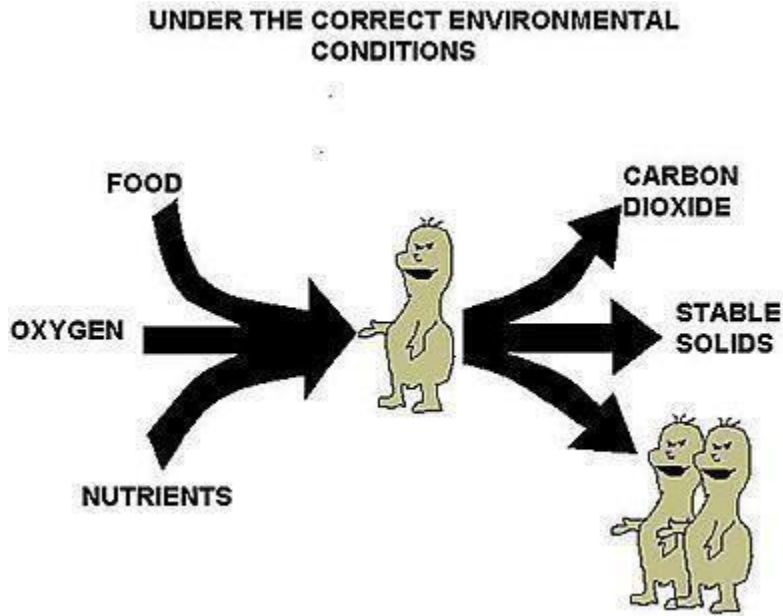
Aerobic bacteria are very efficient in breaking down waste products. The result of this is: aerobic treatment usually yields better effluent quality than that obtained in anaerobic processes. The aerobic pathway also releases a substantial amount of energy. A portion is used by the microorganisms for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



Path of Aerobic Digestion

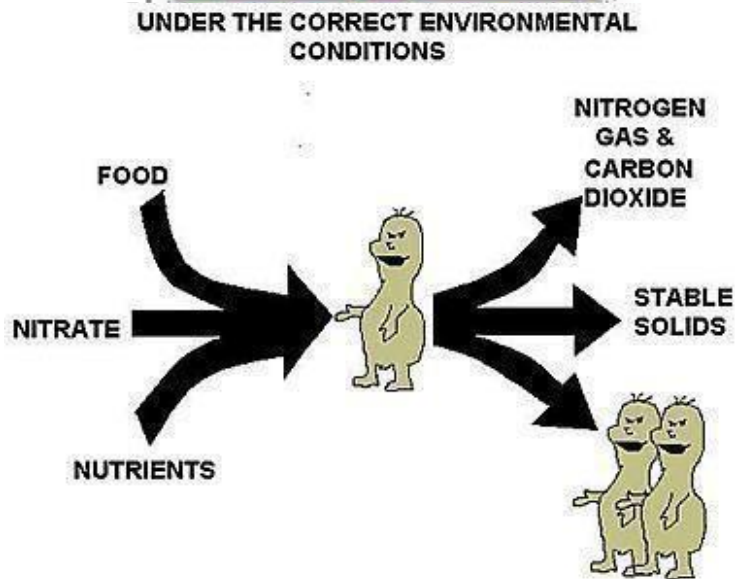
Aerobic Decomposition

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, carbon dioxide, 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 1½ days. Anoxic organisms work well with aerobic and anaerobic organisms. Facultative and anoxic are basically the same concept.



AnoxicDecomposition

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, stablesolids, andmoreorganisms.



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: Methane 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 possible 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.

