7.2. Biomass Conversion Technologies

A wide variety of conversion technologies is available for manufacturing premium fuels from biomass (see table 7.2.1). Some are simple and well understood like digestion and fermentation ; others like gasification have been tested in large pilot plants and are now being commercialised.

Table 7.2. Biomass Conversion Technologies

	Conversion Process	*Principles Products*			*Further Treatment*	*Premium Fuels*
		Solids	*Liquid*	*Gases*		
Wet	Anaerobic Digestion			Methane[b] and carbondioxide	Carbon dioxide removal	Methane
	Fermentation		Ethanol		Distillation	Ethanol
	Chemical Reduction		Mixture of oils		Fractional distillation	Hydrocarbon liquids
Thermal Processes	Liquefication Gasification Steam-gasification	Char Char Char	Pyroligneous acids oils and tars	Fuel gas[b] Fuel gas[a,c] Methane[c]	Steam reforming and/or shift reaction	Methane Methanol or Higher Alcohols
Thermal Processes	Hydrogenation		Mixture of oils		Fractional distillation	Hydrocarbon liquids
	Oil Extraction		Vegetable oil		Esterification	Diesel Substitute

Key : a = low calorific value (5-10 MJ/m^3), b = medium calorific value (10-25 MJ/m^3), c = high calorific value (30-45 MJ/m^3).

Each biomass resource—wood, dung, vegetable waste can be treated in many different ways to provide a wide spectrum of useful products. Domestic refuse, for example, can be dried and burnt to provide heat or converted into low calorific value gas by 'pyrolysis' (heating without air). Alternatively, it can be stirred into a slurry and digested to yield methane. Like-wise, liquid and gaseous fuels such as methanol and methane can be manufactured by several different routes and from a variety of feedstocks.

The choice of the process is determined by a number of factors: the location of the resource and its physical condition, the economics of competing processes, and the availability of a suitable market for the product.

Biomass conversion, or simply bio conversion can take many forms : (1) direct combustion, such as wood waste and bagasse (sugar cane refuge), (2) thermochemical conversion, and (3) biochemical conversion.

Thermochemical conversion takes two forms : gasification and liquefaction, *Gasification* takes place by heating the biomass with limited oxygen to produce low heating value gas or by reacting it with steam and oxygen at high pressure and temperature to produce medium heating value gas. The latter may be used as fuel directly or used in liquefaction by converting it to methanol (methyl alcohol CH_3OH) or ethanol (ethyl alcohol CH_3CH_2OH) or it may be converted to high heating value gas.

Biochemical conversion takes two forms. Anaerobic digestion and fermentation. *Anaerobic* digestion involves the microbial digestion of biomass. (An anaerobe is a micro-organism that can live and grow without air or oxygen, it gets its oxygen by the decomposition of materials containing it). It has already been used on animal manure but it is possible with other biomass. The process takes place at low temperature upto 65°C, and requires a moisture content of at least 80 per cent. It generates a gas consisting mostly of CO_2 and methane (CH_4) with minimum impurities such as hydrogen sulfide. The gas can be burnt directly or upgraded to synthetic natural gas by removing the CO_2 and the impurities. The residue may consists of protein-rich sludge that can be used as animal feed and liquid effluents that are biologically treated by standard techniques and returned to the soil.

Fermentation is the breakdown of complex molecules in organic compound under the influence of a ferment such as yeast, bacteria, enzymes, etc. Fermentation is a well-established and widely used technology for the conversion of grains and sugar crops into ethanol. About 500 million gal ethanol per year by 1985, were produced in the limited states by the use of surplus gain. It is intended for with gasoline to produce *gasohol* (90 percent gasoline, 10 percent ethanol). This process requires high cost and high energy required. One scheme considered for reducing costs of ethanol production by fermentation is in finding less expensive grains or sugars and a process that requires less energy. Glucose produced by hydrolysis of an abundant carbohydrate polymer called *ligno cellulose* is being considered for the former.

Biomass energy concepts under study are resulting in the cultivation of large forests in areas not suitable for food production. The trees are to be harvested by automated means, then chipped and pulverized for burning in a power plant that would be located in the middle of the forest.

7.2.1. Wet Processes

Anaerobic digestion. Biogas is produced by the bacterial decomposition of wet sewage sludge, animal dung or green plants in the absence of oxygen. Feedstocks like-wood shavings, straw, and refuse may be used, but digestion takes much longer. The natural decay process, 'anaerobic decomposition' can be speeded up by using a thermally insulated, air-tight tank with a stirrer unit and heating system. The gas collects in the digester tank above the slurry and can be piped off continuously. At optimum temperature (35°C) complete decomposition of animal or human faces takes around 10 days. Gas yields depend critically on the nature of the waste-pig manure, for example, is better than cowdung or household refuse. Each kilogram of organic material (dry weight) can be expected to yield 450-500 litres of biogas (9-12 MJ) at atmospheric pressure in a modern batch or continuous feed unit—one and a half to two digester volumes of gas per day. The residue left after digestion is valuable fertilizer. It is also rich in protein and could be dried and used as animal feed supplement.

Fermentation. As stated, ethanol (ethyl alcohol) is produced by the fermentation of sugar solution by natural yeasts. After about 30 hours of fermentation the brew (or 'beer') contains 6-10% alcohol and this can readily be removed by distillation. Traditionally, the fibrous residues from plant crops like sugar cane bagasse have been burnt to provide the heat. Suitable feed stocks include crushed sugar cane and beet, fruit etc. Sugar cane also be manufactured from vegetable starches and cellulose, maize, wheet grain, or potatoes, for example, must be ground or pulped and then cooked with enzymes to release the starch and convert it to fermentable sugars. Cellulose materials like wood, paper waste or straw, require harsher pre-treatment typically milling and hydrolysis with hot acid. One tonne of sugar will produce upto 520 litres of alcohol ; a tonne of grain, 350 litres and a tonne of wood, an estimated 260 to 540 litres. After fermentation, the residue from grains and other feed stuffs contains high protein content and is a useful cattle-feed supplement.

The hydrolysis and distillation steps require a high energy input ; for woody feedstocks direct combustion or pyrolysis is probably more productive at present, although steam treatment and new low-energy enzymatic hydrolysis techniques are under development. The energy requirement for distillation is also likely to be cut dramatically. Alcohol can be separated from the beer by many methods which are now under intensive development. These include solvent extraction, reverse osmosis, molecular sieves and use of new dessicants for alcohol drying. It may soon be possible to *halve* the energy required for alcohol production to produce a greater net energy gain.

Chemical reduction. Chemical reduction is the least developed of the wet biomass conversion processes. It involves pressure—cooking animal wastes or plant cellulosic slurry with an alkaline catalyst in the presence of carbon monoxide at temperatures between 250°C and 400°C. Under these conditions the organic material is converted into a mixture of oils with a yield approaching 50%. If the pressure is reduced and the temperature increased, the product is a high calorific value gas.

