UNIT 3 BIOGAS ENERGY

Structure

3.1 INTRODUCTION

More than two billion people cannot access affordable energy services based on efficient use of conventional energy sources (coal, gas, oil) and electricity. Without access to energy, their opportunities for economic development and improved living standards are heavily constrained. Due to the wide disparities in urban areas and rural areas in accessing the affordable commercial energy and energy services create a huge gap in human development, and threaten social stability. The decentralized small-scale energy technologies can play a vital role to reduce this gap and also become an important element of successful poverty alleviation. Another serious issue is of the environmental impacts on human health. The human heath is threatened by high levels of pollution resulting from particular types of energy use at the household, community, and regional levels.

Major changes are required in energy system development worldwide due to the emissions of greenhouse gases, mostly from the production and use of conventional energy. These emissions are altering the atmosphere resulting in adverse effects on the regional or global climatic patterns. Finding ways to expand energy supplies while simultaneously addressing the environmental impacts associated with conventional energy use represents a critical challenge to humanity. The resources and technology options available to meet these challenges are identified as energy efficiency, renewable energy sources, and advanced energy technologies.

Objectives

After reading this unit, you will be able to understand

- Biomass used for biogas production,
- Characteristics of Biogas,
- Biogas production and factors affecting the production, and
- Advantages of biogas.

3.2 ENERGY, ENVIRONMENT AND HEALTH

The relationship between energy and social issues is related to address the energy needs of the majority of rural people, specially the poor. A large majority of rural masses has very low ability to pay for energy in our country and require major structural changes. The productivity and income generating potential of a family is highly dependent on the availability of convenient and affordable energy. The contribution of supply of affordable energy can help families and communities break out of the cycle of poverty. The economic levels of villages can be increased by more energy inputs in agricultural sector (such as increase in irrigated land area) and by reducing the inputs of chemical fertilizers, which can be replaced by bio-fertilizers (such as biogas manure).

The human health and quality of life always have close relationship with energy consumption and its clean production. The energy potential for enhancing human well -being is unquestionable. Therefore, the realization of absolute link between meeting the needs of rural areas economic growth and energy security, dispersed resources like dung etc. can make the energy system more reliable and sustainable.

On the other hand, in developing countries, most of the inhabitants in rural areas are dependant on dung and organic residue as fuel for cooking and heating. Such is the case, for example, in the treeless regions of India (Ganges plains, central highlands), Nepal and other countries of Asia. The burning of dung and plant residue is a considerable waste of plant nutrients.

Other than land, labor, capital and water; energy and manure has also become the most crucial factor for economic and social growth of villages. The efforts has to be made in this direction to create self-reliant villages in energy and manure production by bio-methanation technology using local resources like cattle dung. This effort would provide a firm basis for the economic and social development and long-term sustainability.

Biomass is the World's 4th Energy Source and its usage is widespread in both industrial and developing countries. The majority is used to provide heat worldwide 15 PWh as thermal energy and about 150 TWh electricity (15% and 1% of world total energy consumption).

3.3 MAIN SOURCES OF BIOMASS FOR BIOGAS PRODUCTION

The major resources which can be used for biogas production are :

- Animal Manure
- Poultry Waste
- Pig Waste
- Night soil
- Municipal Organic Waste
- Agricultural Residues
- Forests Residues (Leafs etc)
- Aquatic Plants (like water hysinth)
- Organic waste water from Industries (Food processing, milk processing etc.)
- Hotels and Restaurants
- Sanitary Land fills

3.4 BIOGAS

The byproducts of anaerobic digestion of organic materials are commonly referred to as 'biogas' because of the biological nature of gas production. Biogas technology refers to the production of a combustible gas (called biogas) and a value added fertilizer (called slurry or sludge) by the anaerobic fermentation of organic material under certain controlled conditions. Biogas is produced by microbial activities and can be used only at the place where it is produced. The main constituents of biogas are :

- about 55-65% Methane (CH_4)
- 30-45% Carbon dioxide (CO_2)
- traces of hydrogen sulfide (H_2S)
- fractions of water vapors

Waste like cow dung, poultry slurry, pig manure and other crop residue have the following biogas composition :

- Methane 50-60%
- Carbon Dioxide 38-45%
- Trace component 2% (Hydrogen, Hydrogen Sulphide, Non Methane Volatile organic, etc.).

The comparative value of energy and their efficiencies of different fuels are given in Table 3.1.

