CHAPTER 3

Review Of Bio-Gas Technology

3.1 Bio-Gas Technology

Bio-gas technology is the transformation of solid waste through anaerobic digestion process to obtain bio-gas such as methane.

3.1.1 Process Microbiology

The biological conversion of the organic fraction of municipal solid waste under anaerobic conditions is thought to occur in three steps. The first step involves the enzyme-mediated transformation (hydrolysis) of higher-molecular-mass compounds into compounds suitable for use as a source of energy and cell tissue. The second step involves the bacterial conversion of the compounds resulting from the first step into identifiable lower-molecular-mass intermediate compounds. The third step involves the bacterial conversion of these intermediate compounds into simpler end products, principally methane and carbon dioxide.

In the anaerobic decomposition of wastes, a number of anaerobic organisms work together to bring about the conversion of the organic portion of wastes into a stable end product. One group of organism is responsible for hydrolyzing organic polymers and lipids to basic structural building blocks such as fatty acids, monosaccharides, amino acids, and related compounds. A second group of anaerobic bacteria ferments the breakdown products from the first group to simple organic acids, the most common of which is acetic acid. This second group of microorganisms, described as nonmethanogenic, consists of facultative and obligate anaerobic bacteria that are often identified in the literature as “acidogens” or “acid formers”.

A third group of microorganisms converts the hydrogen and acetic acid formed by the acid formers to methane gas and carbon dioxide. The bacteria responsible for this conversion are strict anaerobes, called methanogenic, and are identified in the literature as “methanogens” or “methane formers”. Many methanogenic organisms identified in landfills and anaerobic digesters are similar to those found in the stomachs of ruminant animals and in organic sediments taken from lakes and river. The most important bacteria of the methanogenic group are the ones that utilize hydrogen and acetic acid. They have very slow growth rates; as a result, their metabolism is usually considered rate-limiting in the anaerobic treatment of an organic waste. Waste stabilization in anaerobic digestion is accomplished when methane and carbon dioxide are produced. Methane gas is highly insoluble, and its departure from a landfill or solution represents actual waste stabilization.

3.1.2 Environmental Factors

To maintain an anaerobic treatment system that will stabilize an organic waste efficiently, the nonmethanogenic and methanogenic bacteria must be in a state of dynamic equilibrium. To establish and maintain such a state, the reactor contents should be void of dissolved oxygen and free of inhibitory concentrations of free ammonia and such constituents as heavy metals and sulfides. Also, the pH of the aqueous environment should range from 6.5 to 7.5. As the methane bacteria cannot function below this point, sufficient alkalinity should be present to ensure that the pH will not drop below 6.2. When digestion is proceeding satisfactorily, the alkalinity will normally range from 1000 to 5000 mg/L and the volatile fatty acids will be less than 250 mg/L. Values for alkalinity and volatile fatty acids in the high-solids anaerobic digestion process can be as high as 12,000 and 700 mg/L, respectively. A sufficient amount of nutrients, such as nitrogen and phosphorus, must also be available to ensure the proper growth of the biological community. Depending on the nature of the sludges or waste to be digested, growth factors may also be required. Temperature is another important environmental parameter, with optimum temperature in the mesophilic, 30 to 38°C (85 to 100°F), and the thermophilic, 55 to 60°C (131 to 140°F) range.

3.1.3 Gas Production

The general anaerobic transformation of solid waste can be described by means of the following equation.

$$\text{Organic matter} + H_2O + \text{nutrients} \rightarrow \text{new cells} + \text{resistant organic matter} + CO_2 + CH_4 + NH_3 + H_2S + \text{heat}$$

3.1.4 Bio-Gas

Bio-gas is a gas generated from the anaerobic digestion of organic waste. It consists of CH_4 (50-70%), CO_2 (30-50%) with the remaining gases being: H_2, O_2, H_2S, N_2 and water vapor. To ensure optimal Bio-gas production, the three groups of micro-organisms must work together. In case of too much organic waste, the first and second groups of micro-organisms will produce a lot of organic acid which will decrease the pH of the reactor, making it unsuitable for the third group of micro-organisms. This will result in little or no gas production. On the other hand, if too little organic waste is present, the rate of digestion by micro-organisms will be minimal and production of Bio-gas will decrease significantly. Mixing could aid digestion in the reactor but, too much mixing should be avoided as this would reduce bio-gas generation. Table 3.1 shows the amount of bio-gas generated from animal waste and agriculture residue.

