Module-3b: Biomass Energy

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Introduction to Biomass:

Biomass energy is a renewable and sustainable form of energy derived from organic materials, such as plants, crops, agricultural residues, forest residues, algae, and animal waste. These biomass resources can be converted into various forms of energy, including heat, electricity, and biofuels. Biomass energy has been used for centuries, but with advancements in technology, it has gained renewed attention as a viable alternative to fossil fuels.

The process of harnessing biomass energy typically involves one of the following conversion methods:

1. Combustion
2. Anaerobic Digestion
3. Gasification
4. Fermentation

Biomass energy offers several advantages:

1. Renewable and Sustainable
2. Reduced Greenhouse Gas Emissions
3. Waste Reduction
4. Energy Security

However, there are also challenges associated with biomass energy, such as ensuring sustainable sourcing, preventing competition with food production, and addressing potential environmental impacts. Proper management and responsible utilization are essential to maximize the benefits of biomass energy while minimizing its drawbacks.

The energy obtained from organic matter derived from biological organisms (plants and animals) is known as biomass energy or simply, bioenergy. Animals feed on plants and plants grow through the photosynthesis process using solar energy.

The photosynthesis process is primarily responsible for the generation of biomass energy. Biomass energy resources are available from botanical plants, vegetation, algae, animals and organisms living on land or in water.

Biomass resources are mainly classified into two categories. They are as follows:

l. Biomass from cultivated fields, crops, and forests.

2. Biomass from municipal waste, animal dung, forest waste, agricultural waste, bioprocess waste, and fishery waste.

Biomass energy may be transformed either by chemical or biological processes to produce intermediate bio-fuels such as methane, producer gas, ethanol and charcoal etc. Biomass cycle maintains the environmental balance of oxygen, C02, rain etc. Biomass is used for producing the process heat and electricity, gaseous and solid fuels, liquid and chemicals.

<u>Photosynthesis Process</u>

Biomass energy is obtained by the photosynthesis process. It means the synthesis process with light. Photosynthesis converts solar energy into biomass energy. It consists in building up simple carbohydrates such as sugar in the green leaf in the presence of sunlight. Solar radiation incident on green plants and other photosynthesis organisms perform two basic functions. They are given below.

1. Temperature control for chemical reactions to proceed and
2. Photosynthesis process.

The fundamental conversion process in green plants is photosynthesis. Photosynthesis is a complex process. It is the process of combining C02, water and light energy to produce oxygen and carbohydrates (sugar, starches, celluloses and hemicelluloses). They are the main source of our foods and clothes (in the form of cotton), furniture, etc. The net energy absorbed from solar radiation during photosynthesis can be measured from its combustion.

$$6CO_2 + 6\ H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

Necessary conditions for photosynthesis process:

1. Light: It is one of the important inputs for biomass production.

2. C02 concentration: It is the primary raw material for photosynthesis.

3. Temperature: Photosynthesis is restricted to the temperature range $O^{O}C$ to $60^{0}C$.

3. <u>BIOFUELS</u>

Biofuels are fuels derived from organic materials, such as plants, crops, algae, and animal waste, that can be used as a renewable and sustainable alternative to traditional fossil fuels. They are considered part of the larger group of renewable fuels and play a crucial role in reducing greenhouse gas emissions, enhancing energy security, and mitigating climate change.

There are several types of biofuels:

Bioethanol: Bioethanol is an alcohol-based biofuel primarily made from sugarcane, corn, wheat, or other carbohydrate-rich crops through a process called fermentation. It is commonly used as a gasoline additive to increase octane levels or as a standalone fuel in flexible-fuel vehicles.

Biodiesel: Biodiesel is a renewable diesel fuel derived from vegetable oils (e.g., soybean, rapeseed, palm, or used cooking oil) or animal fats. It is produced through a chemical process called transesterification, where the triglycerides in the oils or fats are converted into biodiesel and glycerol.