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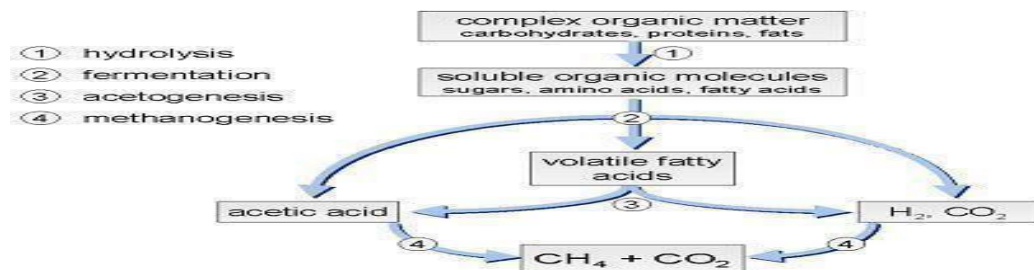
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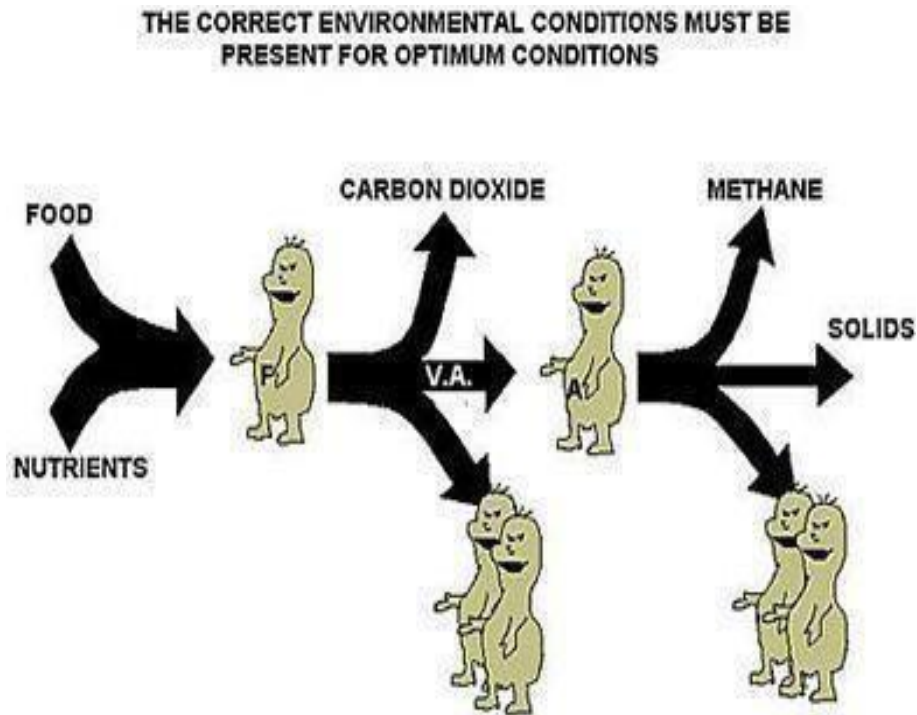
PathofanaerobicDigestion

AdvantagesofAnaerobicDigestion

Wastewater pollutants are transformed into methane, carbon dioxide, and smaller amounts 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.

AnaerobicDecomposition

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 sulphide, 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 consistently constant, slightly basic, to optimize the creation of methane. You need to constantly feed it sodium bicarbonate to keep it basic.



Biogas – Digestertypes

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-domeplants

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.