Table 3.1 Amount of bio-gas generated from animal waste and agriculture residue

animal	gas produced L/kg-solid
Pig	340-550
Cow	90-310
Chicken	310-620
Horse	200-300
Sheep	90-310
Straw	105
Grasses	280-550
Peanut shell	365
Water Hyacinth	375

3.1.5 Factor Affecting Gas Generation

To ensure a constant generation of gas, the following factors should be considered :

- Organic waste should be sufficient at all time.
- Daily input of waste should conform with reactor size. Too much input will reduce the gas generation rate.
- Digestion period (retention time) should be about 60-80 days

$$\text{Digestion period} = \frac{\text{Volume of reactor}}{\text{Daily input of waste}}$$

- pH within reactor should be about 7.0-8.5. Too low a pH will inhibit gas production.

3.1.6 Benefit of Bio-Gas Technology

The following benefits will be obtained from bio-gas technology:

- Energy

Bio-gas could be used as a fuel alternative to wood, oil, LPG and electricity.

- Agriculture use

Sludge from the bio-gas reactor could be used as compost. Organic nitrogen from waste will be transformed into ammonia nitrogen, a form of nitrogen which plants can uptake easily.

- Protect environment

Using bio-gas technology on animal waste treatment will reduce risk of infection from parasite and pathogenic bacteria inherent in the waste. Odor and flies will be significantly reduced in the area, and water pollution created by the dumping of waste can also be prevented.

3.2 Review of Bio-Gas Reactor

The anaerobic digestion of organic waste materials, such as farm manure, litter, garbage, and night-soil, accompanied by the recovery of methane for fuel, has been an important development in rural sanitation during the last few decades. This development is basically an extension of the anaerobic process for sludge digestion used in municipal sewage treatment to small digestion-tank installations on farms. These farm plants comprise of one or more small digesters and a gas-holder. Manure and other wastes are placed in a tank which is sealed from atmospheric oxygen, and are permitted to digest anaerobically. The methane gas, which is produced during the anaerobic decomposition of the carbonaceous materials, is collected in the gas-holder for use as fuel for cooking, lighting, refrigeration, and heating, and for other domestic or agricultural purposes, such as providing power for small engines.

This method provides for the sanitary treatment of organic wastes, satisfactory control of fly-breeding, efficient and economical recovery of some of the waste carbon as methane for fuel, and retention of the humus matter and nutrients for use as fertilizer.

Most of the farm installations have, so far, utilized only animal manure and organic litter; however, night-soil can be satisfactorily treated together with the other wastes in these digesters if adequate digestion time is allowed to permit the destruction of the pathogenic organisms and parasites. Such a practice has many advantages on farms and in villages where water-carried sewage disposal is not available. The use of the digestion tank can eliminate the dangerous insanitary practice of allowing night-soil to be deposited on fields, and in the immediate environment of homes, without proper treatment. Straw, weed trimmings, or any other type of cellulose materials may be digested together with the manure and night-soil for the production of methane.

Digester tanks with gas collection are particularly advantageous in areas which are short of fuel and where animal dung is burned for cooking. The burning of dung destroys, with digestion, the valuable nitrogen and other nutrients which could be used as fertilizer. The nitrogen, phosphorus, potash, and other nutrients are retained in the tank as humus and liquid while much of the carbon and hydrogen are evolved as methane, for collection and use as fuel. The quality of the humus is similar to that obtained from aerobic composting, and when the liquid is utilized together with the solids as fertilizer, practically all of the fertilizer nutrients are reclaimed.