Biogas: Biogas is produced through anaerobic digestion, a biological process where organic matter, such as food waste, agricultural residues, or sewage sludge, is broken down by microorganisms in the absence of oxygen. The main component of biogas is methane, which can be used for electricity generation, heating, or as a vehicle fuel.

Syngas (Synthesis Gas): Syngas is a gas mixture produced through biomass gasification or other thermal processes. It consists mainly of carbon monoxide (CO) and hydrogen (H2) and can be further processed into biofuels like synthetic diesel or jet fuel.

Hydro-processing Vegetable Oil (HVO): HVO is a renewable diesel fuel produced through hydro processing of vegetable oils or animal fats. It has properties similar to fossil diesel and can be used in existing diesel engines without any modifications.

Green Jet Fuel: Green jet fuel is a bio-based aviation fuel derived from various feedstocks, including algae, plant oils, and agricultural residues. It is a promising option to reduce carbon emissions in the aviation sector.

Biofuels have the advantage of being carbon-neutral or low-carbon, as the carbon dioxide released during combustion is offset by the carbon dioxide absorbed during the growth of the feedstock. However, the production of biofuels must be managed sustainably to avoid negative impacts on food production, deforestation, and biodiversity. Research and technological advancements continue to improve the efficiency and viability of biofuel production, enabling their broader adoption as an eco-friendly energy source.

Biomass Resources

Biomass resources refer to organic materials derived from plants, animals, and microorganisms that can be used to produce energy or valuable products. These resources are renewable and widely available, making them an essential component of the sustainable energy landscape. Some common biomass resources include:

1. Agricultural Residues: Crop residues, such as straw, husks, stalks, and stems left after harvesting, can be utilized as biomass feedstock for energy production. These residues are often abundant in agricultural regions.
2. Energy Crops: Certain crops are grown specifically for biomass energy production. Examples include switchgrass, miscanthus, and fast-growing trees like willow and poplar.
3. Forestry Residues: Forest residues, such as branches, tops, and sawdust generated during timber harvesting and wood processing, can be used as a biomass resource.
4. Wood and Wood Waste: Wood is a versatile biomass resource and can be sourced from sustainably managed forests or urban wood waste, such as construction and demolition debris and wood packaging materials.
5. Municipal Solid Waste (MSW): Organic components of municipal waste, including food scraps and yard trimmings, can be processed for biomass energy production through composting or anaerobic digestion.
6. Animal Manure: Livestock waste, such as cow dung and poultry litter, can be processed through anaerobic digestion to produce biogas for energy.

7. Algae: Certain types of algae are being researched as a potential biomass resource for biofuels and high-value products due to their rapid growth and high lipid content.
8. Industrial Wastes: Various industrial processes generate organic waste that can be used as biomass resources, such as sawdust from wood processing, bagasse from the sugarcane industry, and spent grains from brewing.
9. Aquatic Biomass: Aquatic plants and algae growing in freshwater or marine environments can be harvested and used for biomass energy production.
10. Food Processing Residues: Residues generated during food processing, such as fruit peels, vegetable trimmings, and coffee grounds, can be utilized for biomass energy.

Biomass resources have the advantage of being carbon-neutral or low-carbon since the carbon dioxide released during combustion or decomposition is offset by the carbon dioxide absorbed during the growth of the biomass. Their utilization helps reduce greenhouse gas emissions, promote waste reduction, and contribute to a more sustainable energy system. However, responsible and sustainable management of biomass resources is essential to avoid negative environmental impacts, such as deforestation and competition with food production.

PRINCIPLES OF BIO-CONVERSION

Bioconversion, also known as biotransformation, is defined as the process of conversion of organic materials such as plant or animal waste into usable products or energy sources by biological processes or agents such as certain microorganisms.