7.2.2. Dry Processes

Pyrolysis. A wide range of energy-rich fuels can be produced by roasting dry woody matter like straw and wood-chips. The material is fed into a reactor vessel or retort in a pulverised or shredded form and heated in the absence of air. (Air would cause the products of pyrolysis to ignite). As the temperature rises the cellulose and lignin break down to simpler substances which are driven off leaving a char residue behind. This process has been used for centuries to produce charcoal.

The end products of the reaction depend critically on the conditions employed ; at lower temperatures—around 500°C—organic liquid predominate, whilst at temperatures nearer 1000°C a combustible mixture of gases results.

Liquefaction. Liquid yields are maximized by rapid heating of the feedstock to comparatively low temperatures. The vapours are condensed from the gas stream and these separate into a two-phase liquor : the aqueous phase (pyroligneous acid) contains a soup of water-soluble organic materials like acetic acid, acetone and methanol ('wood alcohol') ; the non-aqueous phase consists of oils and tars. These crude products can be burnt (with some difficulty), but it is usually more profitable to up-grade them to premium fuels by conventional refining techniques.

Other pyrolysis products include fuel gas—essentially carbon-monoxide and hydrogen and carbon char. The gas is generally burnt to maintain the temperature of the reactor ; the char can be manufactured into briquetts for use as solid fuel.

Pyrolysis can also be carried out in the presence of small quantities of oxygen ('gasification'), water ('steam gasification') or hydrogen ('hydrogenation').

Gasification. Pyrolysis of wet biomass produces fuel gas and very little liquid. An alternative technique for maximising gas yields is to blow small quantities of air or oxygen into the reactor vessel and to increase the temperature to over 1000°C. This causes part of the feed to burn. Fuel gas from air-blown gasifiers has a low calorific value (around 5 MJ/m^3) and may contain upto 40% inert nitrogen gas overall yields of 80-85% can be expected. Fuel gas from oxygen-fed systems has a medium calorific value (10-20 MJ/m^3). This gas can either be burnt or converted into substitute natural gas (methane) or methanol by standard catalytic processes. Methanol yields of around 50% can be achieved from biomass.

Steam-gasification. Methane is produced directly from woody matter by treatment at high temperatures and pressures with hydrogen gas. The hydrogen can be added or, more commonly, generated in the reactor vessel from carbon monoxide and steam. Recent analyses suggest that steam gasification is the most efficient route to methanol. Net energy yields of 55% can be achieved although higher yields are likely in the future as the technology is developed.

Hydrogenation. Under less severe conditions of temperature and pressure (300-400°C and 100 atmospheres), carbon monoxide and steam react with cellulose to produce heavy oils which can be separated and refined to premium fuels.

Many countries are actively developing commercial processes for biomass liquefaction and gasification.

7.3. Photosynthesis

The most important chemical reaction on the earth is the reaction of sunlight and green plants. Radiant energy of sun is absorbed by the green pigment chlorophyll in the plant and is stored within the plant in the form of chemical bond energy. Photosynthesis in the plants is an example of biological conversion of solar energy into sugars and starches which are energy rich compounds. So if plant fast growing trees having high photo-synthesis efficiency we can harvest and burn them to produce steam in a similar manner as in thermal power stations ultimates to produce the electric power. Such an "energy plantation" would be a renewable resource and an economical means of harnessing solar energy. However, photo-synthesis concepts are less attractive as the average efficiency of solar energy conversion in plants s about 1% and the overall efficiency of the conversion sunlight to lectricity would be about 0.3% compared to 10% for photo-voltaic cells

The process photo-synthesis is extremely complex and not completely understood by scientists. (In Greek photo means light and synthesis means combination). In this reaction, water and CO molecules broken down and a carbohydrate is formed with the release of pure oxygen. The process can be expressed as follows :

$$CO_2 + H_2O + light + Chlorophyll \longrightarrow \underset{(Sugar)}{(H_2CO)_6} + O_2 + Chlor...$$

or

$$6CO_2 + 12H_2O \longrightarrow C_6H_{12}O_6 + 6H_2O + 6O...$$

The absorbed light is in the ultraviolet and infrared ra... Visible light having a wavelength below 700 A° is absorbed by the chlorophyll which becomes activated and passes its energy on t... water molecules. A hydrogen atom is then released and reacts wi... carbon dioxide molecule, to produce H_2CO and oxygen. H_2CO ... basic molecule forming *carbohydrate*, stable at low temperatu... breaks at high temperature, releasing an amount of heat eq... 112,000 cal/mole.

$$H_2CO + O_2 \longrightarrow CO_2 + H_2O + 112 \text{ kcal/mole}$$

The absorbed energy of photons should be atleast equal ... amount. It is, therefore, possible to produce large amount ... bohydrate by growing say, algae under optimum conditions in ... tubes or in ponds. The algae could be harvested, dried and burn... production of heat that could be converted into electricity by c... tional methods.

Thus photo-synthesis consists in building up of simpl... bohydrates such as sugar etc. in the green leaf in presence of su... The oxygen liberated is from H_2O molecule and not from CO_2... process is called as carbon fixation or carbon assimilation. Pho... thesis is essentially a *reduction* and *oxidation* process.

The process of photosynthesis has two main steps :

(*i*) Splitting of H_2O molecule into H_2 and O_2 under the in... of chlorophyll and sunlight. This phase of reaction is called th... *reaction*. In this phase of reaction, light absorbed by chlorophyll ... photolysis of water. O_2 escapes and H_2 is transformed int... unknown compounds. Thus solar energy is converted into po... chemical energy.

(*ii*) In the *second phase*, hydrogen is transferred from t... known compound to CO_2 to form starch or sugar. Formation of ... or sugar are *dark reaction* not requiring sunlight.

The *conditions* necessary for photo-synthesis are :

(1) *Light*. One of the important inputs for biomass produ... the intensity of solar radiation only a part of this energy (40-45...

the appropriate wavelength (400-700 A°) to produce photosynthesis. The plants use radiations between 400 to 700 A° only a part of this energy is actually used in photosynthesis. This range of light is called photo-synthetically active radiation (PAR). The upper limit of the photo-synthesis efficiency is about 5%.

(2) CO_2 *Concentration.* Carbon dioxide is the primary raw material for photo-synthesis. CO_2 constitutes about 0.03% of the atmosphere. However, if CO_2 availability is increased artificially, linear increase in the yield of several crops, upto a limit, have been observed. Hence one of the methods of increasing biomass is by supplying additional CO_2 to the plants. The main sources of CO_2 are :

(*i*) animal respiration,

(*ii*) combustion of fuel,

(*iii*) the major source is the decay of organic matter by bacteria, nd

(*iv*) ocean also is an important store of CO_2, much of which comes rom photo-synthesis by plants. Respiration of marine plants and nimal releases CO_2 into the water.

(3) *Temperature.* Photosynthesis is restricted to the temperature ange which can be tolerated by proteins, *i.e.* 0°C to 60°C. Although hoto chemical part is not affected by temperature, but biochemical art, controlled by enzymes, is highly sensitive to temperature.

hotosynthetic Efficiency

Efficiency of a solar energy utilization by biomass route obviously very important parameter. The energy stored in the plants by way of rbon fixation in the form of chemical bond energy when expressed as fraction of total insolation falling on the plant, it is called as photosynetic efficiency. This can be explained by taking a specific case as llows :

Let us consider that the energy received by a surface at sea level 100%.