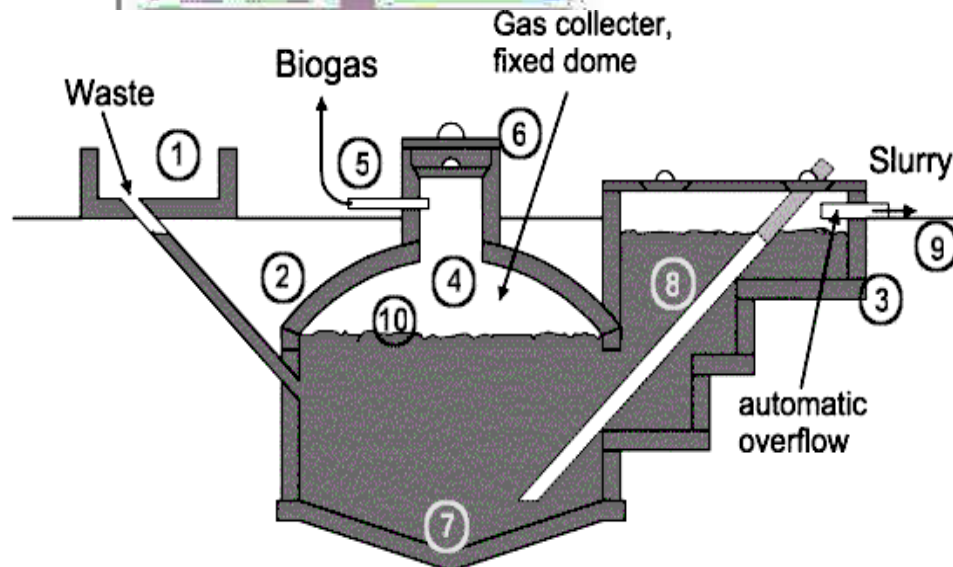


Figure 1: Fixed-dome plant Nicarao design:

Sources

1. Mixing tank with inlet pipe and sand trap
2. Digester
3. Compensation and removal tank
4. Gasholder
5. Gas pipe
6. Entry hatch, with gas-tight 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 a closed, dome-shaped digester with an immovable, rigid gas holder and a displacement pit, also named a 'compensation tank'. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e., with the height difference between the two slurry levels. If there is little gas in the gas holder, the gas pressure is low.

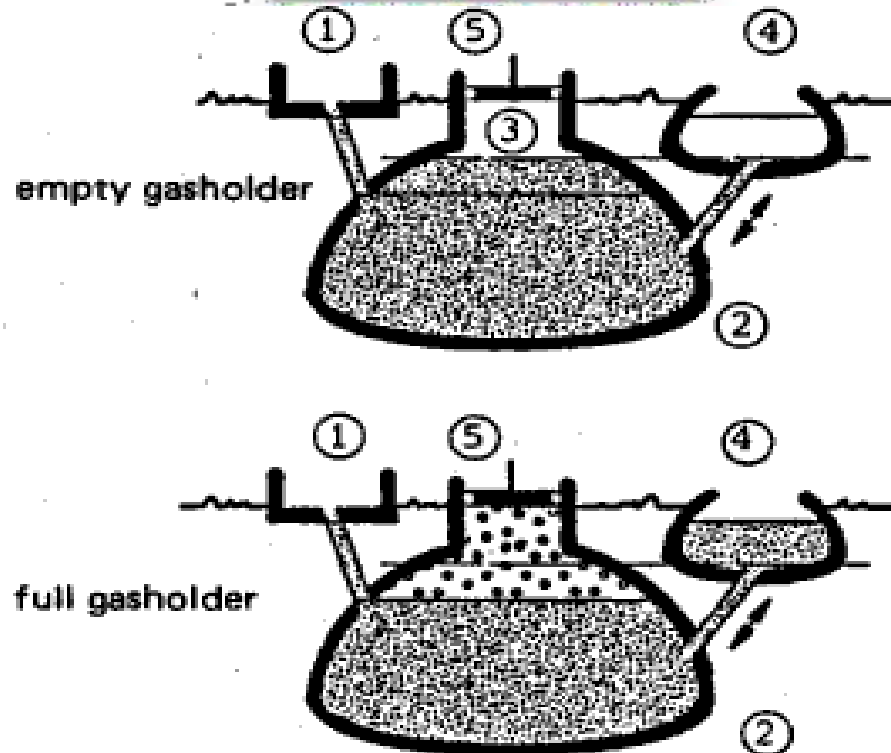


Figure2:Basicfunctionofafixed-domebiogasplant,1Mixingpit,2Digester,3Gasholder,4Displacementpit,5Gaspipe

Digester:

The digesters of fixed-dome plants are usually masonry structures; structures of cement and ferrocement also 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:



Figure3:Fixed-domeplantinTunisia.Thefinallayersofthemasonry structure arebeingfixed.