BIOMASS CONVERSION PROCESSES

Biomass conversion processes refer to various methods used to convert organic matter derived from plants, animals, and microorganisms into useful energy or valuable products. Biomass is a renewable resource and can be a sustainable alternative to fossil fuels, helping to reduce greenhouse gas emissions and dependence on non-renewable resources. Some common biomass conversion processes include:

1. **Combustion:** Biomass can be burned directly to produce heat and steam, which can be used for electricity generation or heating applications. Biomass power plants and biomass stoves are examples of combustion-based systems.
2. **Anaerobic Digestion:** This process involves the decomposition of biomass by microorganisms in the absence of oxygen. It produces biogas, mainly composed of methane, which can be used for electricity generation and as a renewable natural gas source.
3. **Fermentation:** Biomass, particularly sugars and starches, can be fermented by microorganisms to produce biofuels like bioethanol (alcohol) and biodiesel. Bioethanol is commonly used as a transportation fuel, while biodiesel can be used as a diesel engine fuel.
4. **Gasification:** Biomass can be converted into a gas mixture known as "syngas" or synthesis gas through a high-temperature process in a low-oxygen environment. Syngas can be used for electricity generation, heating, or further converted into liquid fuels or chemicals.
5. **Pyrolysis:** This thermal decomposition process occurs in the absence of oxygen and converts biomass into bio-oil, biochar, and syngas. The bio-oil can be further processed into transportation fuels.

6. **Hydrothermal Processing:** Biomass is treated with heat and pressure in a water-based environment, leading to the production of bio-oil or biocrude, which can be upgraded to transportation fuels.

These biomass conversion processes play a crucial role in the development of bioenergy and the utilization of biomass as a sustainable source of energy and valuable products. However, it's essential to consider factors like feedstock availability, environmental impacts, and economic feasibility when implementing these processes on a larger scale.

Urban waste to energy conversion

Urban waste to energy conversion, also known as waste-to-energy (WTE) or energy-from-waste (EfW), is the process of converting municipal solid waste (MSW) generated in cities and urban areas into useful forms of energy. This approach helps to reduce the volume of waste sent to landfills, recover energy from the waste, and contribute to sustainable waste management and renewable energy production. Several methods are used for urban waste to energy conversion:

Incineration: Incineration is the most common method, where MSW is burned at high temperatures in a controlled environment. The heat generated during the combustion process is used to produce steam, which drives turbines to generate electricity.

Gasification: Gasification involves converting MSW into a combustible gas (syngas) by subjecting it to high temperatures in a low-oxygen environment. The syngas can then be used to produce electricity, heat, or further refined into transportation fuels or chemicals.

Anaerobic Digestion: Organic waste in MSW can be processed through anaerobic digestion, where microorganisms break down the waste in the absence of oxygen. This process produces biogas, which mainly contains methane and can be used for electricity generation or as a renewable natural gas source.

Pyrolysis: Pyrolysis is a thermal decomposition process that occurs in the absence of oxygen, converting organic components of MSW into biochar, bio-oil, and syngas. The bio-oil can be further processed into transportation fuels, and biochar can be used as a soil amendment.

Mechanical Biological Treatment (MBT): MBT is a combination of mechanical and biological processes that separate and treat organic waste from MSW. The organic portion can be used for anaerobic digestion or composting to produce biogas or compost, respectively.

Gasification and Its Types

A gasifier is a device that converts solid or liquid carbonaceous materials, such as biomass, coal, or municipal solid waste, into a combustible gas known as syngas (synthesis gas). Syngas mainly contains carbon monoxide (CO), hydrogen (H_2), and other components like methane (CH_4), carbon dioxide (CO_2), and nitrogen (N_2).

The main types of gasifiers:

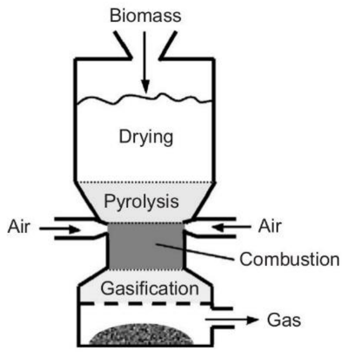
Updraft gasifiers: These gasifiers are the simplest type of gasifier. The fuel is fed into the top of the reactor, and air is blown in from the bottom. The gasification reactions occur in a countercurrent flow, with the hot gases rising through the fuel bed. Updraft gasifiers are typically used for small-scale applications, such as cooking and heating.

