CHAPTER-4

ANEAROBIC DIGESTION

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4.1 ANAEROBIC DIGESTION AND CHEMISTRY OF BIOMETHANATION

Anaerobic digestion (AD) is a process of converting organic materials in to methane (CH_4), Carbon dioxide (CO_2), and water vapour (H_2O) through microbial fermentation in the absence of oxygen [151]. At the end of the process the left over slurry is rich in nitrogen. In fact anaerobic digestion is a process that is taking place in nature.

A typical anaerobic digestion process shown in figure no. 4.1 as a block diagram.

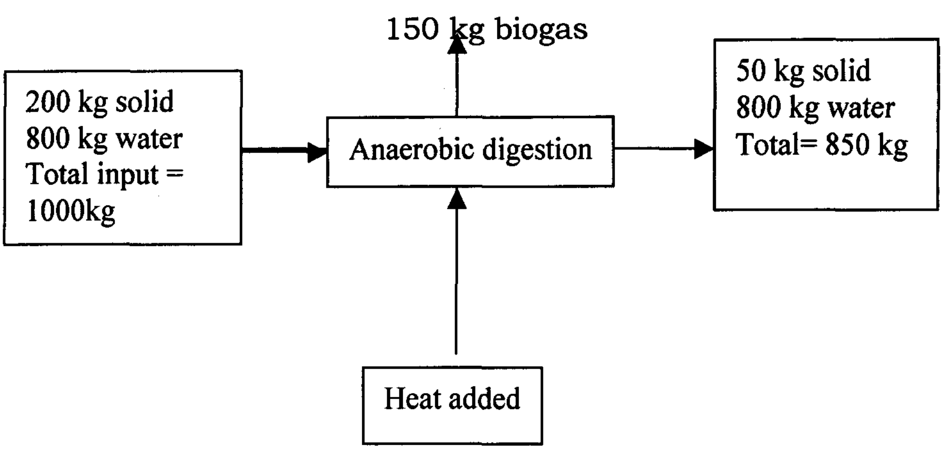


Fig. No. 4.1. Anaerobic Digestion Process

Source: Advanced Biological Treatment of MST, DEFRA,

Anaerobic digestion is a wet process used for solids with moisture content ranging between 60%-95%. Anaerobic digestion processes create much lower amount of biologically produced heat on the contrary additional heat may be required to maintain optimal temperature at 35°-40°C [152].

Methane is produced during the anaerobic catabolism of organic substances such as Napier grasses, rabbit waste, cow manure, cattle dung, night soil, tomato waste, vegetable processing waste, market waste, cauliflower, rotten cabbage, wheat straw, rice straw, etc. [153]. Rice husks, sediments of lake, ponds and puddles, salt marshes, sandy lagoons, sewage digester are the sources of methane.

In such anaerobic location organic substances are fermented to acetate, carbon dioxide and molecular hydrogen. It is these products of the breakdown that are utilized by the methanogenic bacteria (methanogens). The methanogenic bacteria are found all over the world but live only in the environment where no or very small concentration of oxygen is present. As time passes the methanogenic bacteria dispersed to environment where oxygen was absent. It can now be found in the bottom sediments of lakes and in marshy lands. The intestine of animals prevails and insects are another place where suitable conditions for the methanogenic bacteria prevail. The anaerobic process is generally characterized by small heat emission per unit-decomposed substrate [154]. This is in contrast to the aerobic processes where large heat emissions per unit-decomposed substrate take place.

There are basically three different phases of biomethanation namely [155-157]:

1. Solubilization: In the first phase facultative microorganisms act upon the organic substrates.
2. Hydrolysis is taking place in which polymers are the substrates for the second phase, converted into soluble monomers. These monomers form the non-methanogenic phase (acidification): The dissolved organic substrates are reduced from their incoming state to soluble simple organic acids (mainly acetic acid, CH_3COOH).

3. Methanogenic phase (methanogenesis): Methanogenic bacteria reduce the soluble organic compounds to methane and carbon dioxide. There are two ways by which the bacteria work. Either they ferment the acetic acid to methane and carbon dioxide or by reduction of carbon dioxide to methane by using hydrogen gas, which is a product of other bacteria.

In the process the amount of oxygen demanding material is reduced which results in a stable end product in comparison to the input in other words BOD of the input materials is being reduced [158].