Solar energy received .... = 100% ...(*i*)

Photosynthetically active radiation (PAR)... = 50% of (*i*)

Losses due to transmission and reflection from leaf surfaces .... = 10% of (*i*)

∴ Net energy available .... = 40% of (*i*)

23% of the net available energy is converted into carbon fixation .... = 23% of net energy = 9.2

40% of thus fixed carbon energy is again lost due to simultaneous espiration process which is just the reverse process of photosynthesis.

$\therefore$ Final net trapped energy = 0.6×9.2

= 5.52% of insolation.

This table gives only a specific case. However in literature we find that photosynthetic efficiencies have been quoted from 0.1 to 5%. This variation is mainly because of two reasons :

(i) There is a wide variation in efficiency from plant to plant.

(ii) There are two basis which are being used for calculation of efficiencies. Some people calculate it on the basis of yearly insolation independent of the duration of maturity of a given crop. For example, even if a particular crop matures in 3 months, the chemical energy stored is presented as a fraction of the total insolation throughout 12 months. On the other hand some efficiencies stated are based upon the insolation received only in the duration of maturation of a particular crop.

7.4. Biogas Generation

Introduction. Biogas, a mixture containing 55-65 percent methane, 30-40 percent carbon dioxide and the rest being the impurities (H_2, H_2S, and some N_2), can be produced from the decomposition of animal, plant and human waste. It is a clean but slow burning gas and usually has a calorific value between 5000 to 5500 kcal/kg (20935 to 23028 kJ/kg) or 38131 kJ/m^3. It can be used directly in cooking, reducing the demand for firewood. Moreover, the material from which the biogas is produced retains its value as a fertilizer and can be returned to the soil. Biogas has been popular on the name, "Gobar Gas" mainly because cow dung hag been the material for its production, hitherto. It is not only the excreta of the cattle, but also the piggery waste as well as poultry droppings are very effectively used for biogas generation. A few other materials through which biogas can be generated are algae, crop residues (agro-wastes), garbage kitchen wastes, paper wastes, sea wood, human waste, waste from sugarcane refinery, water hyacinth etc., apart from the above mentioned animal wastes. Any cellulosic organic material of animal or plant origin which is easily bio-degradable is a potential raw material for biogas production.

Biogas is produced by digestion, pyrolysis, or hydrogasification. *Digestion* is a biological process that occurs in the absence of oxygen and in the presence of anaerobic organisms at ambient pressures and temperatures of 35-70°C. The container in which this digestion takes place is known as the *digester.*

Anaerobic digestion. Biogas technology is concerned to micro-organisms. These are living creatures which are microscopic in size and are invisible to unaided eyes. These are different types of micro-organisms. They are called bacteria, fungi, virus etc. Bacteria again can be classified into two types—beneficial bacteria and harmful bacteria. Compost making production of biogas, vinegur, etc., are examples of beneficial bacteria. Bacteria causing cholera, typhoid, diphtheria are examples of harmful bacteria. This type of bacteria which causes disease both in animals and human beings is called *pathogen*.

Bacteria can be divided into two major groups based on their oxygen requirement. Those which grow in presence of oxygen are called *aerobic* while the others grow in absence of gaseous oxygen are called *anaerobic*. When organic matter undergoes fermentation (process of chemical change in organic matter brought about by living organisms) through anaerobic digestion, gas is generated. This gas is known as *bio-gas*. Biogas is generated through fermentation or bio-digestion of various wastes by a variety of anaerobic and facultative-organisms. Facultative bacteria are capable of growing both in presence and absence of air or oxygen.

Aerobic and anaerobic fermentation can be used to decompose organic matter. Normally aerobic fermentation produces CO_2, NH_3, and small amounts of other gases along with a decomposed mass and evolution of heat. Anaerobic fermentation produces CO_2, CH_4, H_2 and traces of other gases along with a decomposed mass. Aerobic fermentation is used when the main aim is to render the material hygenic and to recover the plant nutrients for reuse in the fields. The residue is rich in C, N_2, P, K and other nutrients. In a biogas plant the main aim is to generate methane and hence anaerobic digestion is used. Here the complex organic molecule is broken down to sugar, alcohols, pesticides and amino acids by acid producing bacteria. These products are then used to produce methane by another category of bacteria.

As already mentioned the treatment of any slurry or sludge containing a large amount of organic matter, utilizing bacteria and other micro-organisms under anaerobic conditions is commonly referred to as anaerobic digestion or simply digestion. This anaerobic digestion consists broadly of three phases :

(*i*) *Enzymatic hydrolysis*. Where the fats, starches and proteins contained in cellulosic biomass are broken down into simple compounds.

(*ii*) *Acid formation*. Where the micro organisms of facultative and anaerobic group collectively called as acid farmers, hydrolyse and ferment, are broken to simple compounds into acids and volatile solids. As a result complex organic compounds are broken down to short chemical simple organic acids. In some cases, these acids may be produced in such large quantities that the pH may be lowered to a level where all biological activity is arrested. This initial acid phase of digestion may last about two weeks and during this period a large amount of carbon dioxide is given off.

(*iii*) *Methane formation.* Where organic acids as formed at ... then converted into methane (CH_4) and CO_2 by the bacteria w... strictly anaerobs. These bacteria are called methane fermen... efficient digestion these acid formers and methane ferment... remains in a state of dynamic equilibrium. This equilibrium ... critical factor which decides the efficiency of generation. It ... demonstrated that the methane formers are sensitive to pH ch... pH value between 6.5 to 8 is the best for fermentation and no... production. If organic acids are formed at a faster rate than th... population of methane formers can assimilate, then the accu... acids will reduce the pH to levels unfavourable to methane fo...

In controlled waste digestion the environment must ... tained suitable for the continued growth of both acid form... methane-forming bacteria. The proper environment req... balance between the population of organisms, food supply, tem... pH, and food accessibility. Digestion processes are being im... the conditions which influence organic metabolism are bett... stood and better equipment and methods are available for c... these conditions.

Basic processes and energetics. The general eq... anaerobic digestion is

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

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

For cellulose this becomes

$$(C_6H_{10}O_5)_n + nH_2O \longrightarrow 3n\ CO_2 + 3n\ CH_4$$

Some organic material (*e.g.* lignin) and all inorganic... do not digest. These add to the bulk of the material, form a... can easily clog the system. In general 95% of the mass of th... is water. The reactions are slightly exothermic, with typic... reaction being about 1.5 MJ per kg dry digestible materi... about 250 kJ per mole of $C_6H_{10}O_5$. This is not sufficient to s... affect the temperature of the bulk material.

If the input material had been dried and burnt, ... combustion would have been about 16 MJ/kg only 10% of th... heat of combustion need be lost in the digestion process. ... conversion efficiency. Moreover very wet input has been ... give a highly convenient and controllable gaseous fuel, whe... of 95% aqueous input would have taken a further 40 MJ pe... input. In practice digestion is seldom left to go to completion the long time involved, and 60% conversion is common. Gas yield is about 0.2 to 0.4 m^3 per kg dry digestible input at STP, with throughput of about 5 kg dry digestible solid per m^3 of liquid.