The evolved gas, which consists approximately of two-thirds methane and one-third carbon-dioxide, will contain 4500 to 6000 calories per cubic metre, thus providing a convenient source of heat at low cost. One cubic metre of the gas at 6000 calories is equivalent to the following quantities of other fuels : 1,000 litres of alcohol; 0.800 litres of petrol; 0.600 litres of crude oil; 1.500 m^3 of commonly manufactured city gas; 1.400 kg of charcoal; and 2.2 kilowatt-hours of electrical energy.

The gas can be stored in the gas-holder and piped into the house to provide clean fuel for cooking and lighting. It has a slight barn-yard odour by which any leaks can be readily detected, and a very low toxicity since it contains very little carbon monoxide—the toxic constituent of most city gas. It burns with a violet flame without smoke. Since a considerable amount of CO_2 is mixed with the methane, the risk of fire or explosion is somewhat less than in the case of city gas. However, every precaution should be taken to avoid obtaining a mixture of methane and air, except when the methane is burned as an open flame. Mixtures of 5% - 14% methane in air are explosive when large quantities are ignited.

There are several basic factors to be considered when constructing or purchasing a digester installation. These are : (1) climate; (2) single or multiple family installations; (3) amount of wastes available; (4) gas production; (5) location of digesters; (6) gas requirements and storage.

3.2.1 Climate

Small digester plants can be used most effectively in temperate climates, where freezing temperatures are infrequent and of short duration. Decomposition and gas production are most rapid at about 35°C, but are satisfactory at temperatures between 15-20°C. Gas production practically ceases at temperatures below 10°C.

3.2.2 Single or Multiple Family Installations

Either single or multiple family installations can be provided, depending on whether the family has sufficient manure and other wastes to operate a unit. A minimum single family installation would normally include a digester tank of about 4-5 m^3 capacity and a gas-holder of at least 2 m^3 capacity. Two or more digesters are desirable so that there will not be an interruption of gas production and so that one tank may be loaded while the other is digesting. A single gas-holder can serve more than one digester unit. If two or more families living in adjacent compounds do not have more than one farm animal each, it may be advantageous to combine their wastes into one digester installation from which the gas could be distributed to each dwelling.

3.2.3 Amount of Wastes Available

As indicated, horses and cows produce between 10 to 16 metric tons of manure per year, depending on stabling conditions and amounts of organic litter used for bedding. To this amount, garbage, waste straw, cane stalks, or any other organic litter may be added. Where night-soil is used as a fertilizer, it should be digested with the other organic wastes before application to the land, in order to prevent the spread of fecal-borne diseases. While human excrement does not add much weight to the digester (15-30 kg per capita per year) it does provide appreciable quantities of the nitrogen and phosphorus necessary for the biological digestion and methane production of cellulose and other materials with a high carbon content.

3.2.4 Gas Production

In practice, about 50% of the carbon theoretically available for gas production is converted into gas. A metric ton of waste will normally yield about 50-70 m^3 of gas per digestion cycle, depending upon the proportion of organic matter and the carbon content of the waste.

The digestion cycle will be shorter at high temperatures than at low temperatures, and the daily yield per ton of material will be greater. Considerably greater digester-capacity is required to produce a fixed amount of gas at a temperature of about 20°C than at a temperature of 30-35°C. Mignotte[54] gives the following estimates for gas production per ton of manure for different digestion periods at different temperatures :

Temperature (°C)	Gas production (m^3 per day)	Digestion period (months)
15	0.150	12
20	0.300	6
25	0.600	3
30	1.000	2
35	2.000	1

3.2.5 Location of Digesters

The digesters should be located near the source of manure and waste material to avoid excessive handling and transportation. Also it is desirable to place them so as to minimize the amount of gas piping required.