Table 3.1 : The Calorific Value and Efficiency

Commonly Used Fuels	Calorific Values	Thermal Efficiency
Bio-gas	4000-5000 KCal/m^3	55%-60%
Dung cake	1900-21003 KCal/Kg	5%-11%
Firewood	2100-4300 KCal/Kg	15-20%
Diesel (HSD)	10550 KCal/Kg	60-70%
Kerosene	10850 KCal/Kg	50-55%

SAQ 1

(a) What is Biogas?

(b) What is its composition?

(c) Can biogas be used in place of fossil fuels? How?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

3.5 PLANT SIZE AND REQUIREMENT OF NUMBER OF CATTLES

The large numbers of biogas plants are working on cattle dung in India. The simple estimation of dung may be done on the basis of number of cattle's. The plant size and number of animals required is given in Table 3.2.

Table 3.2 : Biogas Plant Size and Cattle Head Needed

Plant Size in m^3	Minimum Number of Cattle Required
2	3
3	4
4	6
6	10
8	15
25	45

SAQ 2

What is anaerobic digestion?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

3.6 CHARACTERISTICS OF FEED MATERIALS

The most important parameters for characterizing the slurries made up from different feed materials are total solids content (TS) and volatile solids content (VS). There is an upper limit for (TS) content above which the material is no longer slurry, and mixing and pumping becomes problematic.

3.6.1 Process

The different pathways of bio-methanation process are suggested by several investigators. Macro level energy conversion of organic waste in bio-methanation is shown in Figure 3.1. In this process of conversion of energy from organic mass is mainly utilized in cell synthesis and formation of methane and carbon dioxide besides some part of it remains in the effluent.

A simple flow chart may describe the three step process of bio-methanation as shown in Figure 3.1. These are briefly described below :

- Hydrolysis : saprophytic bacteria converts complex organic compounds into less complex organic compounds, which are water-soluble.
- Acid formation : acid forming bacteria degrades organic compounds to volatile fatty acids and ammonia.
- Methane formation : methane forming bacteria utilizes these acids to form methane (CH_4) (Veziroglu, 1991).

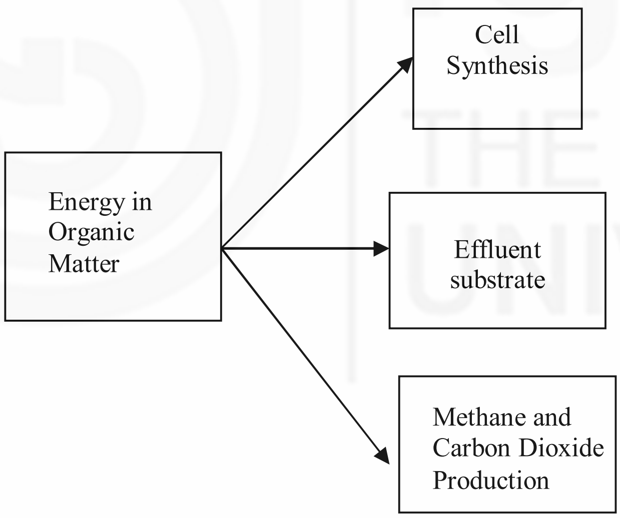

Figure 3.1 : Energy Conversion in Process

Each stage is being carried out by different types of bacteria with different environmental requirements.

Hydrolysis

Hydrolysis is the first step in anaerobic degradation and also the rate limiting step. The hydrolysis of organic polymers such as polysaccharides, fats and proteins converts these polymers into smaller units, such as sugars, long-chain fatty acids and amino acids. This group of bacteria called as facultative anaerobes/microbes.

Acid forming Microbes or Acitogenesis :

The sugars, long-chain fatty acids and amino acids resulting from hydrolysis are used as substrates by a wide variety of bacterial generation of different fermentative organisms or by anaerobic oxidizers. The complex organic matters in liquid phase digestion convert the small water-soluble molecules by fermentation into acetate, carbon dioxide and hydrogen. The acid forming bacteria also converts the intermediate products to acetic acid, carbon dioxide and hydrogen.