The anaerobic bacteria that are involved in the last step being strictly anaerobic, will not work properly if there is oxygen present. The main bottleneck in this process is the solubilization of the organic polymers [159,160]. The main objective being to maintain an absolute oxygen free environment, however the initial phase will be less efficient due to presence of some air to start with. The facultative microorganisms will have better environment for growth and improvement of the solubilization phase initially [161]. Other characteristics of the processes are the symbiosis between different groups of microorganisms. Different groups of bacteria are involved in the different stages. These bacteria are sensitive to heat changes. According to Fulford, D. (1988) [162] a temperature variation in the slurry over a day of 5°c can cause the bacteria to stop work, which will result in a build up of organic compounds from the second phase (acetic acid mainly), which can cause the unit to go sour. Normal operating temperature range of a biogas plant under mesophilic condition is 30°C- 35°C.

The basic content of biogas is methane (CH_4) and carbon dioxide (CO_2), which is found in different proportions depending on: input to the system and the conditions during the fermentation process.

Traces of hydrogen sulphide, ammonia and oxygen can also be found in biogas in various degrees depending on feedstock and process. However presence of hydrogen sulphide (H_2S), which is a poisonous, and corrosive gas and is rather undesirable [163].

Composition of biogas as reported by different researchers is shown in table no. 4.1 below:

Table No. 4.1 Composition of Biogas

Methane (vol. %)	Carbon dioxide (vol.%)	Others	Sources
55-70 %	30-35 %	traces	(Meynell 1976)
50-70 %	30-35 %	traces	(Engel et al.1977)
55-70%	30-45%	1-2%	(Myles 1985)
58 %	42 %	traces	(Fulford 1988)
65-85 %	30-35 %	traces	(Singh 1994)
50%	50%	traces	(Chawla, 1996)

Source: Gustavsson , Mathias., Biogas Technology- Solution in search of its problem, Human Ecology Reports Series, 2000-01, P85.

It is therefore evident from the above table that biogas generally contains methane in the range of 50-70%.

4.1.1 Principles of Anaerobic Digestion

Anaerobic digestion is an application of biological methanogenesis that is a digestion process, which refers to various reactions, and interaction that takes place among the methanogens, non-methanogens and substrates fed into the digester as inputs. This is a complex physio-chemical and biological process involving different bacteria in different stages. This process of digestion is summarized below. The breaking down of inputs that are complex organic materials is achieved through the process, which can be divided into three stages as described below:

Stage 1-Hydrolysis/Liquifaction:

Complex organic compounds converted into soluble sugars, fats, and amino acids. The waste material of plant and animal origin consists mainly of carbohydrates, lipids, proteins and inorganic materials. Large molecular complex substances are solubilised into simpler ones with the help of extra-cellular enzymes released by the bacteria. This stage is also known as polymer breakdown stage. For example, the cellulose consisting of polymerized glucose is broken down to dimetric, and then to monomeric sugar molecules (glucose) by cellulolytic bacteria [164]

The polymers (large molecules) are reduced to monomers (basic molecules) and the resulting products are as follows

Lipids ⟶ Fatty Acids

Polysaccharides ⟶ Monosaccharides

Fat ⟶ Fatty Acids

Protein ⟶ Amino Acids

Nucleic Acids ⟶ Purines and Pyrimidines

Carbohydrates ⟶ Sugar

Stage 2- Acidification:

(i) Acidogenesis: The above organic compounds converted into organic acids, alcohols, carbon dioxide, hydrogen and ammonia. The monomer such as glucose that is produced in stage 1 is fermented under anaerobic condition into various acids with the help of enzymes produced by the acid forming bacteria. At this stage, the acid- forming bacteria breaksdown molecules of 6 atoms of carbon (glucose) into simpler molecules containing less number of atoms of carbon (acids) which are in a more reduced stage than glucose [165]. On an average, acidogens grow much quickly than methanogen. They are also much hardier organisms, able to survive in a wider range of temperature and pH.

(ii) Acidogenesis: The above conversion is followed by acidogenesis to convert the above products to acids like acetic acid, propionic acid, butyric acid and ethanol.

Stage 3- Methanogenesis / Methanization:

The principal acids produced in stage 2 are processed by methanogenic bacteria to produce methane. The reaction that takes place in the process of methane production is called methanization and is expressed by the following equation [166].

