Education Manual

by

Kiran Kumar Kudaravalli

Edited by David Fulford

Foundation SKG Sangha

Kolar, Karnataka, India

www.skgsangha.org

July 2014

Prepared for UNDP funded Biogas Project in Egypt

Contents list

List of Figures

List of Tables

Education Manual

Biogas Technology – Biogas production

A biogas plant uses anaerobic digestion, which uses a population of many different microbes that work together. They are *symbiotic*, which means that they depend on one another. The complex processes can be simplified to three basic stages (see Figure 1).

The important stages in digestion are:

a. Hydrolysis
b. Acidification
c. Methanization

Hydrolysis:

Large molecular complex substances are broken down into simpler ones, which are soluble in water, with the help of extracellular enzymes released by microbes. This stage is also known as polymer breakdown stage. For example, the cellulose, which consists of polymerized glucose is broken down to dimeric sugars, and then to monomeric sugar molecules (glucose and other simple sugars) by cellulolytic microbes, by the addition of water to the long chain molecules (see Figure 3). In the process, the structure of the fibres in the organic wastes is also broken down. (see Figure 2).

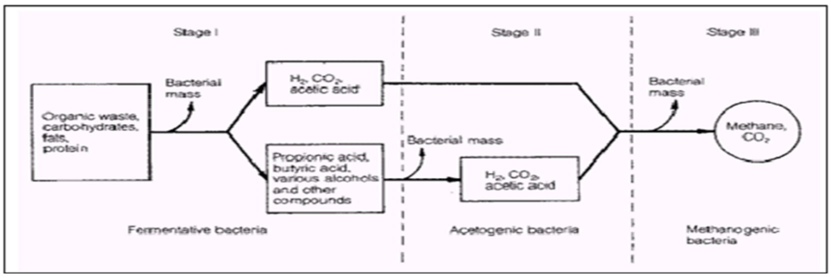


Figure 1 The three stages of anaerobic fermentation

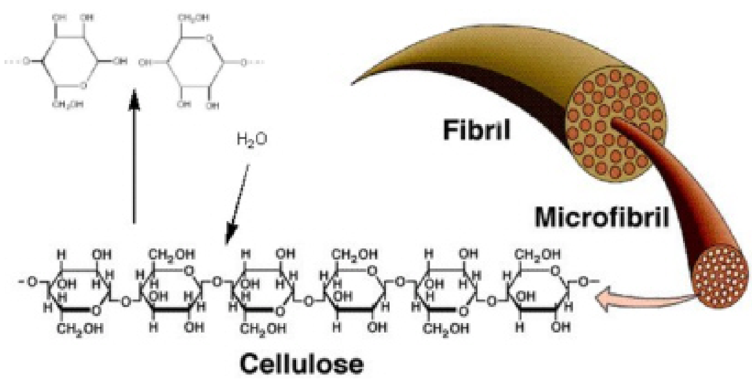


Figure 2 The structure of cellulose in food material

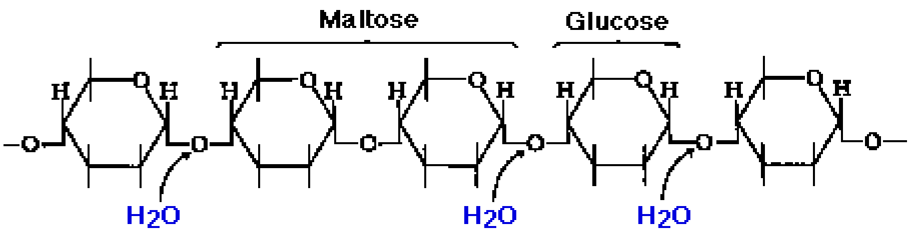


Figure 3 The effect of adding water (hydrolysis) to cellulose to release sugars

Acidification

The soluble chemicals, such as glucose, are fermented under anaerobic condition into volatile fatty acids (VFAs) with the help of enzymes produced by the acid forming microbes. At this stage, the acid-forming bacteria break down molecules of six atoms of carbon (glucose) into molecules with less atoms of carbon (acids), which are in a more reduced state than glucose. The principal VFAs produced in this process include: acetic acid, propionic acid, and butyric acid. These VFAs have strong odours which cause rotting foods to smell obnoxious. Other chemicals are also formed, such as ethanol.