The three stages of Biogas production

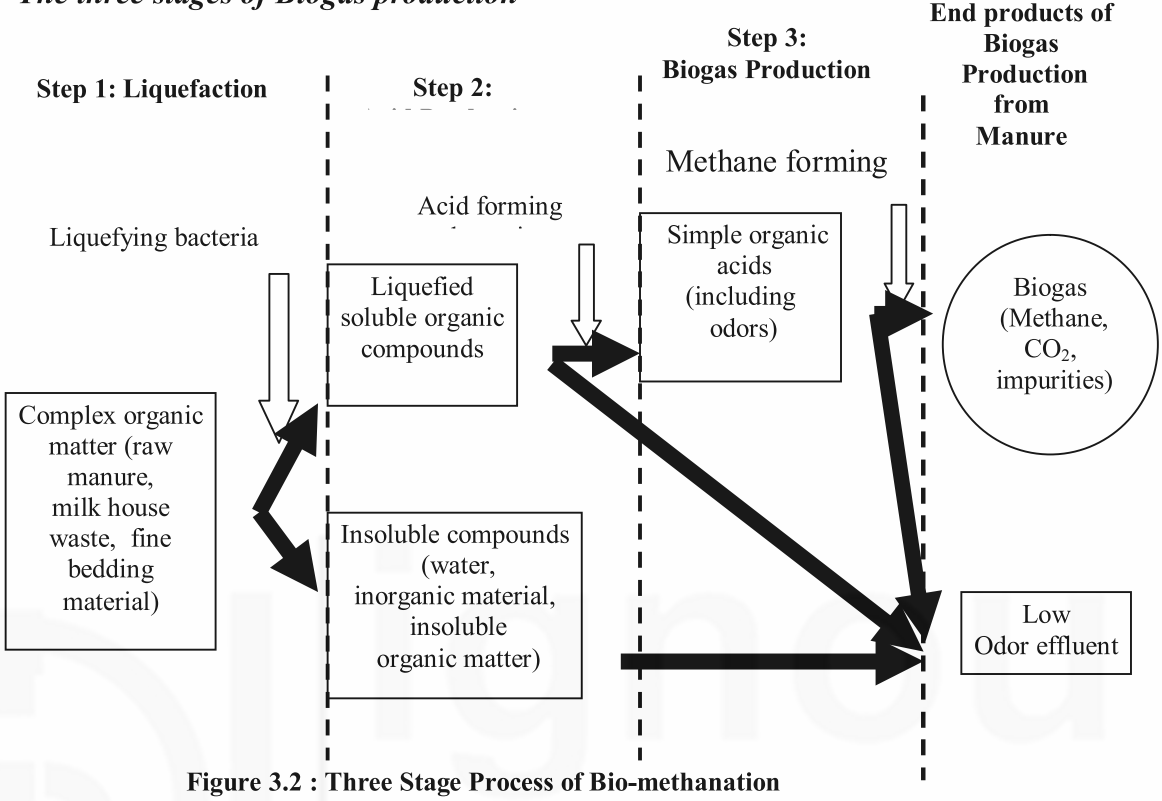

Figure 3.2 : Three Stage Process of Bio-methanation

Methane forming Microbes or Methanogenesis

Acetate, carbon dioxide and molecular hydrogen can be directly utilized as a substrate by the group of anaerobic microorganisms called Methane genesis or methane forming bacteria. Methane can be synthesized via two different pathways, of which one involves acetate and the other molecular hydrogen. The estimations indicated that about 70% of the methane is produced from acetate and 30% comes from hydrogen. The Volatile Fatty acids (VFA) accumulation is to be avoided in the digester to produce the high gas content.

SAQ 3

(a) What materials can "feed" your digesters?

(b) Besides biogas, what comes out of the digesters?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

3.6.2 Stoichiometric Calculation of the Biogas Yield and Composition

Bio-methanation process is carried out by symbiotic action of methane- and acid-producing bacteria. The interrelated behaviors of all classes of bacteria create the environment for each other to survive and grow simultaneously. The estimation of biogas production form the organic waste materials may be done on the basis of Stoichiometric equation of the conversion process.