3.2.6 Gas Requirements and Storage

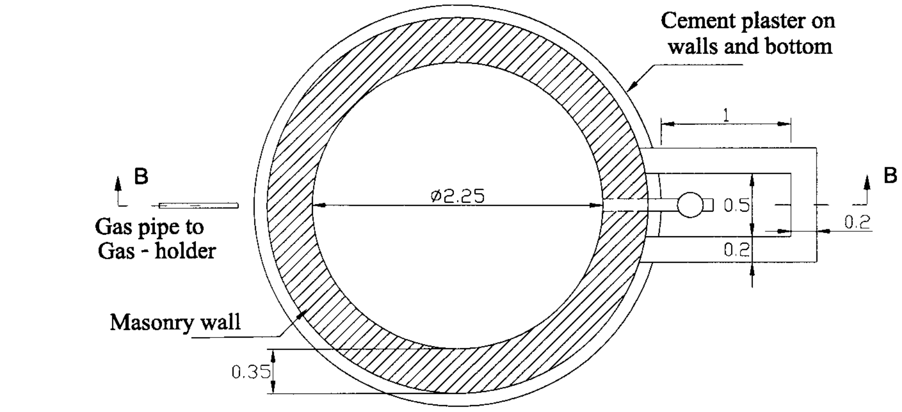
The gas may be used for domestic purposes, such as cooking, heating water, food refrigeration, and lighting. The following are some approximate quantities of gas for these different uses : domestic cooking, 2 m^3 per day for a family of five or six people; water heating, 3 m^3 per day for a 100-litre tank or 0.600 m^3 for a tub bath and 0.35 m^3 for a shower bath; domestic food refrigeration, 2.5-3 m^3 per day for a family of five or six people; lighting, 0.100-150 m^3 per hour per light.

Since the gas is produced continuously, day and night, but is used largely during the daytime, it is necessary to provide storage facilities so that the gas will not be wasted and will be available when needed. The storage capacity should be estimated to meet peak demands. For small installations, storage capacity of about one day's requirement of gas should be provided. The volume of the gas-holder should not be less than about 2 m^3, even for very small installations.

The gas-holder may be circular or square and should be provided with a water seal to prevent the escape of gas or admission of air. The weight of the floating cover of the gas-holder provides the gas pressure.

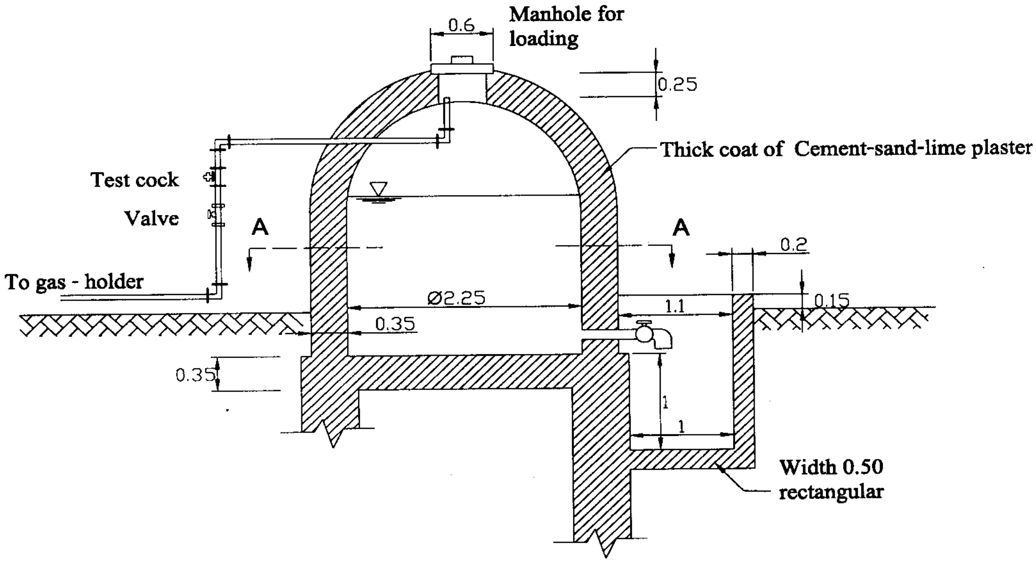
3.3 Example of Digesters

Some examples of digesters are shown in Figures 3.1-3.6. They are individual digester unit, manure gas plant with latrine, digester and latrine, gas holder for manure gas plant and manure digester with floating cover for gas holder.