Methane Generation

The VFAs produced in Stage 2 are processed by methanogenic microbes to produce methane and carbon dioxide. The reaction that takes place in the process of methane production is called Methanization and is expressed by the following equations.

$CH_3COOH \rightarrow CH_4 + CO_2$

Acetic acid → Methane + Carbon dioxide

$2CH_3CH_2OH + CO_2 \rightarrow CH_4 + 2CH3COOH$

Ethanol + carbon dioxide → Methane + Acetic acid

Hydrogen is also produced in the process, but only as an intermediate product:

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

Three important things to keep in mind regarding a biogas plant

1. The important bacteria involved in biogas production process are anaerobes and slow growing, so things happen slowly;
2. These anaerobic microorganisms are observed to have metabolic specialization; and
3. Most of the free energy present in the substrate is found in the product of the process: biogas, so the microbes generate only small amounts of energy for their own use.

Three important aspects of a biogas plant

1. Microbial diversity of the population in the plant;
2. The physio-chemical environment of the biogas plant; and
3. The nature of the substrate/feed material.

Microbial bio-diversity

Studies of a healthy biogas plant have found at least seventeen species of microbe that appear to play important roles for the production of biogas. A good population balance is required.

Physio-chemical conditions: pH

The optimum biogas production is achieved when the pH value of input mixture in the digester is between 6 and 7.

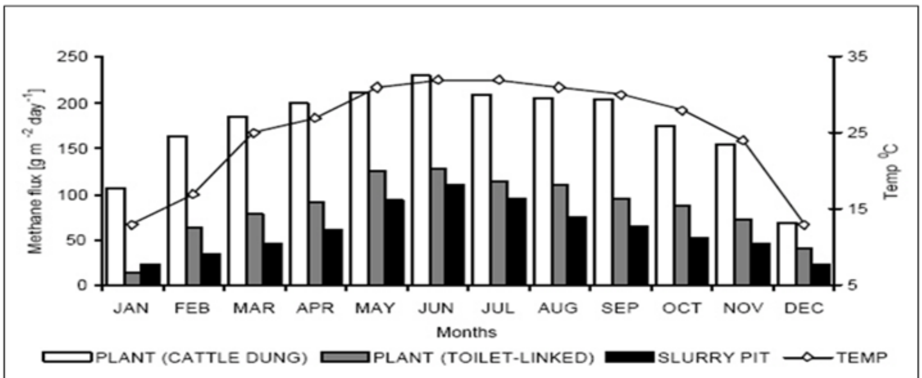
In the initial period of fermentation, as large amounts of organic acids are produced by acid forming bacteria, the pH inside the digester can decrease to below 5. This inhibits or even stops the digestion or fermentation process. Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.5.

Later, as the digestion process continues, the concentration of NH_4 increases due to digestion of nitrogen compounds 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.

Physio-chemical conditions: Temperature

The methanogens are inactive in extreme high and low temperatures. The optimum temperature is 35 degrees C.



Seasonal methane flux from 85 m^3 biogas plant and slurry drying pit.

Figure 4 Physio-chemical conditions: Hydraulic Retention time (HRT)

The average period that a given quantity of input remains in the digester to be acted upon by the methanogens.

The volume of the digester

The volume of the daily feed.

The temperature inside the digester.

The types of feed material.

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.

For a night soil biogas digester, a longer retention time is needed so that the pathogens present in human faeces are destroyed.

The retention time is also dependent on the temperature and up to 35 degrees C, the higher the temperature, the lower the retention time

HRT Affects

The Degree of digestion and the microbial population

HRT is high:

The material remains more time in the digester

The degree of digestion is more

Energy saved from material is more.