The simple equation is considered by Ghaly and Ramkumar (1999) for calculations of the theoretical yield of methane and carbon dioxide, i.e. biogas, produced by anaerobic digestion using the Buswell's formula :

$$C_n H_a O_b + (4n – a- 2b) H_2O \rightarrow (4n + a – 2b)/8\ CH_4 + (4n – a + 2b)/8\ CO_2$$

Veziroglu, (1991) has given the formula for the biogas production from organic substances which are not containing sulfur materials and can be written as :

$$C_aH_bO_cN_d + (4a - b - 2c + 3d)/4\ H_2O \rightarrow (4^a + b - 2c - 3d)/8\ CH_4$$

$$+ (4a-b+2c+3d)/8\ CO_2 + d\ NH_3$$

The formula for the conversion of organic substance in an aqueous environment into CH_4 and CO_2 and into ammonia and hydrogen sulphide, (if N and S are contained in the substrates) is Boyle (1996)

$$C_nH_aO_bN_cS_d + (4n – a – 2b + 3c + 2d)/8\ H_2O \rightarrow$$

$$(4n – a + 2b + 3c + 2d)/8\ CO_2 + (4n + a - 2b - 3c - 2d)/8\ CH_4$$

$$+ cNH_3 + d\ H_2S$$

It is interesting to note that any organic matter will generate biogas, but the higher the energy of the materials, the more biogas they will create. For example, deep fryer oil can generate about 60 times as much biogas as cow dung for any given quantity.

3.7 PROCESS PARAMETERS AFFECTING THE BIOGAS PRODUCTION

All kinds of organic waste such as kitchen waste and garden waste, cattle dung and sewage, etc. can be used in a biogas plant. The efficiency of the biogas production is affected by the following factors :

1. Amount of organic material
2. Digestibility of the material
3. A combination of microbial and engineering factors such as
   - (a) Organic loading rates
   - (b) Solids Concentration
   - (c) Retention Times
   - (d) Temperature
   - (e) Carbon to Nitrogen Ratio
   - (f) Toxicity, etc.

3.6.1 Organic Loading Rate (OLR)

The organic loading rate (OLR) of a process is a measure of how much organic material is fed to each cubic meter of reactor volume during one day (i.e. Kg of VS /m^3 or COD/m^3 day).The biogas is formed from the anaerobic degradation of volatile solids (VS). The volatile solids fed per Kg in reactor will normally produces maximum biogas in the range of 0.25-0.70 m^3 depending on the operating conditions of reactor.

Accordingly, the loading rate should be in the range of 1-1.5 Kg volatile solids/m^3 digester/day which is highly dependent on the reactor design. The biogas production is also affected by overfeeding or underfeeding of the feed materials. In continues feed digesters, the large fluctuations of flow and concentration of substrate will also give low biogas production. Volatile Solids (VS) is measured as the weight of solids that is combustible “volatilized” at a temperature of 550°C. It is reported as a percent of the total weight of the manure sample. Methane production is often based on the volatile solids portion of the manure.

Approximately 50-70% of the VS can be converted to biogas depending on the design of the digesters.

3.7.2 pH-value

The pH value is defined as follows :

The pH affects severely the biogas and methane production rate which decreases with high and low pH values. The pH value should be between 7 and 7.4 and the dilution for water and fresh dung ratio 1:1 by weight. The maximum percentage of methane can be produced in the optimum range of pH vales 6.8-7.2. The methane forming bacteria cannot survive below 5.5 pH, while acid forming bacteria can survive up to 4.5 pH. Therefore, the water is normally used for buffering solution and to be used in sufficient quantities for anaerobic digestion/fermentation process.

The control of decrease in pH of an anaerobic reactor may be done by stopping the feeding and increase the buffering capacity, e.g. through adding some chemicals as calcium carbonate, sodium bicarbonate or sodium hydroxide.

3.7.3 Alkalinity

Alkalinity of a liquid is mainly a measure of its acid neutralizing capacity. Carbonate, bicarbonate and hydroxide ions are normally used for as neutralizing agents.

3.7.4 Temperature

The biogas production is highly dependent on operating temperature of anaerobic digester. Three ranges of temperatures and their respective retention times are given in Table 3.3 for the operation of digesters.

Table 3.3 : Temperature and Retention Time

	Temperature Range	Retention Time	
➢	**Psychrophilic**	0 to 20°, 100-120 days	
➢	**Mesophilic**	20 to 42°C and	30- 60 days
➢	**Thermophilic**	42 to75°C	3- 20 days

Methanogenesis is also possible under psycrophilic conditions (temperatures below 20^{0}C) but occurs at lower rates. The quantity and quality of biogas production is different in different temperature ranges. Optimum gas production is also found at 33^{0}C and 52^{0}C in Mesophilic and Thermophilic ranges respectively. The trend in biogas production with temperature in different ranges is shown in Figure 3.3.