CH_3COOH	$\rightarrow$	CH_4	$+ CO_2$
Acetic acid		Methane	Carbon dioxide

$2CH_3CH_2OH$	$+ CO_2$	$\rightarrow$	CH_4	$+ 2CH_3COOH$
Ethanol	Carbon dioxide		Methane	Acetic acid

CO_2	$+ 4H_2$	$\rightarrow$	CH_4	$+ 2H_2O$
Carbon dioxide	Hydrogen		Methane	Water

The above equation shows that many products, by-products and intermediate products are produced in the process of digestion of inputs in an anaerobic condition before the final product (methane) is produced. Obviously, there are many facilitating and inhibiting factors that play their role in the processes [167].

Methane production is higher from reduction of carbon dioxide but limited hydrogen concentration in digesters results in that the acetate reaction is the primary producer of methane [168]. The methanogenic bacteria include *methano bacterium, methano bacillus, methano coccus*, and *methano sarcia*. Methanogens can also be divided into two groups- one is acetate consumer and the other is H_2 / CO_2 consumer.

4.1.2 Microbes involved in methane production.

The methanogens belong to a special group of bacteria strictly anaerobic in nature and on the basis of this and other differences within the prokaryotes; the methanogens are assigned to the archaebacteria [169]. They differ from other bacteria not only in their type of metabolism but also in a number of characteristic features in the composition of their cell constituents. They lack a typical peptydoblican skeleton. *Methanococcus* has only a protein envelope, a peptide sheath is found in *methanospirillum,* whilst the cell wall of *methanosarcina barkeri* consists of a polysssacharide composed of uronic acids, neutral sugars and amino sugars. Besides these, there are mesophillic and thermophillic species. The cytopalsmic membrane of the methanogens contains lipids consisting of glycerol ethers of isoprenoid hydrocarbons [170].

4.1.3 General mechanism.

It has been noticed that the methanogens are in close association with hydrogen producing bacteria. During such association hydrogen is rarely liberated in gaseous form, rather, hydrogen dissolved in the aquatic medium is directly used by methanogens for producing methane. This sort of mutual symbiotic process for generation of methane is commonly noticed in anaerobic area, in sediment water or soil, which are rich in cellulosic or such other detritus organic matter. Methanogenic bacteria are able to act on hydrogen and couple its oxidation to the reduction of carbon dioxide. The microbial synthesis of methane is sometimes, regarded analogues to carbonate respiration [171].

$$4 H_2 + CO_2 \rightarrow CH_4 + 2 H_2O$$

The above equation of biochemical conversion of H_2 and CO_2 to methane is common in methanogens.

4.1.4 Methanogenic bacteria or methanogens

These are the bacteria that act upon organic materials and produce methane and other gases in the process of completing their life- cycle in an anaerobic condition. As living organisms, they tend to prefer certain conditions and are sensitive to micro- climate within the digester. There are many species of methanogens and their characteristics vary. The different methane forming bacteria have many physiological properties in common, but they are heterogeneous in cellular morphology. Some are rods, some cocci, while other occur in clusters of cocci known as sarcine. The family of methanogens (Methanobacteriacea) is divided into following four genera on the basis of cytological differences [172]:

- A rod- shaped bacteria
  - (a) Non- Sporulating, Methanobacterium.
  - (b) Sporulating, Methanobacillus
- B. Spherical
  - (a) Sarcinae, Methanosarcina
  - [b] Not in sarcinal groups, Methanococcus

A considerable level of scientific knowledge and skill is required to isolate methanogenic bacteria in pure culture and to let them survive in a laboratory. Methanogenic bacteria develop slowly and are sensitive to a sudden change in physical and chemical conditions. For example, a sudden fall in the slurry temperature even by 20°C may significantly affect their growth and gas production rate [173].

4.1.5 Pathogenic bacteria and diseases

The digestion process results in the killing of pathogenic bacteria especially those found in animal and human faeces (*Salmonella* bacteria) thus reducing by over 90% in a digester [174].
The more fully the sludge is digested, the more pathogens are killed. High temperature and long retention time kills bacteria hence hygienic. The following are the principal organisms killed in biogas plants: Typhoid, paratyphoid, cholera and dysentery bacteria (in one or two weeks) hookworm and bilharzias (in three weeks) [175,176].