Downdraft gasifiers: These gasifiers are similar to updraft gasifiers, but the fuel is fed into the bottom of the reactor and air is blown in from the top. The gasification reactions occur in a concurrent flow, with the hot gases descending through the fuel bed. Downdraft gasifiers are typically used for larger-scale applications, such as electricity generation and industrial heat.

Cross draft gasifiers: These gasifiers are a hybrid of updraft and downdraft gasifiers. The fuel is fed into the side of the reactor, and air is blown in from both the top and bottom. The gasification reactions occur in a crosscurrent flow, with the hot gases moving horizontally through the fuel bed. Crossdraft gasifiers are typically used for applications where a high-quality syngas is required.

Down Draft Biomass Gasification

Down-draft biomass gasification is a thermochemical process that converts biomass into a combustible gas called syngas (synthesis gas) in a downward flow of reactants and gases. This gasification process occurs in a fixed-bed reactor, and it is one of the common types of biomass gasification technologies used to produce renewable energy and valuable products.



The main steps involved in down-draft biomass gasification are as follows:

Feedstock Preparation: Biomass, such as wood chips, agricultural residues, or energy crops, is dried and sometimes ground into small particles to improve gasification efficiency.

Charging: The prepared biomass is loaded into the gasifier's upper chamber, called the reaction zone or gasification zone.

Gasification: The biomass is subjected to high temperatures (typically between 700 to 1,200 degrees Celsius) in the presence of a limited amount of air or oxygen. In down-draft gasifiers, air or oxygen is introduced at the top of the reactor, and it moves downward through the biomass bed.

Drying and Pyrolysis: Initially, the heat from the combustion of a small portion of the biomass drives off moisture and initiates pyrolysis, a process where organic material breaks down into volatile gases, tars, and char.

Reduction and Gasification: As the gases and heat move downward through the biomass bed, the remaining volatile components undergo reduction reactions, converting into carbon monoxide (CO) and hydrogen (H2) in the presence of char and some oxygen.

Syngas Production: The product of gasification is a mixture of CO, H2, methane (CH4), carbon dioxide (CO2), nitrogen (N2), and trace amounts of other gases. This mixture is collectively referred to as syngas.

Gas Exit and Cleanup: The syngas exits the gasifier through an outlet at the bottom of the reactor. Before utilization, the gas typically undergoes cleaning processes, such as tar and particulate removal, to ensure the gas is suitable for use in various applications.

Merits:

- Produce syngas with a low tar content
- Relatively simple to operate and maintain
- Can gasify a variety of biomass feedstocks, including those with high moisture and ash content
- Can be used to produce a variety of products, including electricity, heat, and vehicle fuel

Demerits:

- Can be more expensive to build than other types of gasifiers
- Has a lower gas yield than other types of gasifiers
- Can be susceptible to slagging and fouling, especially when gasifying biomass with high ash content
- Requires careful control of the gasification process to avoid the production of harmful pollutants

Biogas Energy

- Biogas is a mixture of different gases, such as methane, carbon dioxide, hydrogen, etc., produced by the biological breakdown of organic matter in the absence of oxygen.
- It is a renewable energy source, and in many cases, it exerts a very small carbon footprint.
- Biogas can be produced by either anaerobic digestion with anaerobic bacteria, which digest material inside a closed system, or fermentation of biodegradable materials.
- Anaerobic digestion is a process that breaks down organic matter into simpler chemical components in the absence of oxygen.
- This process has proved to be very effective to treat organic wastes for minimizing environmental pollution.

The common organic wastes are listed as follows:

1. Sewage sludge
2. Organic farm wastes
3. Municipal solid wastes
4. Organic industrial and commercial wastes
5. Forests and agricultural wastes

- The digestion process itself takes place in digester, which is classified in terms of temperature, water content of feedstock and the number of stages (single or multi-stage).
- The by-products of anaerobic digestion, namely biogas and digestate.