It is generally considered that three ranges of temperature favour particular types of bacteria. Digestion at higher temperature proceeds more rapidly than at lower temperature, with gas yield rates doubling at about every 5°C increase. The temperature ranges are (1) psicrophilic, about 20°C, (2) mesophilic, about 35°C and (3) thermophilic, about 55°C. In tropical countries unheated digesters are likely to be at average ground temperature between 20 and 30°C. Consequently the digestion is psicrophilic, with retention times being at least 14 days. In colder climates the digesters have to be heated, probably by using part of the biogas output, and a temperature of about 35°C is likely to be chosen. Few digesters operate at 55°C unless the purpose is to digest material rather than produce excess biogas.

The *biochemical processes* occur in three stages, each facilitated by distinct sets of anaerobic bacteria :

1. Insoluble biodegradable materials, *e.g.* cellulose, polysaccharides and fats, are broken down to soluble carbohydrates and fatty acids. This occurs in about a day at 25°C in an active digester.

2. Acid forming bacteria produce mainly acetic and propionic acid. This stage likewise takes about one day at 25°C.

3. Methane forming bacteria slowly, in about 14 days at 25°C, complete the digestion to ~ 70% CH_4, ~ 30% CO_2 with trace amounts of H_2 and perhaps H_2S. H_2 may play an essential role, and indeed some bacteria (*e.g. clostridium*) are distinctive in producing H_2 as the final product.

The methane forming bacteria are sensitive to pH, and conditions should be mildly acidic (pH 6.6 to 7.0) and certainly not below pH 6. Nitrogen should be present at 10% by mass of dry input, and phosphorus at 2%. A golden rule for successful digester operation is to maintain *constant conditions* of temperature and suitable input material. As a result a suitable population of bacteria is able to become established to suit these conditions.

When comparison of methane percentage from different organic matter was done for example cowdung. Poultry dropping and dairy waste scum, then best result was observed in dairy waste. 75 to 79 methane percentage found in dairy waste biogas while in cowdung, biogas was only 65 percent.

Advantages of anaerobic digestion. There are number of advantages of anaerobic digestion.

1. *Calorific value of gas.* One of the main benefits is the production of a biproduct the biogas which has a calorific value and can

therefore, be used as an energy source to produce steam or hot water. Because in dairy industries energy source is very important for dairy use, so there is no problem of gas storage or supply, but gas can be directly useful in heat energy.

2. *New sludge production.* The conversion of organic matter to methane and carbon dioxide results in a smaller quantity of excess sludge.

3. *Stable sludge.* In the case of municipal digestion the main reason for their installation was to produce a non-putrescable and inoffensive sludge and in many cases only a proportion of the gas produced was utilised.

4. *Low running cost.* There is no airation in the anaerobic treatment naturally in this digestion, running costs are a quarter of the equivalent aerobic system.

5. *Low odour.* Since the system is enclosed the odours are contained. Compounds which are responsible for odour are broken down during digestion. The only slight odour of hydrogen sulphide normally presents in gas. However if the gas is burnt the problem will not arise.

6. *Stability.* A well adapted anaerobic sludge can be presented unfed for a considerable period of time without appreciable deterioration.

7. *Pathogen reduction.* Work has shown that passage of the effluent through the digester reduces the number of pathogens present, so reducing subsequent disposal problems.

8. *Value of sludge.* The cases where aerobic sludge is treated anaerobically the resultant sludge has a higher nitrogen content giving it increasing value as a fertilizer. It has also been reported that the sludge acts as a soil conditioner.

9. *Low nutrient requirement.* As a consequence of the low production of the bacterial solids the nutrient requirement is also low.

In addition using of biogas in industries will curtail the consumption of coal. If biogas is used instead of coal in boilers, it will lessen the air pollution.

7.5. Factors Affecting Biodigestion or Generation of Gas

The following are the factors that affect generation of biogas :

(1) pH or the hydrogen-ion concentration

(2) Temperature

(3) Total solid content of the feed material

(4) Loading rate

(5) Seeding

(6) Uniform feeding
(7) Diameter to depth ratio
(8) Carbon to Nitrogen ratio
(9) Nutrients
(10) Mixing or stirring or agitation of the content of the digester
(11) Retentation time or rate of feeding
(12) Type of feed stocks
(13) Toxicity due end product
(14) Pressure
(15) Acid accumulation inside the digester.

1. *pH or hydrogen ion concentration.* pH of the slurry changes at various stages of the digestion. In the initial acid formation stage in the fermentation process, the pH is around 6 or less and much of CO_2 is given off. In the latter 2-3 weeks time, the pH increases as the volatile acid and N_2 compounds are digested and CH_4 is produced. To maintain a constant supply of gas, it is necessary to maintain a suitable pH range in the digester.

The digester is usually buffered if the pH is maintained between 6.5 to 7.5. In this pH range, the micro-organisms will be very active and biodigestion will be very efficient. If the pH range is between 4 and 6 it is called acidic. If it is between 9 and 10 it is called alkaline. Both these are deterimental to the methanogenic (Methane production) organisms. It should always be remembered that there should not be any sudden upset in the pH by the addition of any material which is likely to cause an imbalance in the bacterial population.

The ideal pH valves for digestion of sewage solids are reported to be in the range 7 to 7.5. But a slightly higher value of 8.2 has been reported to be optimum for digestion of raw animal or plant wastes.

2. *Temperature.* Methane bacteria work best at a temperature of between 35°—38°C. The fall in gas production starts at 20°C and stops at a temperature of 10°C. At one experiment 2.25 cu m of gas was produced from 4.25 m^3 of cattle dung everyday when the digester temperature was 25°C. When the temperature was raised to 28.3°C, the gas production increased by 50% to 3.75 cu m/day.

There are two significant temperature zones in anaerobic digestion. These have been studied in some detail for digestion of sewage sludges for 90% digestion. Fig. (7.5.1) shows the time required for 90% digestion at various temperatures, and the two temperature zones. It has been established that two types of micro organisms, mesophilic and thermophilic are responsible for digestion at the two temperature ranges. The optimum mesophilic temperature lies at about 35°C, while the optimum thermophilic temperature is around 55°C. In temper... climates most of the sewage digestion tanks are heated to 35°C ... reduce the time required for digestion and therefore the capacity ... tanks. The thermophilic range has not been put to use because ... problems associated with heating the tanks to such high temper... Heating of tanks designed mainly for collection of biogas may ... practicable, but it must be understood that temperature is ... important factor since it affects the bacterial activity directly. An... deviation from a normal operating temperature may result ... unsatisfactory performance of the digester.