HRT is low

The material comes out of the digester before it is fully digested.

The energy saved from feed material is less

Possibility that bacteria may get washed out even before they fully multiply

C/N Affects

In the case of C : N ratio, 25–30 : 1 is optimum for biogas production .

High C/N ratio means low nitrogen content. Bacteria will not be able to use all the carbon and excess carbon will be wasted. Acids will be produced and mix will go sour.

Low C/N ratio. Means high nitrogen content and the excess nitrogen will combine with hydrogen to form ammonia which will inhibit the growth of methanogenic bacteria

Toxicity

Mineral ions, heavy metals and the detergents are some of the toxic materials that inhibit the normal growth of microbes in the digester. Small quantity of mineral ions (e.g. sodium, potassium, calcium, magnesium, ammonia and sulphur) also stimulates the growth of microbes, while very heavy concentration of these ions will have toxic effect.

One of the most poisonous chemicals for anaerobic digestion is chlorine. Any cleaning material that contains chlorine will prevent the plant from working. Small quantities of chloride ions, such as those in salt (sodium chloride), will not affect the functioning of the plant, although excessive amounts will be toxic.

Solid Concentration

The optimum solid concentration in the slurry, when the dung is mixed with water is: 8-10%

The solid concentration influences the digestion process and the flow of slurry inside the plant

Mixing water with a substrate allows it to flow more easily.

When the slurry flow easily, the microbes find it easier to come in contact with feed material.

If the slurry is too dilute, the biogas produced per unit volume of plant will be reduced. Also a dilute slurry separates, with solids sinking to the bottom of the digester pit and scum floats to the top.

If the slurry is too thick, the microbes cannot contact materials so that acetic acid accumulates in the digester, inhibiting the fermentation process.

Toxicity Levels

NH_4 from 50 to 200 mg/l stimulates the growth of microbes, whereas its concentration above 1,500 mg/l produces toxicity.

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+)	3,500 - 5,500 mg/l
Potassium (K+)	2,500 - 4,500 mg/l
Calcium (Ca++)	2,500 - 4,500 mg/l
Magnesium (Mg++)	1,000 - 1,500 mg/l
Manganese (Mn++)	Above 1,500 mg/l
Source: The Biogas Technology in China, BRTC, China (1989)	

Table 1 Effects of toxic inhibitors

Biogas Technology – Technical details of biogas

The following tables give information about biogas systems.

Availability of dung wastes	kgs/day
Cow	10
Calf	5
Buffalo	15
Pig	2
Human	0.4
Sheep/Goat	2
Horse	10
Poultry Bird	0.18

Table 2 Typical amounts of dung from different animals

Material	Average gas yield – l/kg VS	Methane content %	Solids concentration %
Pig Droppings	450	67	16
Cow Dung	250	65	16
Poultry Droppings	460	60	25
Horse Dung	250	0	
Sheep Dung	200	0	30
Grain Straw	250	0	
Rice Straw	220	59	89
Bagasse	160	0	65
Vegetable Residue	350	50	
Water hyacinth	325	52	7
Algae	460	63	
Sewage Sludge	450	0	

Table 3 The gas generated from various materials

For Cooking	0.3 to 0.4 m^3/day/person
For lighting	0.10 to 0.12 m^3/h/100 candle power light
For running Engine	0.4 to 0.5 m^3/HP/hour

Table 4 Gas usage for various application

Optimum gas to air ratio for complete combustion (by volume)	6 – 7 10 to 1
Explosive limits to air (by volume)	5 - 15
Ignition temperature	650 °C
Calorific Value - 60% Methane - Without CO2	 22.350 to 24.220 MJ/m^3 33.525 to 35.390 MJ/m^3

Table 5 Properties of biogas

Gas	Symbol	% biogas
Methane	CH_4	50 - 60
Carbon dioxide	CO_2	45 - 30
Hydrogen	H_2	5 – 10
Hydrogen Sulphide	H_2S	0.5 – 0.7
Oxygen	O_2	Traces