BIOGAS AND ITS COMPOSITION

- Biogas is a clean, non-polluting, and low-cost fuel.
- It contains about 50%–70% methane, which is inflammable.
- A methane gas molecule has one atom of carbon and four atoms of hydrogen (CH_4) and is the main constituent of popularly known biogas.
- A colourless, odourless, inflammable gas also been referred to as sewerage gas, clear gas, marsh gas, refuse-derived fuel (RDF), sludge gas, gobar gas (cow dung gas), and bio energy.
- It produces about 9,000 kcal of heat energy per cubic metres of gas burnt and specifically used for cooking, heating, and lighting.
- The composition of biogas, which mainly composed of 50% to 70% methane (CH_4), 30% to 40% carbon dioxide (CO_2), and traces of other gases.
- Biogas is lighter than air by about 20% and has an ignition temperature in the range of 650°C to 750°C burns with clear blue flame similar to that of liquefied petroleum gas (LPG) and burns with 60% efficiency in a conventional biogas stove.

ANAEROBIC DIGESTION

- It is a biological process that produces a gas (commonly known as biogas) in the absence of oxygen and has major components of methane (CH4) and carbon dioxide (CO2).
- Anaerobic digestion of methane gas production is a series of processes in which microorganism break down biodegradable material in the absence of oxygen which completes through following steps:

1. In the first step, the organic matter (e.g. plants residues, human and animal wastes and residues) is decomposed (hydrolysis) to break down the organic material into usable-sized molecules such as sugar.

2. Conversion of decomposed matter into organic acids is the second step.

3. Finally, organic acids are converted to biogas (methane gas).

Process Stages of Anaerobic Digestion

The biological and chemical stages of anaerobic digestion are shown in Figure 4.6. These are divided into the following four main stages:

1. Hydrolysis 2. Acedogenesis 3. Acetogenesis 4. Methanogenesis

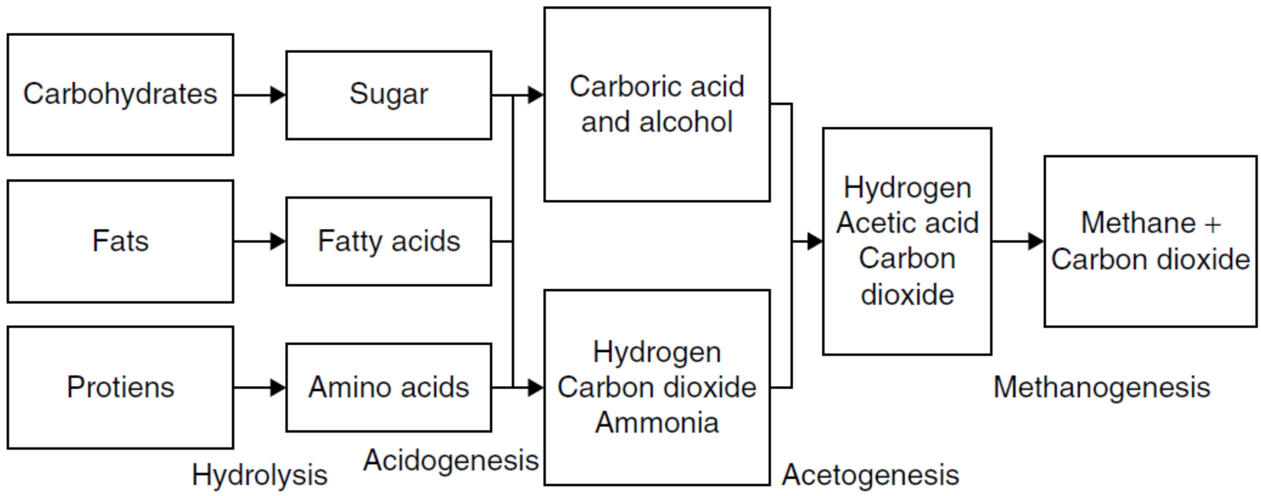


Figure 4.6 Process of Anaerobic Digestion

The four main stages are explained as follows.

