Unit 3 - BIO MASS

INTRODUCTION

Plants grow through photosynthesis process which takes place primarily in their green leaves. Biomass is mainly in the form of wood and it is the source of energy. Biomass is used both in domestic and in industrial activities by way of direct combustion. Hence, we use solar energy in the form of biomass for cooking and heating purpose. The dominant use of biomass or fuel wood in the world is made for cooking and heating primarily in rural areas. Biomass accounts for about 15% of the energy used in the world. Biogas is the gaseous fuel which is obtained from biomass by means of anaerobic fermentation. The raw materials for biogas include waste from agriculture, waste from forest, rural animal waste, urban waste (left over food and other rubbish) and aqua waste (fishery, algae and hyacinth).

Biomass is organic or carbon-based material that can either react with oxygen for combustion or undergo metabolic process to release heat.

Biomass can be used as such in its original form. More often, it is transformed to more convenient and useful form, thereby forming solid, liquid and gaseous fuels.

PHOTOSYNTHESIS

Photosynthesis is the process by which plants use their chlorophyll in green leaves to convert solar energy into carbohydrates in the presence of carbon dioxide from the atmosphere and water. The carbohydrates are used by plants for their growth. The plants absorb red and blue light but they do not absorb green light. This is the reason why leaves of plant or chlorophyll look green. The overall chemical reaction involved in photosynthesis is as follows:

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

In respiration process, energy is released which is used by plant for growth and other activities.

$$\text{Carbohydrate} + O_2 = CO_2 + \text{energy} + \text{water}$$

Biomass production efficiency

It is the efficiency of converting incident solar energy into the chemical energy, that is, carbohydrates in plants. Plants use visible light with wavelengths between 0.4 and 0.7 μm, which is called photosynthetically active radiation (PAR). To understand biomass production efficiency, consider that (i) intercepted PAR is 50% of the total radiation, (ii) 80% of intercepted PAR is used by photosynthetically active compounds and rest is lost, (iii) 28% of used energy is converted into carbohydrates and (iv) 40% carbohydrates energy is used in respiration. Then biomass production efficiency is given by:

$$\eta = 100 \times 0.50 \times 0.86 \times 0.28 \times 0.60$$

$$= 6.7\%$$

Condition for photosynthesis

The photosynthesis depends on the following factors:

(i) Temperature should be between 20 and 30°C to have photosynthesis at the maximum rate.
(ii) Concentration of carbon dioxide in atmosphere as it increases the photosynthesis.
(iii) Concentration of oxygen as it reduces the photosynthesis
(iv) Water as its use efficiency increases with photosynthesis
(v) Intensity and proper wave distribution of solar radiation as PAR increases the photosynthesis.

Biofuels

The biofuels can be fuelwood, charcoal, fuel pellets, bioethanol, biogas, producer gas and biodiesel.

Fuel wood

It is the most common source of biomass energy. Direct combustion is the simplest way to obtain heat energy. It has energy density of about 16–20 MJ/kg.

Charcoal

It is obtained by carbonization of woody biomass. This helps in providing higher energy density per unit mass of about 30 MJ/kg. Charcoal can burn without generating smoke.

Fuel pellets

Fuel pellets are formed from crop residues such as straw or rice husk which are pressed into solid mass.

Bioethanol

It is derived from wet biomass containing sugars from sugarcane, starches from grains and potatoes or cellulose from woody matters. Ethanol (C_2H_5OH) is a colourless liquid biofuel with boiling point of 78°C and energy density of 26.9 MJ/kg.

Biogas

Biogas is the gaseous fuel obtained from biomass (organic waste from plants, animals and humans) by means of anaerobic digestion or fermentation. The anaerobic digestion process can be profitably applied to any wet organic matters. Anaerobes are microorganisms or bacteria found to live and grow in organic matter at the temperature of less than 60° in presence of moisture but in the absence of air or oxygen. The anaerobic organism consumes oxygen which it obtains from decomposition of organic matters. Decomposition of the organic matters by anaerobic microorganism is called digestion or fermentation. The biogas is liberated from the organic matters during digestion or fermentation. The biogas produced by digestion contains (i) methane gas (CH_4) 65–75%, (ii) carbon dioxide gas (CO_2) 25–35% and (iii) small traces of nitrogen, ammonia, hydrogen sulphide and other gases. The biogas has energy density of about 23 MJ/m^3. It can be used for cooking, lighting, heating and operating small IC engines.