Table 6 Typical composition of biogas

1 m^3 of biogas	0.6 liters of Kerosene
1 m^3 of biogas	3.5 Kg. of Fuel Wood
1 m^3 of biogas	0.4 kg of LPG

Table 7 Equivalents of biogas to other fuels

1 m^3 of Biogas	1000 Litres
1 m^3 of Biogas	35.7 ft^3
1 ft^3 of Biogas	0.28 m^3

Table 8 Volume equivalents

Biogas technology - Slurry production

Slurry Analysis and explanations

	Microbial analysis	Unit	Result
1	Total Bacteria Count	N / g	21.7×10^{8}
2	Fungi	N / g	40×10^{4}
3	Actinomycetes sp	N / g	19×10^{5}
4	Azospirillum sp	N / g	15.6×10^{7}
5	Phosphate Solubilizer Sp	N / g	38×10^{3}
6	Pseudomonades sp	N / g	$>11 \times 10^{4}$
7	Rhizobium sp	N / g	26×10^{6}
8	Nitrogen Fixing Bacteria(Azobzcter sp)	N / g	32×10^{6}

Table 8 Analysis of microbes in slurry

Notes:

1. Actinomycetes sp: Actinomycetes and *Streptomyces* sp. in particular, are non-obligate anaerobic predators of bacteria in soil.
2. Azospirillum sp: Plant growth promoters. They will accumulate at roots and helps the plant growth
3. Rhizobium sp: Basically nitrogen fixation bacteria. It works to reduce the soil contamination by metals.
4. Pseudomonades sp: The antibiotics phenazine-1-carboxylic acid (PCA) and 2,4-diacetylphloroglucinol (Phl) are major determinants of biological control of soil borne plant pathogens by various strains of fluorescent Pseudomonas spp.

Nitrogen fixation

Nitrogen is extremely important in agriculture because it is a constituent of proteins, nucleic acids and other essential molecules in all organisms. Most of the nitrogen is derived from reduced or oxidised forms of nitrogen in the soil by growing plants, because plants and animals are unable to utilise atmospheric nitrogen, which is abundant (nearly 80 percent). Yields of many crops, particularly cereals, have been increased over the years by the application of large quantities of nitrogen fertilizers. This practice is expensive and leads to the eventual contamination of waterways with high levels of nitrates. The only other sources available to plants is from decomposing organic matter, soil reserves, biological nitrogen fixation, and from other sources such as automobile exhaust. Biological nitrogen fixation (enzymic conversion of atmospheric N_2 gas to ammonia) is the most important source of fixed nitrogen entering the soils. **A relatively small number of bacterial species have the special ability to reduce or fix atmospheric N_2 to form ammonia, a product that can be used by plants and other microbes.** It is a building block for the synthesis of ammonia acids and other nitrogenous compounds. On a global scale the amounts of N_2 fixed by these bacteria are nearly 200 million tonnes each year.

The reduction of N_2 is catalyzed by the nitrogenise system, which is very similar in composition and function in all prokaryotes which produce it. Nitrogenise is found only in prokaryotic microorganisms (bacteria and archaea) and thus eukaryotes, such as plants, can benefit from N_2 fixation only if they interact with N_2-fixing species of microorganism or obtain the fixed nitrogen after the death of the organisms. Nitrogenise functions only under anaerobic conditions because it is irreversibly inactivated by oxygen. The fixation of N_2 requires large amounts of energy, about 30 moles of ATP per mole of N_2 reduced, and thus acts as a major drain for energy produced by N_2 fixing microorganisms. The natural supply of nitrogen to certain plants is achieved by close association between them and nitrogen fixing microorganisms. Of the important crop species, only the legumes exhibit this phenomenon; nitrogen-fixing nodules are formed on their roots due to a symbiotic relationship with bacteria. Nodule formation depends on recognition between the appropriate bacteria strain and the legume host.