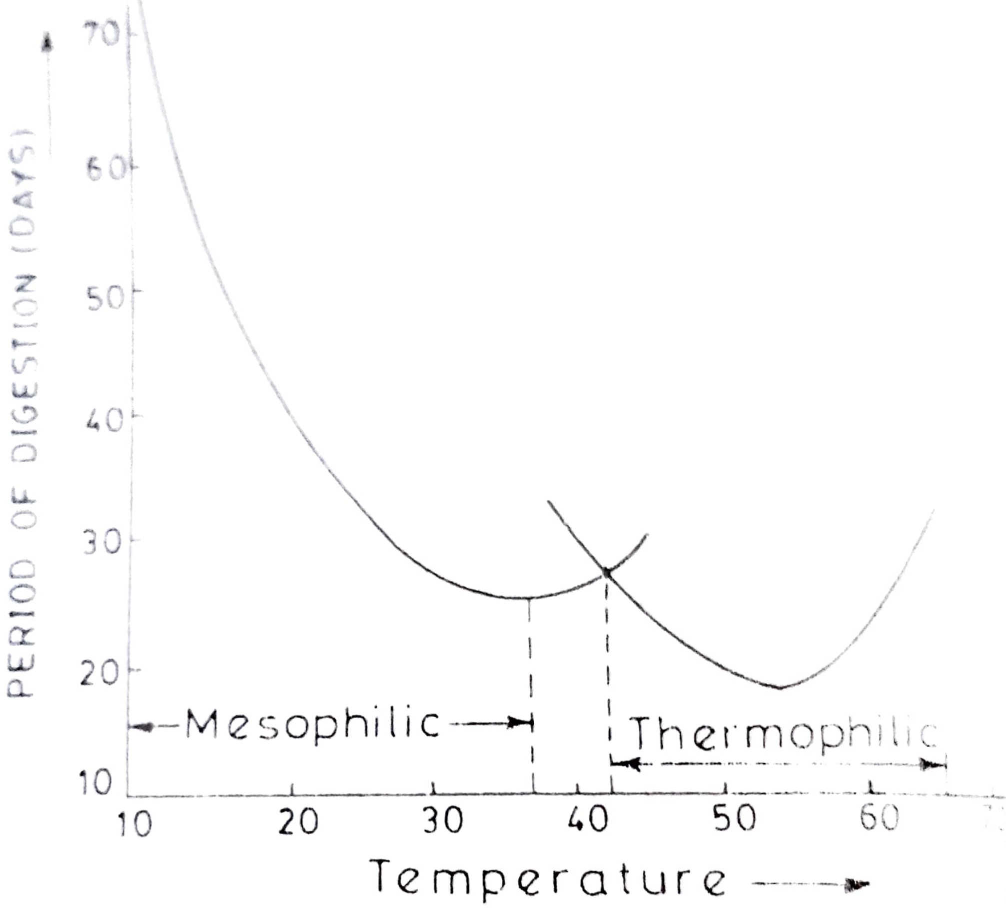


Fig. 7.5.1. Effect of temperature on digestion.

The gas production starts falling very steeply when the ... ture goes below 20°C and almost stops at 10°C. Generally it is ... maintain the temperature of the digester at the mesophilic ran... than at the thermophilic range.

In addition to ambient temperature, other weather co... also influence the gas generation *viz*.

(*a*) Wind velocity (chill factor)

(*b*) Sun shine directly available to keep the dome at the ... temperature

(*c*) Type of food given to cattle (in case of Gobar gas gen...

7.6. Classification of Biogas Plants

Biogas plants are mainly classified as :

(1) Continuous and batch types (as per the process).

(2) The dome and the drum types.

(3) Different variations in the drum type.

1. Continuous and batch types

(a) *Continuous plant* There is a single digester in which raw material are charged regularly and the process goes on without interruption except for repair and cleaning etc. In this case the raw material is self buffered (like cow dung) or otherwise thoroughly mixed with the digesting mass where dilution prevents souring and the biogas production is maintained. The continuous process may be completed in a single stage or separated into two stages.

(i) *Single stage process* The entire process of conversion of complex organic compounds into biogas in completed in a single chamber. This chamber is regularly fed with the raw materials while the spent residue keeps moving out. Serious problems are encountered with agricultural residues when fermented in a single stage continuous process. Refer Fig. (7.6.1).

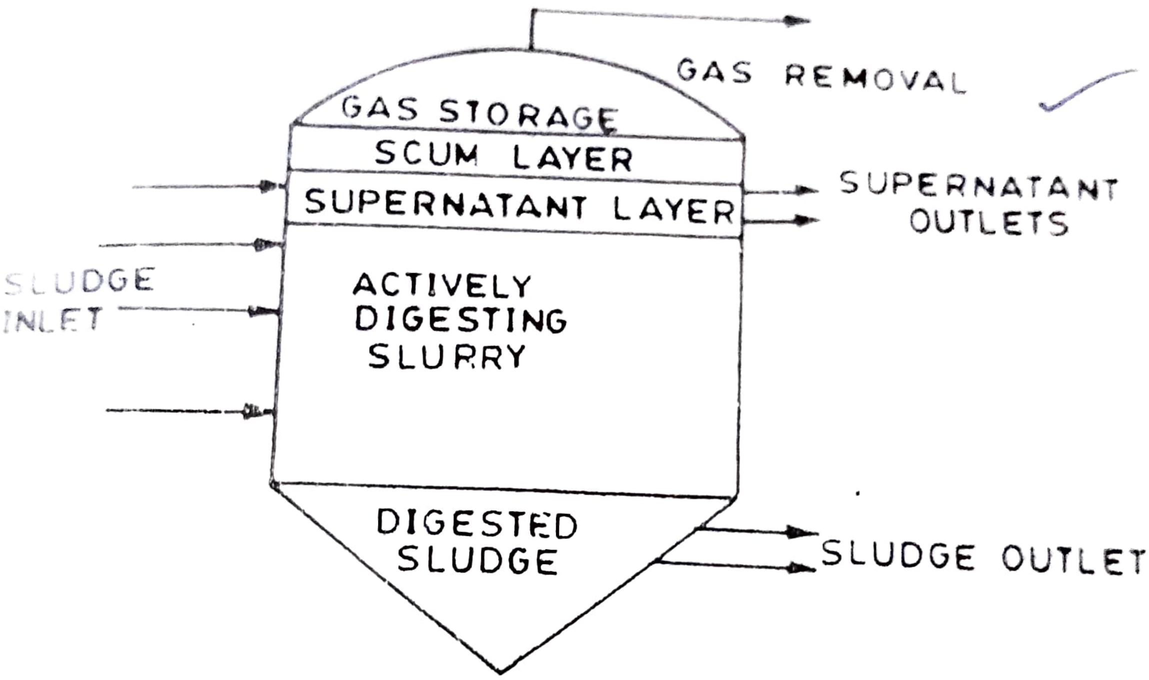


Fig. 7.6.1. Schematic of single process conventional digester.

(ii) *Double stage process*. The acidogenic stage and methanogenic stage are physically separated into two chambers. Thus the first stage of acid production is carried out in a separate chamber and only the diluted acids are fed into the second chamber where bio-methanation takes place and the biogas can be collected from the second chamber. Refer Fig. 7.6.2. Considering the problems encountered in fermenting fibrous plant waste materials the two stage process may offer higher potential of success. However, appropriate technology suiting to rural India is needed to be developed based on the double stage process.

The main features of continuous plant are that :

(1) It will produce gas continuously ;

(2) It requires small digestion chambers ;

(3) It needs lesser period for digestion ;

(4) It has less problems compared to batch type and it is easier in operation.