4.2 MICROBIOLOGY OF BIOMETHANATION

Anaerobic digestion technology or the methane- generating bioconversion yields both fuel (biogas) and organic fertilizer (sludge), products that are the final result of microbial action on cellulose. These substrates are obtained through a series of degradative steps that involve a variety of bacteria. In the first step, complex polymeric organic substrates proteins, carbohydrates, and fats-are transformed by non- methanogenic bacteria into essentially non-methanogenic substrates like butyrates, propionate, lactate, and alcohol. Through a second step that involves the acetogenic bacteria, the composition and identity of which still remain to be determined, these compounds are transformed into methanogenic substrates, i.e, acetate, H_2 and Cl compounds that are converted into methane and carbon dioxide by the methane bacteria, obligate anaerobes that multiply in a neutral or slightly alkaline environment [177].

The smooth cooperation of the three groups of bacteria has to be well regulated which was exemplified by Bryants. In his discovery it was found that two mutually inter- dependent species existed in a symbiotic association in a pure culture under the name of

Methanobacillus omelianskii [178]. The association is comprised of two symbionts: an acetogenic organism and a methanogenic organism. The acetogen produces acetate, hydrogen and carbon dioxide, thereby disrupting the process of auto- inhibition with the acetogen, which succumbs to the hydrogen, it's products.

Again, it is necessary that both aspects of the anaerobic digestion process- liquefaction and gasification be well balanced. If the methane bacteria are absent the digestion process may only succeed in liquefying the material and may render it more offensive than the original material. On the other hand, if liquefaction occurs at a faster rate than gasification, the resulted accumulation of acids may inhibit the methane bacteria and the bioconversion processes well.

4.3 ORGANIC MATERIALS FOR BIOGAS PRODUCTION AND THEIR CHARACTERISTICS

Most forms of organic matter containing proteins, fats or carbohydrate, cellulose (except mineral oils and lignin) can be microbiologically transformed into biogas (methane and carbon dioxide). These three groups of organic material theoretically lead to different compositions of methane and carbon dioxide as shown in table no.4.3

Table No. 4.3 Theoretical Methane and Carbon dioxide Composition in Biogas

Sub strate	Gas yield (litre per kg of dry substrate)	CH_4 %	CO_2%
Protein	700	70	30
Fat	1200	77	23
Carbohydrate	800	50	50

Source: Nijaguna, B.T., "Biogas Technology", Published by New age International (P), 2002, p 25.

The following are the various kinds of organic matter with potential for methane production (broadly they are land based, animal based and water based resources).

4.3.1 Land based resources

Crop wastes, Sugarcane trash, Weeds, Corn and related crops, Straw, spoilt Fodder, Forest litter like leaves, urban solid wastes, etc.

By-products from agro-based industries: Oil cakes, Bagasse, Rice bran, Tobacco wastes and seeds, Waste from fruits and vegetables processing, Press mud from sugar factories, Tea wastes, Cotton dust from textile mills etc and Municipal sewages

4. 3. 2 Animal based resources:

Animal Wastes, Cattle shed wastes (dung, urine, litter), Poultry litter, Sheep droppings, Slaughter house waste (blood, meat), Fishery waste, Human wastes like excreta, urine, etc.

Amount of Biogas generated from animal waste has been shown in table no. 4.3.2

Table No.4.3.2 Biogas yield from various animal waste.

Animal Waste	Gas yield (Litre/Kg-of solid)	Gas yield (m^3/kg. of dung)
Pig	340-550	0.040-0.059
Cattle (Cows & Buffaloes)	90-310	0.023-0.040
Poultry (Chickens)	310-620	0.065-0.116
Horse	200-300	0.051-0.039
Sheep	90-310	0.023-0.059
Human	80-218	0.020-0.028

Source: Updated guide book on Biogas Development, 1984

4.3. 3 Water based materials:

Marine, Sea-weeds, Water hyacinth.

4.3.4 Land Based Materials

Table 4.3.4. Break- up yield of different crop residues per hectare area

Type of residue	Yield (Tones/ Hectare)
Rice Husk	1.0-1.3
Leaves and stalk from corn	6.0-10.0
Bagasse	220.0-25.0
Pulp from sugar beat	8.0-15.0
Groundnut shells	0.6-2.3
Jute and Mesra fiber	0.6-2.3
Forest wastes	1.2
Sunflower stalks	2.5
Wheat straw struble	3.0-3.5

Source: Nijaguna, B.T., Biogas Technology, New Age International (P) Ltd. New Delhi, 2002, p26.

The rate of biogas production varies from one type of waste to the other. Chief among the parameter deciding the amount of biogas generated from substrate are its TS content, % of VS destruction, %C and % N.