Genus	Species	Group	Properties of interest
Azotobacter	Vinelandii	Gram negative bacterium	Fixes N_2 in air; contains a protein that protects nitrogenise from oxygen damage
Azospirillum	_	Gram negative bacterium	Associated with roots of grasses and other plants.
Rhizobium	_	Gram negative bacterium	Nodulates some leguminous plants; Fixes N_2 in legume root nodules.
Klebsiella	Pneumoniae	Gram negative bacterium	Model system for nif genetics. Genetics of nif well understood, particularly after transfer to Escherichia coli
Frankia	_	Gram negative bacterium	Nodulates a range of unrelated shrubby and woody dicotyledonous plants; some species can be cultured
Rhodospirillum Rhodopseudo-monas	_	Gram negative bacterium	Purple green photosynthetic bacteria
Clostridium	_	Gram positive bacterium	Obligate anaerobe
Anabaena Nostoc	_	Filamentous blue green algae	Form symbiotic associations with a range of plants (Cycads,Azollz)fungi etc. Fixes N_2 in specialized cells called heterocysts
Methanococcus	_	Archaea	_

Table 9 List of some prokaryotic microorganisms that fix nitrogen

Nitrogen Fixing Organisms and Associations:

There is a list of simple non-nucleated prokaryotes in Table 9. Nitrogen-fixers have not yet been found among nucleated eukaryotes. Genetic studies show that the structural genes are highly conserved in all known nitrogen-fixing species suggesting that the nif genes must have evolved and then spread throughout virtually all groups of prokaryotic microorganisms. Most important nitrogen fixing associations that occur in nature, both in terms of the amounts of N_2 fixed and the benefits to particular crops, involve symbiotic associations in which plants provide specific structures in which the microorganisms are contained. The best known examples are root nodules which are induced by species of Rhizobium on leguminous plants, by the blue-green algae Nostoc on Cycads, and the special pockets in the leaves of the water fern Azolla containing the blue-green alga Anabaena. In all these symbioses, the microorganisms live inside the plant as monocultures. They receive carbon compounds directly from the host and the fixed nitrogen is made available directly to the host.

Manure and its link with soil

Organic manure helps in the aggregation of small soil particles. Work at the Indian Agricultural Research Institute (IARI) demonstrated that the addition of fresh biogas slurry helps to form a level of 30% of aggregates of more than 0.25 mm size in the soil. With dried bio gas manure the percentage comes to about 28% and with farmyard manure it is about 23%. The presence of organic matter prevents soil forming into large lumps, called puddling, and keeps the structure open.

Organic matter also serves the ability to help soil retain moisture. In drought conditions the soil tends to lose water and become parched. If organic matter is present in soil it resists evaporation of soil moisture, so during long dry spells, soil rich in organic matter keeps the crops alive. The retention of moisture also means the soil retains trace amounts of many other inorganic elements, which are necessary for plant growth. Organic matter also supplies these minor elements and keeps the plants healthy. It is possible that organic matter supplies other ingredients like hormones or enzymes or some other obscure elements.

Organic matter from cattle manure and especially biogas slurry provides more than just major plant nutrients, such as NPK, but also provides micro-nutrients and provides a source of microbes that benefit the soil.

Principle of Fixed model biogas plant functionality

The Deenbandhu model biogas plant is a fixed model biogas plant and was developed in India. Initially the plant needs to be fed with animal dung and water in equal proportions up to the prescribed level as shown in Figure 4. The bacteria in the dung start working and replicate themselves in the anaerobic conditions created in the digester. Initially the material in the feed material are hydrolyzed to volatile solids and then converted into organic acids before methanogenic microbes start working. The initial conversion process generates many kinds of gases including hydrogen, carbon dioxide and hydrogen sulfide. The combination of these gases should be released. At this stage the gas smells bad and should not be tested for its inflammability. The air that initially existed in the plant and the hydrogen generated by the facultative bacteria makes the gas more likely to explode.