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 from moving into the upper parts of the gas-holder.

Typesoffixed-domeplants

- 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 led to cracks in the gas holder — very few of these plants 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.

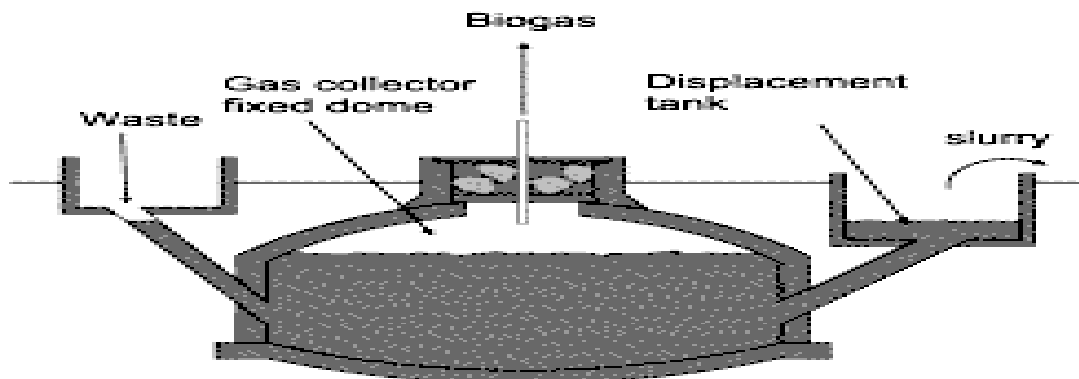


Figure4:Chinese fixeddomeplant

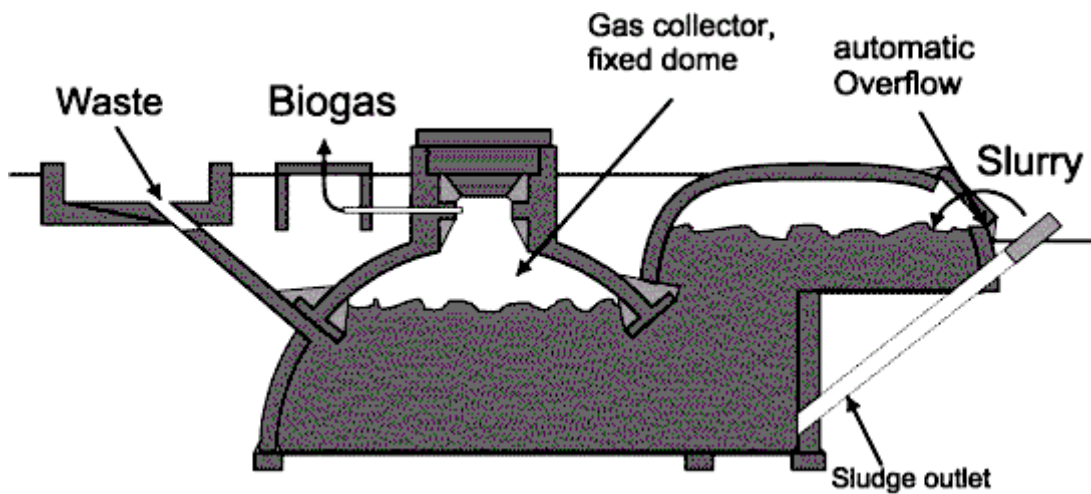


Figure5: FixeddomeplantCAMARTECdesign

Climateandsize

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 provides 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 200 m³ 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, P.R. China

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: 5–15 m³) or in institutions and larger agro-industrial estates (digester size: 20–100 m³).

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 gas-holder 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 lifetime 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 fiberglass reinforced polyester.
- BORDA model: The BORDA plant combines the static advantages of a hemispherical digester with the process stability of the floating-drum and the longer lifespan of a water-jacket plant.