4.4 FACTORS AFFECTING METHANE PRODUCTION

Various factors such as bio-gas potential of feed stock, design of digester, inoculums, nature of substrate, pH, temperature, loading rate, hydraulic retention time (HRT), C/N ratio, volatile fatty acids (VFA) Seeding, Uniform feeding, Diameter to depth ratio of the digester, Nutrients, stirring or agitation of contents of the digester, toxicity, due end product pressure, acid accumulation inside the digester etc, influence the methane production [179].

4.4.1 Biodegradability

The waste treated by anaerobic digestion may constitute a biodegradable organic fraction, a combustible and an inert fraction. The biodegradable organic fraction includes kitchen scraps, food residue, grass and tree cuttings. The combustible fraction includes slowly degrading ligno cellulosic organic matter containing coarser wood paper and cardboard. As these ligno cellulosic organic materials do not readily degrade under anaerobic conditions, they are better suited for waste to energy plants. Finally, the inert fraction contains, stones, glass, sand, metal etc. This fraction ideally should be removed, recycled or used as landfill. The removal of inert fraction prior to digestion is important because it increases digester volume and wear of equipment.

The composition of the feed materials to the digester is variable and rarely any of the natural digester feeds completely and breaks down or transformed to biogas. The natural substrate is 100% biodegradable. This due to imperfect physico chemical factors, non-degradable components, conversion to cell mass etc. In the ideal condition a small fraction (2-5 %) of the volatile solids (VS) destroyed is converted to cell mass. The major factor in hindrance for biodegrability is lignin present in the digester feed (20).

For any substrate, it is possible to predict the gas yield by using the following formulae [180,181].

$C_nH_aO_b$ + (n –a/4-b/2) H_2O +(n/2-a/8 +b/2) CO_2 + (n/2 + a/8 –b/4) CH_4 ------- (1)

Using the above equation the gas yield from glucose will be as shown below

$C_6H_{12}O_6 + H_2O$ ------------$3CH_4+3CO_2$ --------------- (2)

4.4.2 Slurry or effluent inside the Digester

This is the residue left after the methanogenic bacteria in an anaerobic condition inside the digester act upon the substrate. After extraction of biogas (energy) the slurry, which is commonly known as effluent, comes out of the digester as by-product of the anaerobic digestion system. It is almost pathogen-free stabilized manure that can be used to maintain soil fertility and enhance crop production. Slurry is found in different layer inside the digester as mentioned below:

A light rather solid fraction, mainly fibrous material which float on the top forming the scum; a light and watery fraction remaining in the middle layer of the digester; a viscous fraction below which is the sludge; and heavy solids, mainly sand and soil that deposit at the bottom. There is less separation in the slurry if the feed materials are homogeneous. Appropriate ratio of urine, water and excrement and intensive mixing before feeding the digester leads to homogenous slurry.

4.4. 3 Digestion temperature

The bacteria are very sensitive to temperature changes. According to Fulford (1988), a temperature variation in the slurry over a day of 5°C can cause the bacteria to stop work which will result in a build-up of organic compounds from the middle layer, acetic acids mainly, which can cause the unit to go sour.

Temperature is an essential parameter in respect of bacterial activity in the digester. Methane bacteria works best in the temperature range of 30- 35°C and satisfactory gas production takes place in the mesophillic range, which is between 25°- 30°C [182]. The fall in gas production starts at 20°C and virtually stops at a temperature of 10°C. The methanogens are inactive in extreme high and low temperature [183-185]. The proper insulation of digester helps to increase gas production in the cold season. When the ambient temperature is 30°C or less, the average temperature within the dome remains about 4°C above the ambient temperature [186-191].

4. 4. 4 pH. Value

The pH of the slurry in the digester is a function of the concentration of volatile fatty acids produced, bicarbonate alkalinity of the system, and the amount of CO_2 produced.

The optimum biogas production is achieved when the pH value of input mixture in the digester is between 6&7. The pH in a biogas digester is also a function of the retention time .In the period of fermentation, large amount of organic acids are produced by acid forming bacteria, the pH inside the digester can go below 5 [192]. This inhibits or even stops the digestion or fermentation process. Methanogen bacteria are very sensitive to pH and do not thrive below a value of 6.5. Later, as the digestion process continues, concentration of NH_4 increases due to digestion of nitrogen, which can increase the pH value to above 8. When the methane production level is stabilized, the pH range remains buffered between 7.2 to 8.2 [193-195].