In normal conditions biogas (a combination of methane and carbon dioxide) will be generated after about 10 days time. A 3 meter long flexible pipe can be connected to the gas outlet pipe of the digester and gas can be tested for its flammability away from the digester at the end of the pipe. Once flammable biogas is generated the plant can be used normally and fed with a slurry of dung and water each day.

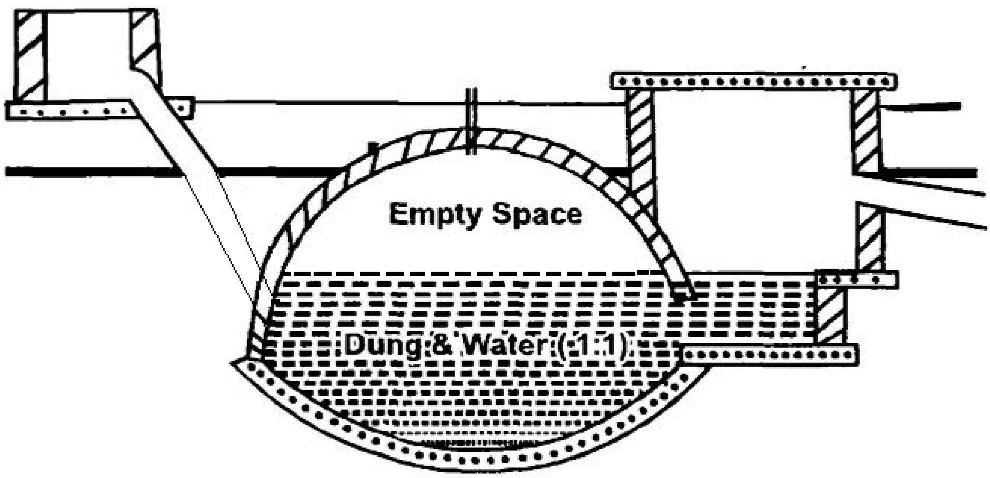


Figure 5 The initial level of feeding with dung and water

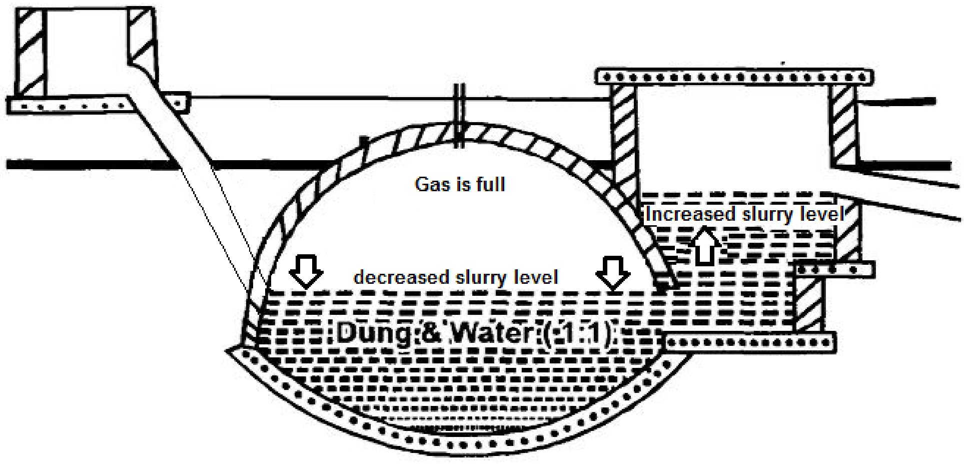


Figure 6 Slurry level changes as gas is produced and collected.

When the microbes produce biogas accumulates and the gas pressure in the dome above the slurry in the digester increases. The slurry is displaced into the displacement chamber increasing the level of slurry in that chamber. As the volume of biogas in the digester increases, the volume of slurry in the displacement chamber increases until the level reaches the slurry exit hole and flows out (Figure:5). This should happen three times a day as the plant is designed to store 1/3 of its daily gas production capacity.