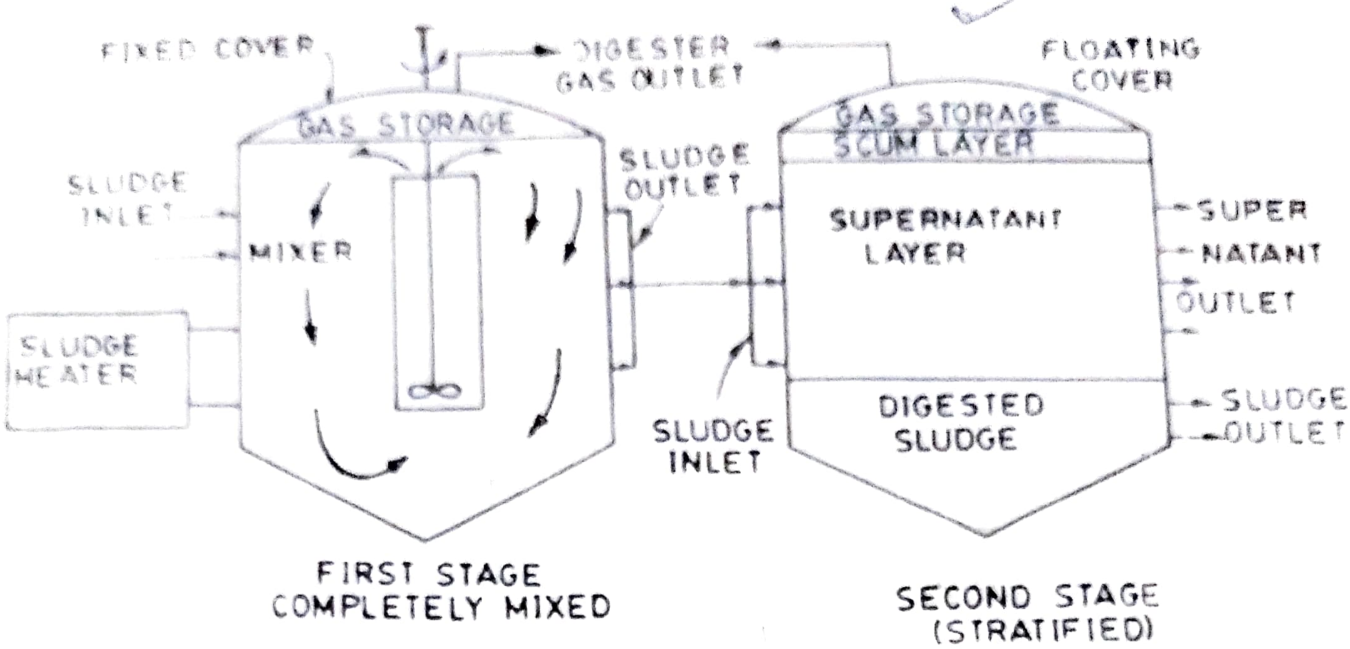


Fig. 7.6.2. Schematic of two-stage digestion process.

(b) *The batch Plant.* The feeding is between intervals, the plant is emptied once the process of digestion is complete. In this type, a battery of digesters are charged along with lime, urea etc. and allowed to produce gas for 40-50 days. These are charged and emptied one by one in a synchronous manner which maintains a regular supply of the gas through a common gas holder. Sometimes the freshly charged digester is aerated for a few days after which it is closed to atmosphere. The biogas supply may be utilised after 8-10 days. Obviously such a plant would be expensive to install and unless operated on large scale it would not be economical. Such systems have been generally installed in European countries. Their installation and operation being capital and labour intensive. They are totally unsuitable for Indian conditions, except when it is taken as a commercial venture.

The main features of the *batch plant* are :

(*i*) The gas production in it, is intermittent, depending upon the clearing of the digester.

(*ii*) It needs several digesters or chambers for continuous gas production, these are fed alternately.

(*iii*) Batch plants are good for long fibrous materials.

(*iv*) This plant needs addition of fermented slurry to start the digestion process. There may be a direct change to the acid phase in absence of the fermented slurry, which affects formation of methane.

(v) This plant is expensive and has problems comparatively, the continuous plant will have less problems and will be easy for operation.

2. The dome and the drum types. There are numerous models of a biogas plant mainly two main types are usually used :

(i) The floating gas holder plant and other is

(ii) Fixed dome digester.

The floating gas holder digester which is used in India is known as KVIC plant. The fixed dome digester is called the Chinese plant. There are different shapes in both the designs, cylindrical rectangular, spherical etc. Again, the digester may be vertical or horizontal. They can be constructed above or underneath the ground. The floating gas holder digester developed in India is of masonry construction with the gas holder made of M.S. plates. The gas holder is separated from the digester. Rusting of the gas holder as well as the cost of the gas holder are the main drawbacks of this system.

In the fixed dome digester, the gas holder and the digester are combined. The fixed dome is best suited for batch process especially when daily feeding is adopted in small quantities. The fixed dome digester is usually built below ground level and is suitable for cooler regions. Local materials can be used in this construction. The pressure inside the digester varies as the gas is collected. This is not found to cause any serious problems in small plants.

3. Different variations in the drum type. There are two main variations in the floating drum design. One with water seal and the other without water seal. Water sealing makes the plant completely anaerobic and corrosion of the gas holder drum is also reduced. The other variations are of materials used both in construction of the digester and the gas holder. Bricks and stones are the commonly used materials. Ferro cement rings are also used in the construction of digester, which are best suited for clayey soils and sandy tracks. Gas holders are also manufactured out of ferro cement, as M.S. sheets get corroded. Polyethylene is also used in the construction of gas holder. The latest design uses fibre glass reinforecd plastic.

The horizontal plants are suited for high ground water level or rocky areas. These are not recommended when retention period is 30 days. Cylindrical shape of the digester is preferred because cylinder has no corners and so that there will be no chances of cracks due to faulty construction. This shape also needs smaller surface area per unit volume, which reduces heat losses also. Moreover the scum formation may be reduced by rotating gas holder in the cylindrical digester.

7.7. Advantages and Disadvantages of Floating Drum

Advantages :

(1) It has less scum troubles because solids are con... submerged.

(2) No separate pressure equalizing device needed wh... waste is added to the tank or digested slurry is withdrawn.

(3) In it, the danger of mixing oxygen with the gas to... explosive mixture is minimized.

(4) Higher gas production per cu m of the digester v... achieved.

(5) Floating drum has welded braces, which help in brea... scum (floating matter) by rotation.

(6) No problem of gas leakage.

(7) Constant gas pressure.

Disadvantages :

(1) It has higher cost, as cost is dependent on steel and...

(2) Heat is lost through the metal gas holder, hence it... in colder regions and periods.

(3) Gas holder requires painting once or twice a year, de... on the humidity of the location.

(4) Flexible pipe joining the gas holder to the main... requires maintenance, as it is damaged by ultraviolet rays in... It may be twisted also, with the rotation of the drum for mixing... removal.