Producer gas

It is obtained by gasification of solid fuels. In this, woody matter (crop residue, wood chips, rice husk, coconut shell and sugarcane residue) is converted into producer gas by thermochemical method which is infact the partial combustion and reduction operation of biomass. The producer gas has 19% carbon monoxide, 18% hydrogen, 1% methane, 11% carbon dioxide and the rest remaining nitrogen. The producer gas is used for IC engines for running pumps, motor vehicles, heating and generation of steam in a small-scale power plant.

Biodiesel

It is produced by blending of vegetable oils, with normal diesel to obtain cheaper version of diesel engine fuel. Besides vegetable oils, certain hydrocarbons having molecular weight equal to that of petroleum and that are obtainable as by-products from certain plants can also be used for blending purpose.

Biomass Resources

The biomass resources include organic materials obtainable from forest, agriculture, aqua culture and organic waste residue from industrial and social activities.

Forests

Forests (natural or cultivated) are source of fuel wood, charcoal and producer gas. Forest waste and residues from forest processing plants can be used as biomass. Certain plants produce seeds to yield vegetable oils which can also be used in biofuels.

Agriculture residues

Straw, rice husk, groundnut shell, coconut shell and sugarcane bagasse are crop residues which are the main biomass resources. The crop residues are generally gasified to obtain producer gas. The crop residues are also converted into fuel pellets to be used as solid fuels.

Energy crops

Energy crops are those cultivations which provide raw materials for biofuels. These include (i) sugar plants to provide bioethanol, (ii) starch plants (tubular plants and grains) to produce bioethanol and (iii) oil producing plants (sunflower, palm oil, groundnut and cottonseeds) to produce biodiesel.

Urban waste

Urban waste can be garbage or municipal solid waste (MSW) and sewage or liquid waste. Garbage can be burnt to obtain biomass energy while sewage has to be processed to obtain biogass.

Aquatic plants

Certain aquatic or water plants are capable of growing extremely fast and supply organic raw materials for producing biogas. The fast growing water plants include water hyacinth, seaweed, algae and kelp.

Advantages and Disadvantages of Biomass Energy

Advantages

(i) It is a renewable source.
(ii) It can be stored and used as per the requirement.
(iii) It helps in waste management.
(iv) It is an indigenous source of energy.
(v) It helps in economic development of rural areas.
(vi) It helps in improving sanitation in rural areas and towns.
(vii) It helps in providing fertilisers.
(viii) It provides economical use of various types of wastes and residues.

Disadvantages

(i) It has low energy density.
(ii) It is a labour intensive energy source.
(iii) Its production requires large land area.

BIOGAS

Biogas is the gaseous fuel which is obtained from biomass by means of an anaerobic digestion or fermentation of wet organic matters. The biogas is a flammable gas. The composition of biogas includes 50–60% methane gas, 35–40% carbon dioxide, 5% hydrogen and a small amount of hydrogen sulphide and other gases. Methane and hydrogen gases form the combustible portion of biogas. The biogas has energy density of about 23 MJ/m^3. It can be used for cookings, heating, lighting and running small IC engine.

Aerobic and Anaerobic Processes

The literary meaning of aerobic is any process taking place in the presence of air, while anaerobic means any process taking place in the absence of air or oxygen. It is the anaerobic process or digestion in biomass slurry which helps in converting biomass into biogas. The anaerobic digestion or fermentation in biomass slurry is started by a microorganism called anaerobe. The anaerobe microorganism grows on biomass at a temperature lower than 65°C in the presence of moisture but in the absence of air or oxygen. The microorganism anaerobe consumes oxygen for survival and growth which is obtained from the digestion or fermentation of the wet organic matter. During anaerobic digestion of wet biomass slurry, the biogas is liberated. Anaerobic bacteria are also called methane formers.

Biogas is produced from biomass slurry having 90–95% water content by the bacterial action of microorganism called anaerobe. The carbon part of biomass is oxidized and the remaining is reduced to produce mainly methane gas (65–75%) and carbon dioxide (25–35%). These bacteria are found to live and grow without atmospheric oxygen as they produce themselves the needed oxygen by decomposing the biomass. The digestion or fermentation process of wet biomass by these bacteria is favoured by the factors such as wetness, warmness and darkness conditions.