The variation of slurry heights will create pressure in the gas, which drives the gas through the pipe to the burner (Figure: 3). As the gas is used, the pressure in the digester will drop and the slurry in the displacement tank will flow back to the digester. The lighter solids in the dung will float upwards and the heavier particles will sink down leaving the well digested slurry to remain in the middle. This middle level material in the digester will flow back and forth to and from the displacement tank. Excess digester slurry will escape through the exit hole. It is better to feed the plant when the gas is in use so that the material flowing back from the displacement tank will keep the fresh feed away from the slurry outlet.

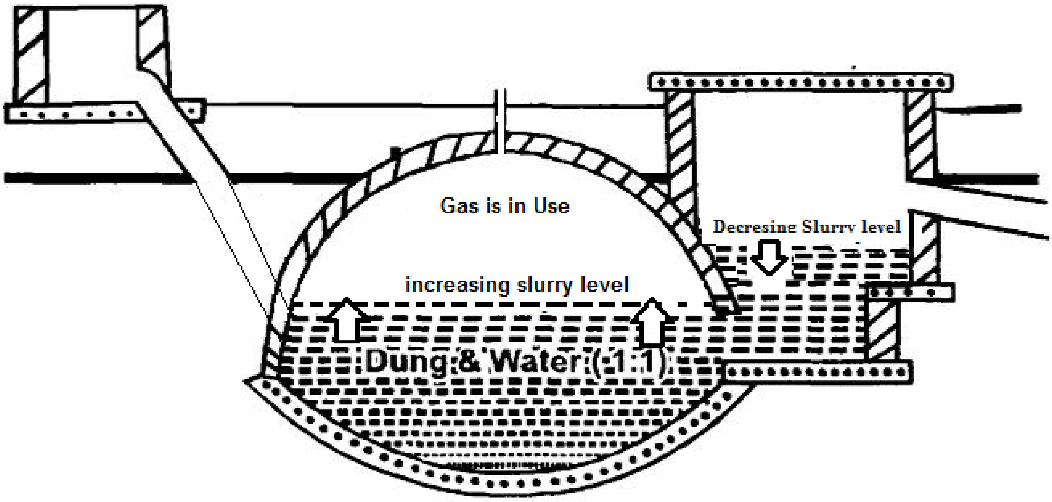


Figure 7 Changes in slurry levels as gas is used

Soil Types and Soil Texture

There are two major types of material in soils: mineral (inorganic) and organic. Mineral soils are a mixture of weathered minerals and decayed plants and animals. There are four main components to consider when considering a mineral soil: mineral matter, organic matter, water, and air (Figure 8). A loamy soil that is ideal for plant growth consists of 45 percent soil mineral particles, 5 percent organic matter, 25 percent air, and 25 percent water by volume. The amount of air and water in the soil can be extremely variable depending on the frequency and amount of precipitation. The combination of these four components helps determine a soil's potential as a building site.

The size range of individual mineral particles (sand, silt, clay) is expressed by soil texture. This size range or texture influences the amount of the other three components present at any one time in a specific volume of soil.

Organic soils consist mostly of decayed plant material (Figure 9) and occur in swamps, bogs, and marshes. Such soils feel very light when dry. Well-decayed muck and peat are powdery when dry but partially decayed peat contains easily identified plant stems and leaves.

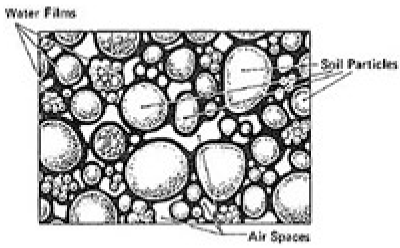


Figure 8 Components of soil

Figure 8 is a representation of the physical relationship between soil particles, water films, and air space in a soil.