7.8. Advantages and Disadvantages of Fixed Dome Typ...

Advantages :

(1) It has low cost compare to floating drum type, as it u... cement and no steel.

(2) It has no corrosion trouble.

(3) In this type heat insulation is better as constru... beneath the ground. Temperature will be constant.

(4) Cattle and human excreta and long fibrous stalks ca...

(5) No maintenance.

Disadvantages :

(1) This type of plant needs the services of skilled mas... are rather scarce in rural areas.

(2) Gas production per cum of the digester volume is al...

(3) Scum formation is a problem as no stirring arrange...

(4) It has variable gas pressure.

7.9. Types of Biogas Plants

As stated earlier there are numerous models of a biogas plant. But they can be grouped under two broad heads—one with the floating gas holder and the other with a fixed dome digester. In floating gas holder plant, the gas holder is separate from the digester. But in the

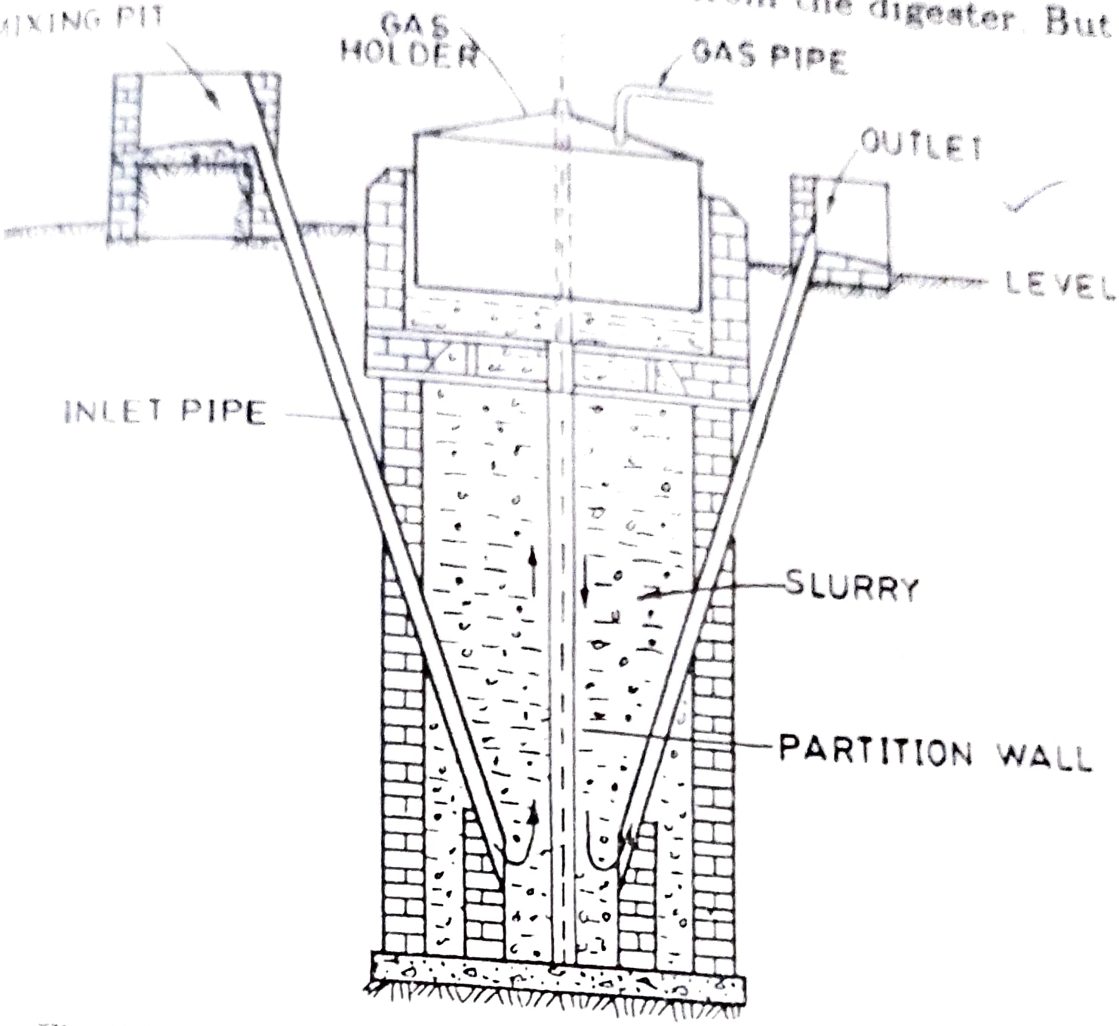


Fig. 7.9.1. Common circular digester with floating gas holder and no water seal (India). (KVIC digester).

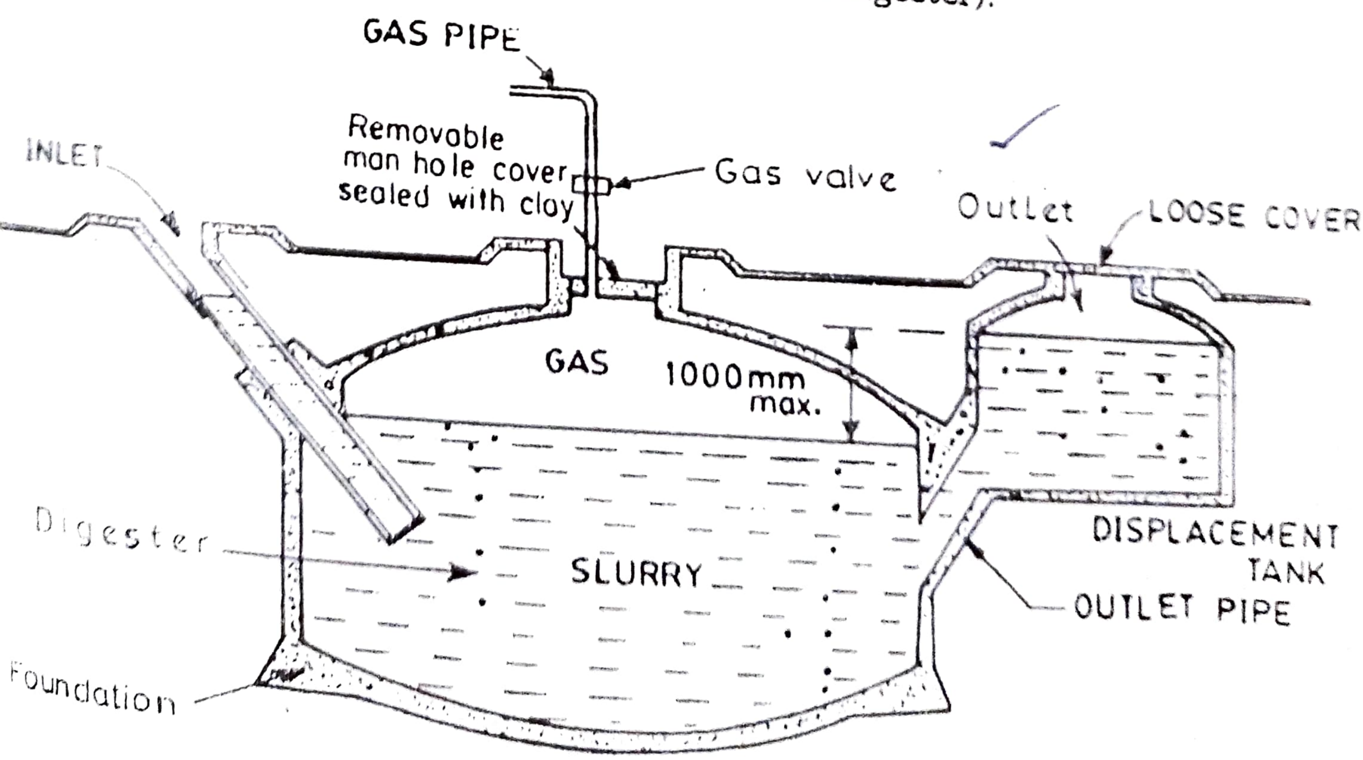


Fig. 7.9.2. Common circular fixed dome digester (China).