The fluctuations in temperature in any range leads to inhibition of methane formation.

3.7.5 Carbon to Nitrogen Ratio

Microorganisms need both nitrogen and carbon for assimilation into their cell structures. The C/N ratio varies from a feedstock to another as shown in Table 3.3. It is mentioned as an important parameter, affecting the biogas production.

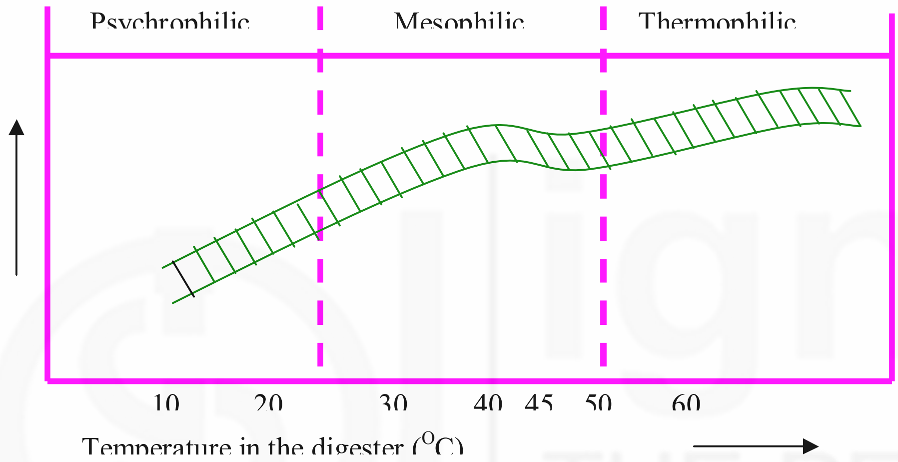

Figure 3.3: Temperature Effect on Gas Production

3.7.6 Nutrients and Trace Elements

Microorganisms require the macro and micro nutrients as trace elements such as phosphorous, nitrogen, sulfur, calcium, potassium, iron, nickel, cobalt, zinc and copper. These are essential required for optimum activity of the microorganisms involved in anaerobic digestion. The most important nutrients are nitrogen and phosphorous and it has been suggested that the C : N : P ratio should be kept at a minimum of 100 : 28 : 6.

3.7.7 Hydraulic Retention Time (HRT)

Hydraulic retention time varies with operating temperature of the anaerobic digester. It may be defined as the average time a volume element of the liquid medium resides inside the reactor. A better production of biogas found at an increase in HRT, if all other parameters kept constant.

Anaerobic digestion can be performed with a relative short HRT, i.e. “high rate” systems, or with long HRT, i.e. “low rate” systems. Low rate systems are normally used to digest slurries and solid wastes, while high rate systems are usually used for treatment of wastewater.

Table 3.4 : C/N Ratios of different Types of Feedstock

Feedstock	C/N ratio Range
Poultry litter waste	5-10
Grass clippings	12-25
Horse stable manure	25-27
Fruit waste	28-35
Leaves	30-80
Straw, wheat	100-138
Night soil	6-10
Sewage sludge	6-8
Animal manure (without litter)	11-25
Farmyard manure (average with litter)	14-20
Green vegetable wastes, weeds	11-20
Cereal straw	45-130
Potato peels	22-25
Cow dung	25-30
Poultry manure	8-15
Pig manure	18-20
Garbage	16-22

3.7.8 Toxicity

Methanogens are most sensitive to any kind of toxicity in comparison to other microorganisms in anaerobic degradation. The Table 3.5 lists the limit concentrations (mg/l) for various inhibitors.

Table 3.5 : Limiting Concentrations for various inhibitors of bio-methanation

Substance	[mg/l]
Copper	10-250
Calcium	8000
Sodium	8000
Magnesium	3000
Nickel	100-1000
Zink	350-1000
Sulphur	200

(Reference : Biogas_gtz_de.pdf, Eschborn, Germany)

3.7.9 Degree of Mixing

Mixing is a control process to keep uniform the pH and other environmental conditions of slurry in the digester. It distributes the buffering agents throughout the reactor volume and prevents localized build up of high concentrations of intermediate metabolic products, which may inhibit methanogenic activities.