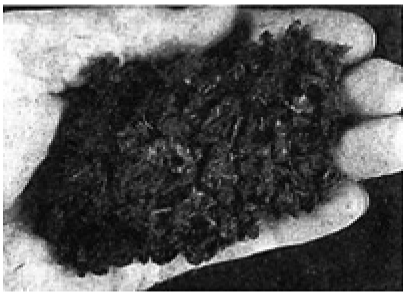


Figure 9 A sample of high organic soil (peat)

Importance of Texture to Building Site Characteristics

The texture of the subsoil indicates the building site potential. If the subsoil is coarse (sandy or loamy sand), water drains through it rapidly (assuming the water table is not high). Coarse-textured soils are easily excavated and quite stable during both dry and wet conditions.

Fine-textured soils (clay soils) have a tendency to expand as the amount of moisture increases and to contract as moisture decreases. Cracks at the soil surface are evidence of this during dry periods. This same expansion and contraction takes place during the winter and spring as the moisture in the soil freezes and thaws. This lack of stability can crack foundations, sidewalks, and driveways if precautions are not taken.

Soils with high levels of organic material (such as peat and muck) may make good garden sites, if adequate drainage can be provided. However, the fact that these soils are easily compacted, resulting in settling if foundations are installed, makes them unsuited for building.

Identification of raw material for biogas production

All putrecible material is suitable for biogas production. Different raw materials have different characteristics. For example, left over food contains more starch and bird droppings contain more nitrogen. Vegetable and fruit peels have contain fibres and bread and rice contain more starch. The carbon:nitrogen ratio of the feed material defines its suitability for biogas production. Material containing about 25 parts of carbon and 1 part of nitrogen is suitable for biogas production. If bird droppings are to be treated in biogas plant then the C/N ratio of this material needs to be analyzed. Often bird droppings about 15 parts of carbon for one part of nitrogen. If this material is fed by itself then digestrate in the digester can become to rich in nitrogen (ammonia) and the pH level can go beyond 8. If there is too much ammonia the methanogenic microbes do not work properly and biogas generation will stop. If left over food containing bread and rice is fed to the digester on its own, the digestate can become acidic and the pH level can drop to 6. This can also cause the biogas production to stop. By mixing different materials having different C/N ratios can be mixed until their combined C/N ratio becomes 1:25 to generate biogas without problems.

In the rural households the following material is available:

Animal dung, animal urine, bird excrements, left over food, human faeces, rotten vegetables and peels, rotten fruits and peels.

The best feed material is animal dung mixed with urine as many plants are working with this feed. There the amount of dung is inadequate and there is rotten and left over food available, it can be added to the biogas plant. If is a good idea to check the C:N ratios of the different materials. If one feed material has a high level of nitrogen, then it should be mixed with a material with a low level of nitrogen, to get the right balance.

Mixing and feeding of material

Once the material for feeding is finalised the next step is to feed it to the digester. At this stage the solid concentration of the material has to be checked. Biogas plants work well with 8-10% solids concentration. If the material is having more solids than 10%, then the material has to be diluted with water. Fresh cow dung has about 16 to 20 % solids in it. To bring down the solids concentration it is suggested that the dung is mixed with an equal amount of water. The material has to be prepared in advance before it is fed to the digester. After the material is mixed, the following aspects have to be checked:

Whether there is material floating on the top, which could and create a layer of scum.

Whether the material contains sediment which can sink and occupy space in the digester.

Whether there are lumps in the material that could block the inlet pipe.

Floating scum can be removed from the surface. If there is a large amount of floating material, such as dried animal dung, it can be left for a time in a container with water, so it can be rehydrated. If there is heavier material, which is likely to sink (such as rotten potatoes), it may be necessary to use a mixing device in the digester. If there are lumps, then they need to be broken up. Vegetables and fruits, especially peels, need to be chopped or crushed before they are added to the digester.

Prepared by: SKG Sangha
Email: skgsegypt@gmail.com
URL: www.skgsangha.org