All Measurements are in metres

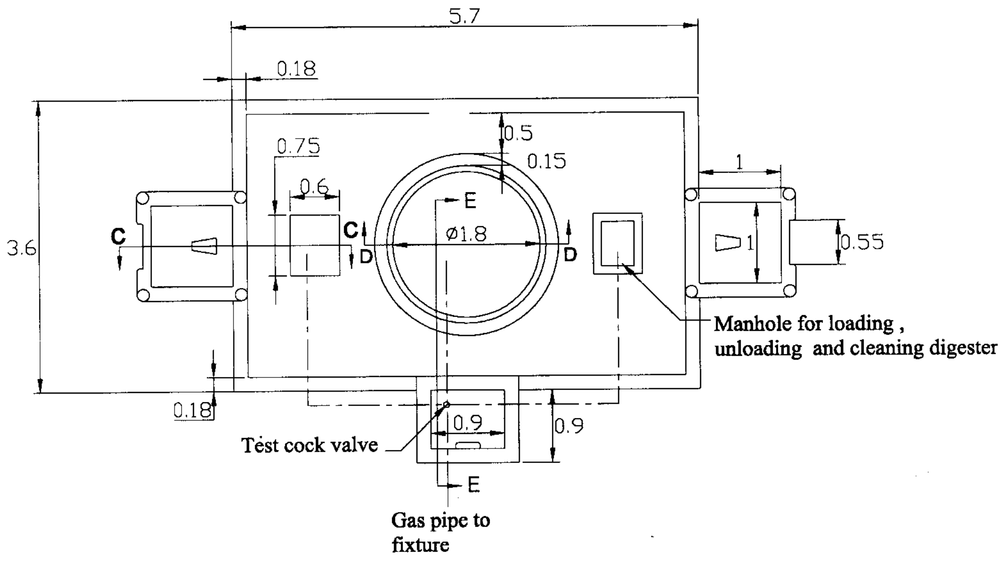
Figure 3.1 Plan of Individual Digester Unit