3.8 EFFICIENCY OF GAS PRODUCTION AND USES

The efficiency of Biogas production is measured in terms of yield as a fraction of the theoretical yields of gas. The biogas production per Kg of raw material may be a good indicator for performance of digester. The efficiency of plant can also be measured on the basis of gas production per unit reduction in total solids, volatile solids, Chemical Oxygen Demand (COD) or Biological Oxygen Demand (BOD). The Total solids and volatile solids are normally used to measure the efficiency as biomass is solid material.

The efficiency of the biogas production depends on the retention time (percentage of daily input of biomass related to total volume). Normally, the efficiency can be expected around 60%. The biogas production also depends on the Biological Oxygen Demand (BOD) in the wastewater. The BOD reduction will generate 0.8 m^3 of biogas each Kg of BOD removal. Adding water with low BOD from the end of the anaerobic process will dilute the high inlet BOD and improve the biogas process.

Uses for Biogas (methane)

The biogas may be used for variety of applications. Some of the application areas are :

(1) producing steam (i.e. heat)

(2) generating electricity (with power generators)

(3) producing "CNG"(with purifiers and compressors).

3.9 MAJOR BENEFITS

The cooking in rural areas is still largely depending on the use of traditional cook stoves (Chullha's). They are burning dung cake, fire-wood and agricultural waste in addition to kerosene up to some extent. The installation of bio-gas plants would directly replace the use of above three and in saving them, following gains would be made :

(a) Reduction in pollution due to burning of dung and other biomass materials. Dung can be conserved, if biogas plants are used. Again, the dung after digestion in gas plant preserves more of Nitrogen, Phosphorus and Potash. The slurry coming out after digestion from different capacity plants are given in Table 3.6.

(b) The rural people would not be dependent on wood which is used for cooking. The deforestation and ecological imbalances can be reduced.

(c) In rural areas instead of kerosene the biogas can be used for lighting. This would reduce the dependence on fossil oil directly and in saving foreign exchange.

(d) The most important benefit would be in keeping the clean inhabitation and environment. The human beings can be saved form bacterial infections and other insects.

(e) The combustion of biogas produces carbon dioxide (CO_2), a greenhouse gas. The carbon in biogas comes from plant matter that fixed this carbon from atmospheric CO_2. Thus, biogas production is carbon-neutral and does not add to greenhouse gas emissions. Further, any consumption of fossil fuels replaced by biogas will lower CO_2 emissions.

Table 3.6 : Slurry manure from Biogas Plants

Size (m^3)	Slurry Manure (Tonnes/yr)
10	49275
15	73912
20	98550
25	123187
35	172462
45	221737
60	295650
85	418837

SAQ 4

(a) What are the environmental impacts of producing/using biogas?

(b) Does biogas contribute to climate change?

....

....

....

....

3.10 LET US SUM UP

Biogas is produced from almost any feedstock containing organic compounds, both wastes and biomass (energy crops), animal manure, sludge settled from wastewater, and at landfills containing organic wastes. Carbohydrates, proteins and lipids are all readily converted to biogas. Many wastewaters contain organic compounds that may be converted to biogas including municipal wastewater, food processing wastewater and many industrial wastewaters. Solid and semi-solid materials that include plant or animal matter can be converted to biogas. Providing the reliable affordable and environmentally clean biomethanation technology can raise the economic and social level of the villagers. In short the per capita income of the villager can be enhanced by conserving their own resources in the village in addition to providing the energy from the available local resources.

3.11 KEY WORDS

Alkalinity : Alkalinity of a liquid is mainly a measure of its acid neutralizing capacity.

Biochemical Oxygen Demand (BOD) : Amount of oxygen needed by bacteria and other microorganisms to decompose organic matter in water.

Bio-energy : Renewable energy produced from organic matter

Bio-fuels : Fuels made from biomass; include ethanol, biodiesel and methanol

Biogas : A combustible gas derived from decomposing biological waste; normally consists of 50 to 60 percent methane.

Biomass : A renewable source of energy derived from organic matter like wood, agriculture waste; also include algae, sewage and other organic substances that may be used to make energy through chemical processes

Bio-fuels : Fuels made from biomass; include ethanol, biodiesel and methanol

Fluidised Bed Combustion : A process of burning powdered coal with air or gases; reduces sulfur dioxide emissions from coal combustion

Methane Genesis : Acetate, carbon dioxide and molecular hydrogen can be directly utilized as a substrate by the group of anaerobic microorganisms called Methane genesis.