The general equation for anaerobic digestion is as follows:

$$C_xH_yO_z + \left(x - \frac{y}{4} - \frac{z}{2}\right) H_2O \rightarrow \left(\frac{x}{2} - \frac{y}{8} + \frac{z}{4}\right) CO_2 + \left(\frac{x}{2} + \frac{y}{8} - \frac{z}{4}\right) CH_4$$

In case of cellulose, the equation is given by:

$$(C_6H_{10}O_5)_n + n\ H_2O \rightarrow 3n\ CO_2 + 3m\ CH_4$$

The airtight equipment used to convert the wet biomass into biogas by digestion or fermentation process is called biogas digester or plant which is properly constructed and controlled to favour biogas or methane production. The conversion process is called biodigestion or anaerobic fermentation and the output is methane or biogas. The residuals or nutrients such as soluble nitrogen compounds remaining in the wet biomass slurry provide or produce excellent natural fertilizers and humus. The biogas can provide 60–75% of the energy of the dry converted biomass during combustion.

The biochemical process of converse in from biomass to biogas takes place in the following three stages:

(i) **Hydrolysis of organic matter.** The biomass (complex compounds of carbohydrate, protein and fats) is broken due to the action of water (hydrolysis) into simpler soluble compounds. Similarly, large molecules (polymers) are reduced to basic molecules (monomers). The process is completed in a day at a temperature of about 25°C.

(ii) **Anaerobic and faculative microorganisms.** These bacteria start growing to produce acetic and propionic acids. The process is completed in a day at the temperature of 25°C. The output of the process is the production of carbon dioxide.

(iii) **Digestion.** Anaerobic bacteria slowly digest the biomass slurry to produce biogas. The process is completed in 2 weeks at the temperature of about 25°C.

Digester

The anaerobic digester or plant is shown in Figure 5.1. Feed consists of organic material slurry prepared in mixing tank. Feed supply per day to the digester is called the loading rate.

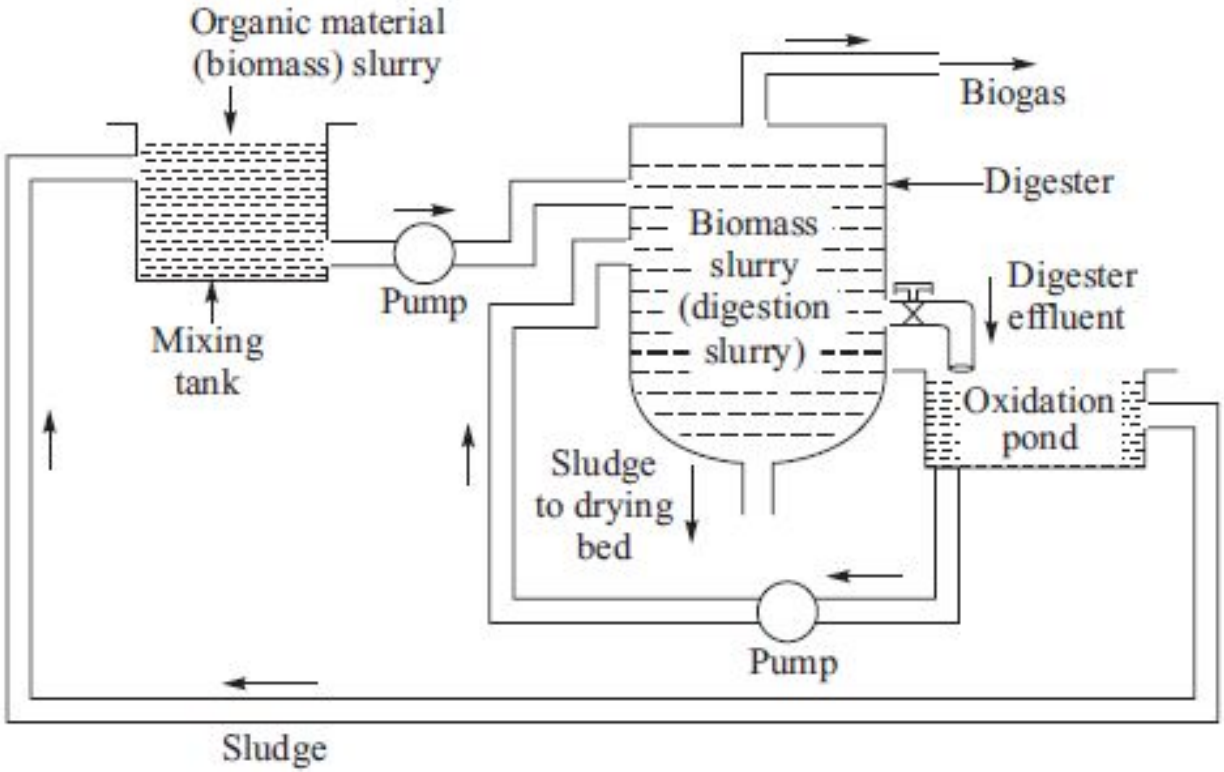

Figure 5.1 Biogas digester or plant.