Maximum manure - storage capacity of digester : 7.860 m^3

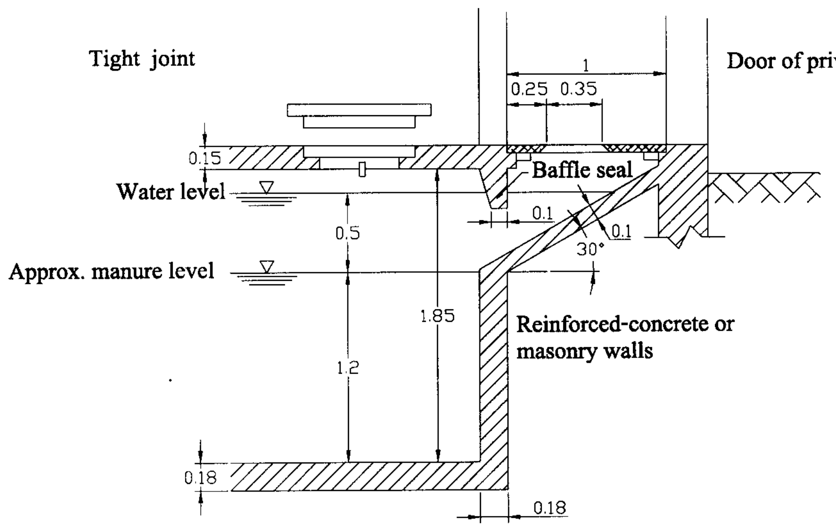
All Measurements are in metres

Figure 3.2 Cross Section of Individual Digester Unit



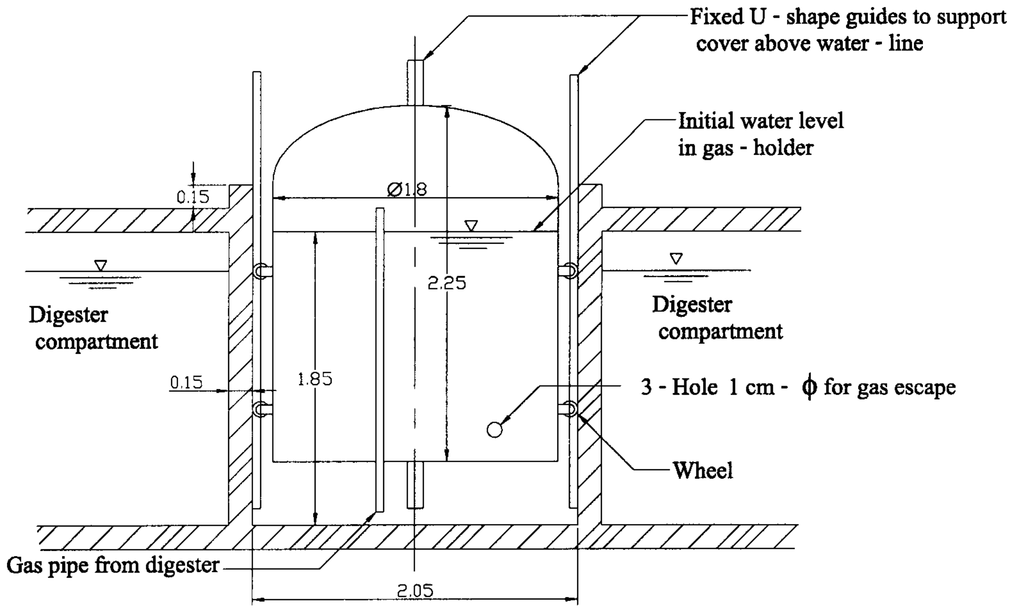
All Measurements are in metres

Figure 3.3 Plan of Manual Gas Plant with Latrines



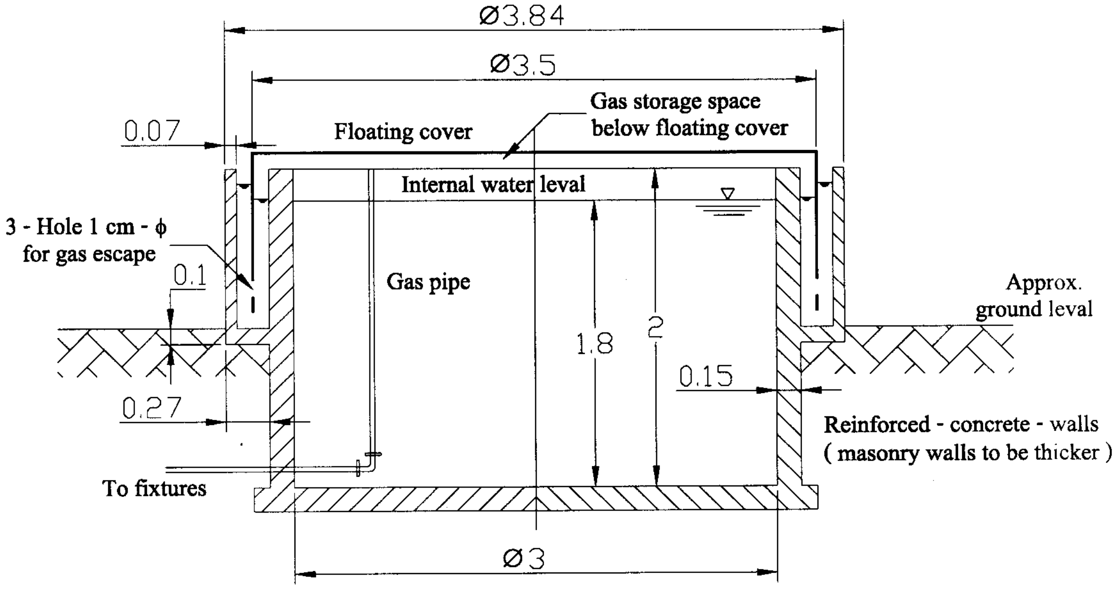
All Measurements are in metres

Figure 3.4 Cross Section of Digester and Latrines



All Measurements are in metres

Figure 3.5 Cross Section of Gas - Holder for Manure Gas Plant



All Measurements are in metres

Figure 3.6 Cross Section of Manure Digester with Floating Cover for Gas - Holder