4. 4. 5 Loading Rate

Loading rate is the amount of raw materials fed per unit volume of the digester capacity per day. If the plant is over fed, acids will accumulate and methane production will be inhibited. Similarly, if the plant is underfed, the gas production will be low.

In other words, organic loading rate (OLR) is a measure of the biological conversion capacity of the anaerobic digestion system. Feeding the system about its sustainable OLR results in low biogas yield due to accumulation of inhibiting substances such as fatty acids in the digester slurry. In such a case, the feeding rate to the system must be reduced. OLR is a particular important control parameter in continuous system. It is reported that many plants failed due to overloading [196].

The concentration of total solids in the input suspension can be varied within the range of 20 to 100 gm/litre. In practice it is recommended to limit the total solids concentration to the range of 20 to 30 gm/litre [197].

4. 4. 6 Retention Time

Retention time (also known as detention time) is the average period that a given quantity of input remains in the digester to be acted upon by the methanogens. Retention period is found to reduce if temperature is raised, or more nutrients are added to the digester. In a cow dung plant, the retention time is calculated by dividing the total volume of the digester by the volume of inputs added daily. A digester should have a volume of 50 to 60 times the slurry added daily. For a night soil biogas digester, a longer retention time (70 –80 days) is needed so that the input materials are completely acted upon by the methanogenic bacteria. Hydraulic Retention Time (HRT) is the most important factor in determining the volume of the digester which in turn determines the cost of the plant, the larger the retention period, higher the construction cost. Digestion period can be calculated from the following: - Digestion Period =Volume of Reactor/Daily slurry input.

4. 4. 7 Toxicity

Mineral ions, heavy metals and the detergents are some of the toxic materials that inhibit the normal growth of pathogens in the digester [198]. Small quantity of mineral ions (sodium, potassium, calcium, magnesium, ammonium and sulphur) also stimulates the growth of bacteria, while very heavy concentration of these ions will have toxic effect [199]. Heavy metals such as copper, nickel, chromium, zinc, lead etc. in small quantities are essential for growth of bacteria but their concentration has toxic effects [200]. The inhibiting levels of some of the major ones are given in table no. 4.4.7

Table No: 4.4.7 Toxic level of various inhibitors

Inhibitors	Inhibiting Concentration
Sulphate (SO4 --)	5,000 ppm
Sodium Chloride or Common salt (NaCl)	40,000 ppm
Nitrate (Calculated as N)	0.05 mg/ ml
Copper (Cu ++)	100 mg/l
Chromium (Cr +++)	200 mg/l
Nickel (Ni +++)	200-500 mg/l
Sodium (Na +)	500-5,500mg/l
Potassium (K+)	2,500-4,500 mg/l
Calcium (Ca ++)	2,500-4,500 mg/l
Magnesium (Mg ++)	1,000-1,500mg/l
Manganese (Mn ++)	Above 1,500mg/l

Source: The Biogas Technology in China, BRTC, China (1989)

4.4.8 Influence of Volatile Solid Concentration

The volatile solids (V.S.) in organic waste are measured as total solids minus the ash content as obtained by complete combustion of the feed waste. The volatile solids comprise the biodegradable volatile solids (BVS) fraction and the refractory volatile solids (RVS), [201], showed that knowledge of the BVS fraction of MSW helps in better estimation of the biodegradability of waste, biogas generation, organic loading rate and C/N ratio, lignin is a complex organic material that is not easily degraded by anaerobic bacteria and constitutes the refractory volatile solids (RVS) in organic MSW. The composition of waste affects both the yield and biogas quality and as well as the compost quality.

The methane yield drops when the effluent volatile solids concentration increases above 40 kg./m^3 at 10 days retention time. At long retention times, the drop of the methane yield at high volatile solids concentration is not as pronounced as compared to short retention times.

4.4.9 Effects of Particle size of the feed material

Biogas production from kitchen waste, food waste and from different biomass needs pre-treatment in order to reduce the sizes of the feedstock. It has been observed that for getting better yield of gas, particle sizes are to be reduced [202,203].

Sharma et al., (1988) [204], have shown that biogas generation is increased when the particle size of organic material is small, in this case less than 1 mm.