Neither overloading nor underloading of the digester is desirable as it reduces biogas production. The acid forming bacteria grows rapidly, whereas methane forming bacteria (anaerobe) grows slowly. To obtain maximum biogas generation rate, seeding of digestion slurry with methane forming bacteria is done. This is achieved by adding certain portion of digested slurry to the fresh slurry. It is also possible to add nutrients containing nitrogen, hydrogen, oxygen, phosphorous, sulphur and carbon, which can also increase the anaerobic digestion rate. The recommended pH value for the digestion of biomass slurry is about to 7–8.

Advantages of anaerobic digestion

(i) It helps to obtain energy from discarded or waste matter. Otherwise, waste matter has to be disposed off with some additional cost.
(ii) It helps to provide two main benefits which include fuel by biogas and fertilizer in the form of sludge.
(iii) The process helps in conserving complete nitrogen content of the biomas. Hence, fertilizer produced as sludge is better in terms of both quantity and quality.
(iv) It helps in the waste management of an industry such as dairy or milk processing plant with simultaneously meeting the energy requirement of the same industry.
(v) It helps in the urban waste management such as municipal solid waste or garbage and sewage or liquid waste. The better management of urban waste improves the sanitation and hygiene in villages and towns.
(vi) Anaerobic digestion is carried out in the airtight enclosures, which helps in containing and controlling the odours of solid and liquid wastes. Digested slurry is completely odourless.

Raw material for biogas

The raw materials for biogas can be waste, cultivated material and harvested material. The waste includes industrial waste, agricultural crop residues and waste, animal waste, urban waste, aqua waste and forest waste. Agricultural crops include rice, wheat and cereals while agricultural wastes include wheat straw, sugarcane biogasses, groundnut shell, coconut shell and rich husk. Animal wastes include cow dung, horse manure, sheep manure and poultry waste. Urban wastes include paper, leftover food, plastic, rubber, wood and textile. Aqua wastes include water plants (hyacinth), algae and waste from fishery. Forest wastes include waste from sugar mill, tannery, fruit processing industry and paper mill.

Factors affecting the performance of a digester

The factors affecting the performance of a digester are as follow:

(i) **Temperature.** Anaerobic bacteria grow and work best in the temperature range of 20–65°C.

(ii) **Pressure.** A pressure of 6–10 cm of water column is considered ideal for proper functioning of the digester.

(iii) **Water.** The presence of water helps in better mixing of various constituents of the biomass, hydrolysis of biomass, movement of bacteria and faster digestion process. The optimum solid content of biomass is 9–10%.

(iv) **pH value.** The pH value in the acid forming stage of digestion process should be about 6 (acidic). During methane forming stage, the pH value should be about 6.5–7.5 as anaerobic bacteria do not grow in acidic solution.

(v) **Feeding rate.** A uniform feeding rate should be maintained. In case of faster feed, acids will accumulate to stop digestion process. In case of slow feed, the digestion progresses slowly due to non-availability of sufficient biomass.

(vi) **Presence of nutrients.** Carbon, nitrogen and other nutrients are essential for digestion. Carbon and nitrogen are main nutrients for anaerobic bacteria and their presence in proper ratio is essential to ensure the maximum microbiological activity. Selected raw materials should added to maintain the proper concentration of nutrients in digestion solution of bacteria.

Factors affecting the performance of a digester

(vii) **Seeding.** To start or accelerate the digestion process, it is customary to add a small amount of digested slurry containing methane forming bacteria to the freshly charged digester. This process is called seeding of bacteria.

(viii) **Mixing and stirring.** Mixing and stirring of digester slurry helps to mix the floating masses of biomass in the slurry for bacterial action so as to speed up the methane forming process in the slurry.

(ix) **Retention time.** It is the duration for which the biomass slurry remains in the digester. The digesters are designed to keep biomass for the retention period ranging from 30 to 50 days depending on the region (climatic temperature) and type of biomass. Retention time is optimised to get atleast 70–80% of digestion of the slurry.

(x) **Toxic substances.** The presence of pesticides, detergents and ammonia in the biomass affects the digestion process.

(xi) **Type of biomass.** The digestion process also depends on the type of biomass. The biomass can be cow dung, poultry manure, sheep manure, night soil, rice husk, algae and water hyacinth and these have a different rate of biogas yield per unit mass.