Organic Loading Rate (OLR) : Organic loading rate (OLR) of a process is a measure of how much organic material is fed to each cubic meter of reactor volume during one day (i.e. Kg of VS /m^3 or COD/m^3 day).

pH Value : pH is defined as follows:

Hydraulic Retention Time (HRT) : HRT varies with operating temperature of the anaerobic digester. It is defined as the average time a volume element of the liquid medium resides inside the reactor.

3.12 ANSWER TO SAQs

SAQ 1

(a) Biogas results from bacteria in the process of bio-degradation of organic material under anaerobic (without oxygen) conditions. The natural generation of biogas is an important part of the biogeochemical carbon cycle. Methanogens (methane producing bacteria) degrade organic material and return the decomposition products to the environment. In this process biogas is generated, which is a source of renewable energy.

(b) Biogas is a mixture of many kinds of gases which comprises of :

Methane (CH_4) : 55-75%

Carbon dioxide (CO_2) : 25-45%

Hydrogen Sulfide (H_2S) : 0.1-1.0%

Hydrogen (H_2) : 0-2 %

(c) Methane is the principal gas in biogas. Methane is also the main component in natural gas, a fossil fuel. Biogas can be used to replace natural gas in many applications including: cooking, heating, steam production, electrical generation, vehicular fuel, and as a pipeline gas.

SAQ 2

Anaerobic digestion is the process by which organic materials, in an enclosed vessel, are broken down by micro-organisms in the absence of oxygen. Anaerobic digestion produces biogas, consisting primarily of methane and carbon dioxide. Anaerobic digestion systems are also often referred to as biogas systems.

SAQ 3

(a) Biogas production is capable of reducing the pollution in wastewater by converting oxygen demanding organic matter that could cause low oxygen levels in surface waters. Nutrients, like nitrogen and phosphorous are conserved in biogas effluents and can be used to displace fertilizers in crop production.

(b) While combustion of biogas, like natural gas, produces carbon dioxide (CO_2), a greenhouse gas, the carbon in biogas comes from plant matter that fixed this carbon from atmospheric CO_2. Thus, biogas production is carbon-neutral and does not add to greenhouse gas emissions. Further, any consumption of fossil fuels replaced by biogas will lower CO_2 emissions.

SAQ 4

(a) Biogas digesters operate with the manure from cattle or pigs. In addition, the digesters make use of kitchen waste, brewery waste, industrial food processing waste, energy crops like corn, fish and poultry remnants, ethanol production waste, etc.

(b) The liquid that results from the anaerobic digestion process has solids which are separated out, composted, and sold to local gardeners, landscapers and farmers. The liquids are returned to the farmer as nutrient rich natural fertilizer, which replaces imported nutrients and thereby cuts costs.

REFERENCES

1. Archer, D B (1983) "The microbial basis of process control in methanogenic fermentation of soluble waste", Enzyme microbial Technology, PP : 162-169.

2. Buswell A M (1952)"Mechanism of methane fermentation", Industrial and Engineering Chemestry, Vol.44 PP : 550.

3. Biomass based Decentralised Power Generation (2005) Edited by B S Pathak and N S L Srivastva, Technical Publication No. SPRERI/2005/03.

4. Biomass Systems – Principles and applications (1996) by K M Mital, Published by New Age International (P) Ltd.

5. Composting – Sanitary disposal and reclamation of organic waste (1956), by Harold B Gotaas, Published by WHO Geneva

6. C A Edwards and J R Lofty, Biology of Earthworms, Published by Chapman and Hall Ltd.

7. Hamoda M F; Qdais H A Abu and Newham j (1998) "Evaluation of municipal solid waste composting kinetics" Resource Conservation and Recycling Vol. 33 pp : 209-223.

8. Gysson A Engene, "Mechanical Volume Reduction" Hand book of Solid Waste Management.

9. Gujert, W; Zehnder, A J B (1983)," Conversion Processes in anaerobic digestion" Water Science and Technology, pp:127-167.

10. Jalan, R K and Srivastava V K "Utilization of Biomass from Muncipal Solid Waste for Energy Recovery, Recycling and Disposal" Biomass Energy System, TERI.

11. Jain, M C; Chhonkar, P K; and Kumar Sushil "Analytical method in Biogas Technology".

12. Renewable Energy Engineering and Tecchnology – A knowledgr compendium (2008), edited by V V N Kishore and Published by TERI Press, TERI, New Delhi.

13. http://www.efe.or.th/download/Chapter7.pdf.