4.5 Benefits and Limitation of Biogas System

Biogas technology has a number of potential benefits as mentioned below:

(i) Energy-related benefits

(ii) Fertilizer-related benefits

(iii) Health-related benefits

(iv) Development-related benefits

(v) Economic benefits

A brief summary of the above potential benefits from biogas technology is mentioned table no. 4.5

Table No. 4.5 Potential benefits from biogas technology

	National Level	Regional Level and Local Level	Individual Level
Energy,replace commercial fuels	Improve BOP	Reduce transportation and need for infrastructure	Reduced spending
Energy replace non commercial fuels	Reduced cost for afforestation	Environmental impact	Less time spent on collecting fuel
Fertilizer, if manure not used prior	Improve BOP	Reduce transportation and need for infrastructure	Reduced spending on fertilizers
Health	Reduced spending on health care	Increased labour availability and equality	Improved health
Development	Rural development Sustainable development	Create employment	Convenient fuel
Economy	Not applicable	Not applicable	Not applicable

Source: - Mathias Gustavsson, Biogas technology solution in search of its problem, 2000, p 18

At face value there are potential benefits at all levels in the society the benefits are here considered at four levels: national, regional, local and individual level.

The national level accounts for India as a country, while the regional level is state, district and in some cases block depending on size.

Panchayats or city urinals and villages account for the local level, while individual level concerns the person(s) involved with the use of the gas and management of the unit. It is normally the women of the households that are in charge of carrying out these chores.

Biogas has the potential to reduce deforestation, as it is usable as a fuel. As a cooking fuel, biogas is cheap and extremely convenient to use. Based on the effective heat produced, a 2 cu. m. biogas plant could replace, in a month, fuel equivalent of 26 kg. of LPG or 37 litres of kerosene or 88 kg of charcoal or 210 kg of fuel wood or 740 kg of animal dung [205].

Biogas is a clean fuel and does not cause any pollution. It is considered as a better fuel than natural gas and liquefied petroleum gas. Biogas contains 4500-6000 calories/m^3, thus providing convenient source of heat at low cost. One cu.m. of gas having calorific value of 6000 calories is equivalent to the other type of fuel has been shown in the following table no. 4.5.1 [206].

Table no. 4.5.1 Equivalent quantity of other fuels for one m^3 of biogas

Type of fuel	Quantity
Biogas at 6000 calories	1 cu. m.
Alcohol	1.000 lit.
Petrol	0.800 lit.
Crude oil	0.600 lit.
Citygas(commonly manufactured)	1.5 m3
Charcoal	1.40 kg.
Electrical energy	2.20 kwh

Use of biogas would reduce the normal practice of indiscrimate felling of trees and consequent soil erosion and floods. Besides the above benefits, biogas mimics natural environmental cycles; nutrients such as Nitrogen, Potassium and Phosphorous are present in the feedstock and can be recycled back to the land in the form of slurry. Use of organic waste as fertilizer in agriculture is a means to decrease the dependence on imported chemical fertilizer, where as burning of the biomass, most of the nutrients are lost. Complete digestions of the waste, kills' seeds of weeds, organism causing plant diseases are also killed. It has been observed that the use of digested slurry as manure improve soil fertility and increases crop yield by 10 to 20 %. [207].

Limitations

Despite its many benefits, it has a number of drawbacks as well, the major one being the availability of suitable design and the initial investment of the plant particularly in the rural areas. The skilled workmanship needed to ensure leak proof construction mainly bioreactor, gasholder and also the proper maintenance of the plant are also some of the limitation. Maintenance of the essential parameters of the feedstock like feed ratio, pH value of the slurry, temperature, C/N ratio and uniform mixing etc in order to get the maximum yield of the gas are also very important.

Benefits and limitations of biogas system are summarized below:

Benefits:

1. In the context of our continued search for energy to meet the developmental needs of the country biogas technology is a very appropriate addition.
2. It is an eco-friendly and sustainable technology.

3. It reduces the deforestation and save fuel woods [210-212]
4. Biogas is a smoke free, pollution free fuel for cooking, lighting and running agro- machinery. A smoke-free and ash-free kitchen means women are no longer prone to lung and throat infections and can look forward to a longer life expectancy [213-216].
5. In rural areas where there is generally no electricity supply, the introduction of biogas has given women more time to engage in some alternative productive activities.

Approximate gas requirements and storage for different domestic uses has been mentioned below: -

(i) Domestic cooking-2m^3 for family of five or six people.