Hydrolysis

- The process of breaking large biomass organic chains into their smaller constituent parts such as sugar, fatty acids, and amino acids and dissolving the smaller molecules into solution is called **hydrolysis**.
- This process assists bacteria in anaerobic digesters to access the energy potential of the material.
- Hydrolysis of these high-molecular-weight polymeric components of biomass completes the first step in anaerobic digestion.

Acidogenesis

- Acidogenesis is the biological process in which the remaining components are broken down by acidogenetic (fermentative) bacteria.
- It creates voltaic fatty acids together with ammonia, carbon dioxide, and hydrogen sulphide, and other by-products.

Acetogenesis

- In this stage of anaerobic digestion, simple molecules created through the acidogenesis phase are further digested to produce more acetic acid, carbon dioxide, and hydrogen.

Methanogenesis

- Finally, the process of biogas production is completed by methanogenesis.
- In this stage of anaerobic digestion, the methanogens use intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water which makes the majority of the biogas emitted from the system.
- Methanogenesis is sensitive to both high and low pH values.
- A simplified generic chemical equation for the overall processes is as follows:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

The remaining indigestible material cannot be used by microbes and any dead bacterial remains constitute the digestate.

Construction Parts of Biogas Plants

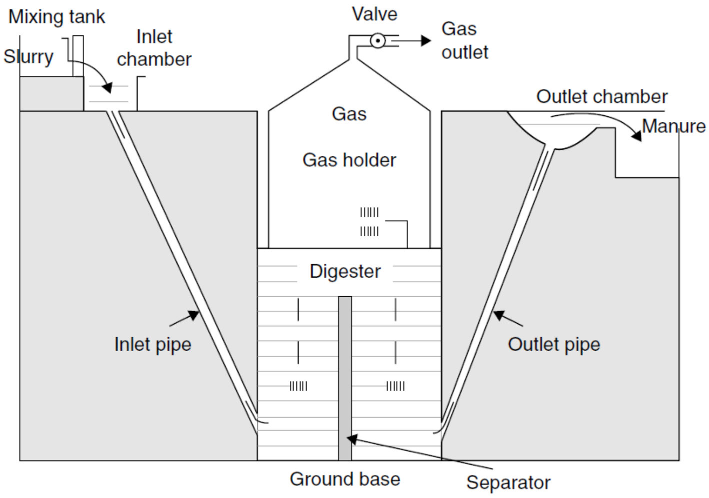


Figure 4.7 A typical Biogas Plants

Figure 4.7 shows various parts of the typical biogas plant.

It is a brick and cement structure having the following five sections:

1. Mixing tank
2. Digester tank

3. Dome or gas holder

4. Inlet chamber

5. Outlet chamber

Mixing Tank

- It is the first part of biogas plants located above the ground level in which the water and cow dung are mixed together in equal proportions (the ratio of 1:1) to form the slurry that is fed into the inlet chamber.

Digester Tank

- It is a deep underground well-like structure and is divided into two chambers by a partition wall in between.
- It is the most important part of the cow dung biogas plants where all the important chemical processes or fermentation of cow dung and production of biogas takes place.
- The digester is also called as **fermentation tank**.
- It is cylindrical in shape and made up of bricks, sand, and cement built underground over the solid foundation.
- Two openings are provided on the opposite sides and at the specified height of digester for inflow of fresh cow dung slurry and outflow of used slurry as manure.

The two long cement pipes are used as follows:

1. Inlet pipe opening into the inlet chamber for inputting the slurry in digester tank.

2. Outlet pipe opening into the overflow tank (outlet chamber) for the removal of spent slurry from the digester tank.

- A separator is also placed in the middle of digester tank to improve effective fermentations of feedstock.

Dome or Gas Holder

- The hemispherical top portion of the digester is called dome.
- It has fixed height in which all the gas generated within the digester is collected.
- The gas collected in the dome exerts pressure on the slurry in the digester.

The dome or gas holder is made either fixed dome or floating dome type.