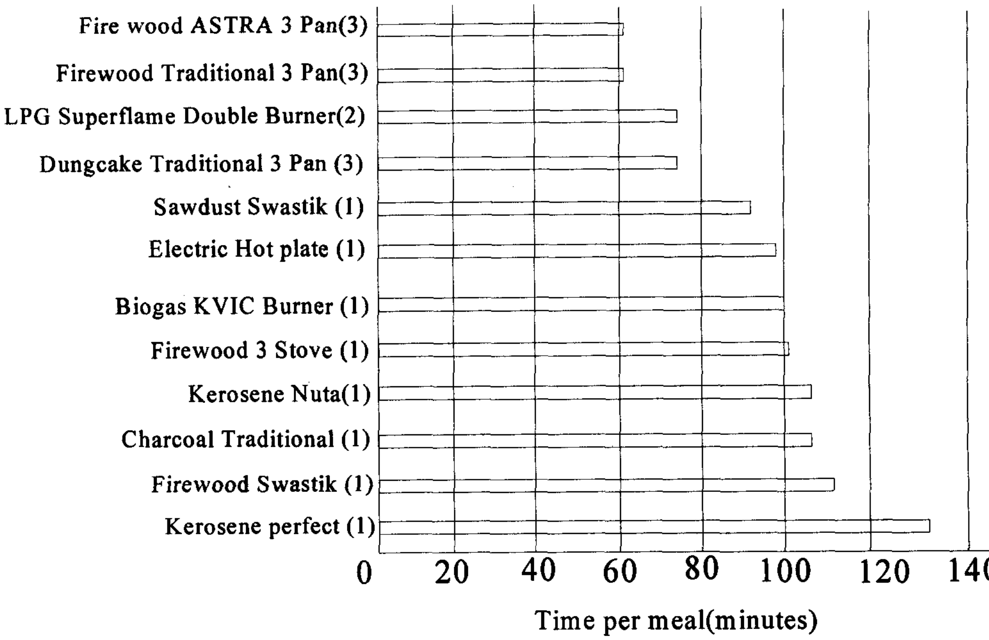
(ii) Water heating-3m^3 per day for a 100litre tank or 0.600m^3 for a tub bath and 0.35m^3 for a shower bath.

(iii) Domestic food refrigeration-2.5-3.0m^3 per day for a family of five or six people.

(iv) Lighting - 0.100- 0.150 m^3 per hour per light (60 Watt).

Cooking Time-The efficiency of the stove does not tell so much about actual cooking time, it is merely a relation between input –and useful energy. The following table no. 4.5 shows the difference in time taken for cooking the meal with various fuel [219-221].

Table No. 4.5 Cooking time against various fuel



In the above figure numbers within bracket indicates number of cooking holes or burners.

Source: Gustavsson, Mathias, "Biogas Technology-Solution in search of its problems", Human Ecology Reports Series 2001,p60.

6. It is a nitrogen rich fertilizer and improves the agricultural productivity. In the biogas plants, nitrogen does not take part in anaerobic digestion, the effluent sludge displaced from the biogas plant contains the same mass of nitrogen as the input slurry. Thus, biogas plants are often called biofertilizer plant [222-224].
7. It has the positive effects on the health of rural people and reduces disease carrying pathogens and parasites
8. Improve sanitation and thus maintain cleaner environment. It also reduces the fly menace. [225-227].

9. Save the woman from the drudgery and lung disease, prevent the damage of eyesight as they get the opportunity to cook the meal in a clean smoke free kitchen [228].
10. Increase employment potential for construction work and maintenance of biogas plant [229].
11. Biogas technology can be made compatible with local village condition and the available biomass can be utilized in a better way.
12. It is a decentralized, self-promoting technology that reduces energy transmission problem.

Limitations

1. Availability of optimum design to suit the variety of local conditions.
2. High cost of installation of the plant some times offsets the benefits.
3. Non-availability of proper skilled workmen for construction of the plant.
4. Operational problem like, leakage, scum removal, pH value, water condensation in gas line, burner problem etc.
5. Availability of required water for feeding the plant, particularly in dry areas.
6. Maintaining continuous feeding of animal waste / feed stock.
7. Problems of co-operation and co-ordination among the users for community plants [230-232].

Despite the above the drawbacks, there are large number of biogas plants which have been installed in China and India. Proper methodology in respect of design, construction and installation are being introduced to the common people under the guidance of WBREDA and MNES in the state. Efforts are on to minimize problems coming in the way of popularization of biogas plants through a process continuous interaction with the users and organizing discussions/meeting with prospective users.