- Cement and bricks are used in the construction of fixed dome, and it is constructed using approximately at the ground surface.
- Floating dome type is an inverted steel drum resting on the digester above the ground surface.
- The drum floats over the digester and moves up and down with biogas pressure.

Inlet Chamber

- The cow dung slurry is supplied to the digester of the biogas plant via inlet chamber, which is made at the ground level so that the slurry can be poured easily.
- It has bell mouth sort of shape and is made up of bricks, cement, and sand.
- The outlet wall of the inlet chamber is made inclined so that the slurry easily flows into the digester.

Outlet Chamber

- The digested slurry from the biogas plants is removed through the outlet chamber.
- The opening of the outlet chamber is also at the ground level.
- The slurry from the outlet chamber flows to the pit made especially for this purpose.

Gas Outlet Pipe and Valve

- The gas holder has an outlet at the top which could be connected to gas stoves for cooking or gas-lighting equipments or any other purpose.
- Flow of the gas from the dome via gas pipe can be controlled by valve.
- The gas taken from the pipe can be transferred to the point of use.

Fixed Dome Type Biogas Plant

A Schematic of a fixed dome biogas plant is given in Figure 4.8. It consists of the following parts.

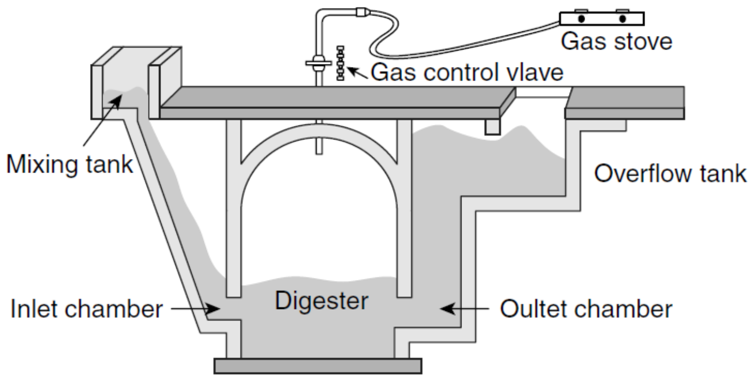


Figure 4.8 Fixed dome type Biogas Plant

***Mixing tank*:**

- In mixing tank, the water and cattle dung are mixed together thoroughly in the ratio of 1:1 to form the slurry.

***Inlet chamber*:**

- The mixing tank opens underground into a sloping inlet chamber.

***Digester*:**

- Digester is a huge tank with a dome type ceiling.

- The ceiling of the digester has an outlet with a valve for the supply of biogas.
- The inlet chamber opens from below into the digester tank.
- The digester opens from below into an outlet chamber which is opened from the top into a small overflow tank.

Working Principle

- The various forms of organic biodegradable biomass are collected and mixed with equal amount of water properly in the mixing tank to form slurry.
- The slurry is fed into the digester tank through inlet chamber and pipe, and the digester is partially filled by about half of its height.
- The feeding of slurry is then discontinued for about 60 days when anaerobic bacteria present in the slurry decomposes or ferments the biomass in the presence of water.
- Biogas is then formed and starts accumulating in the upper dome area of the biogas plants, and the pressure is exerted on the spent slurry to force it flow into the outlet chamber.
- Finally, the spent slurry overflows into the overflow tank from where it is manually removed and used as manure for agricultural crops and plants.
- Gas control valve at the top of dome is opened partially or fully to supply required gas for particular applications.

Advantages of fixed dome-type biogas plant are as follows:

1. The costs of a fixed dome biogas plant are relatively low as compared to floating dome type.
2. It is simple in construction as no movable dome exists.
3. It is made up of concrete, bricks, and cements and long life of the plant (20 years or more) can be expected.
4. Underground and almost ground surface dome construction saves space and protect from physical damage to the plant.
5. The anaerobic digestion processes in the digester are little influenced by temperature fluctuation in day and night.

Disadvantages of biogas plant are as follows:

1. Porosity and cracks in plant walls is the major drawbacks.
2. Maintenance is rather difficult.