fixed dome digester, the gas holder and the digester are combined. The family size biogas plants available today in India are broadly of two types. The Khadi Village Industries Commission (KVIC) model and Janta model which are shown in Figs. (7.9.1) and (7.9.2). The KVIC plant is of steel drum type or floating gas holder design, in which the digestion takes place in a masonry well and the drum floats as the gas collects and is taken out from the top.

The Janta model or fixed dome digester (also called Chinese plant) is a drumless type similar in construction to the KVIC model except that the steel drum is replaced by a fixed dome roof of masonry construction. The floating gas holder digester developed in India is of masonry construction with gas holder made of M.S. plates. The drum in the KVIC model is the costliest component and its life is comparatively less (about 10 years). The dome roof in the Janta model requires specialised design and skilled masonry construction. A poorly constructed roof generally leads to leakage from top and junction of the roof with the digester wall, thereby causing drop in gas yield. The overall cost of both types varies from Rs. 5000 to Rs. 15,000 depending upon the capacity of the biogas plant and subsoil conditions.

In addition to the aforesaid cost and construction material problems, there are constructional problems which the farmers or beneficiaries face. The construction of biogas plants especially in Janta type needs the services of skilled masons who are becoming rather scarce in rural areas. It is observed that plants constructed by unskilled masons or untrained workers have structurally failed or unable to retain dung slurry, gas or even both while the failure of such plants adversely affects plants owners. The prospective plant owners are seldom sure about the correct choice of the plant. Besides the construction of the plant, there are some operational and maintenance problems which almost hinder progress of biomass development.

Fig. (7.9.3) shows a flexible bag digester. The digester is made of plastic material and can be easily installed. The short life of the material due to the effect of ultraviolet rays is a main drawback.

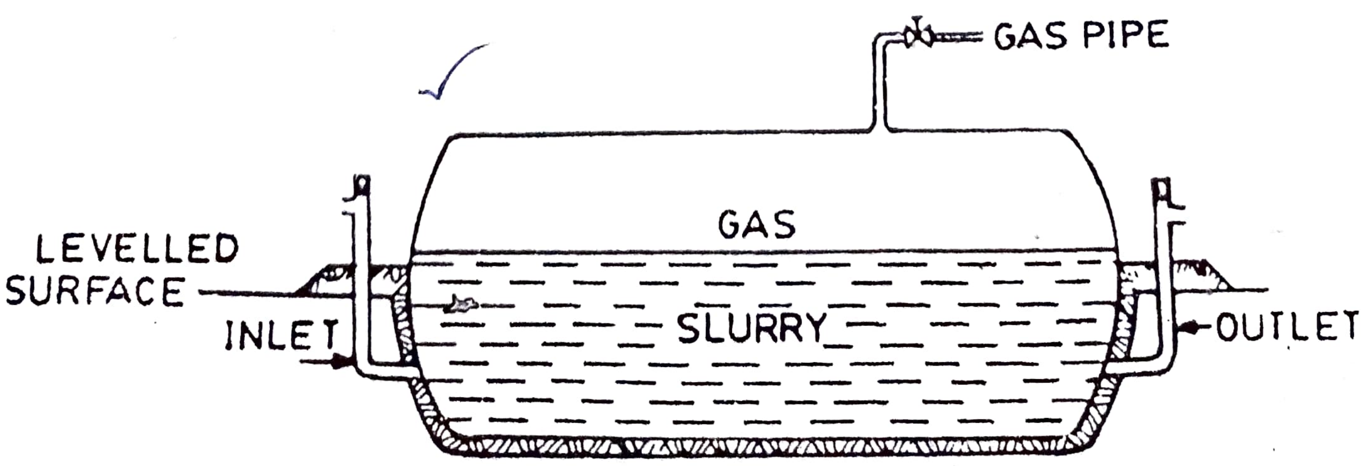


Fig. 7.9.3. Flexible bag type combined digester/gas holder.

Fig. (7.9.4) shows a digester suitable for high water-table. Here the digester diameter below the gas holder is increased so that the total depth can be reduced.

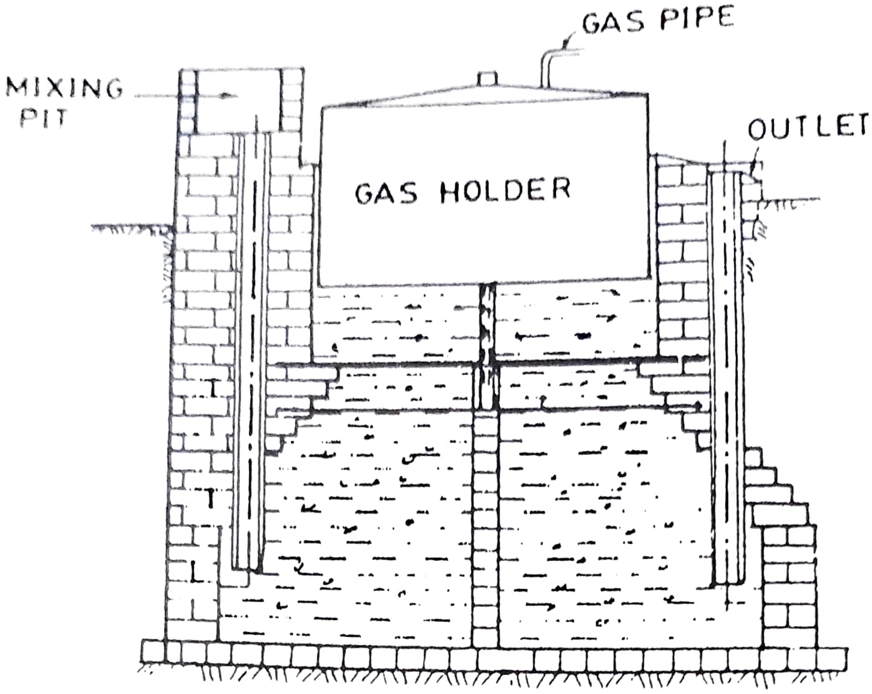


Fig. 7.9.4. Taper digester with floating gas holder (Nepal).

When absolute segregation of the slurry is required a floating gas holder with water seal is used. This construction is shown in Fig. (7.9.5).

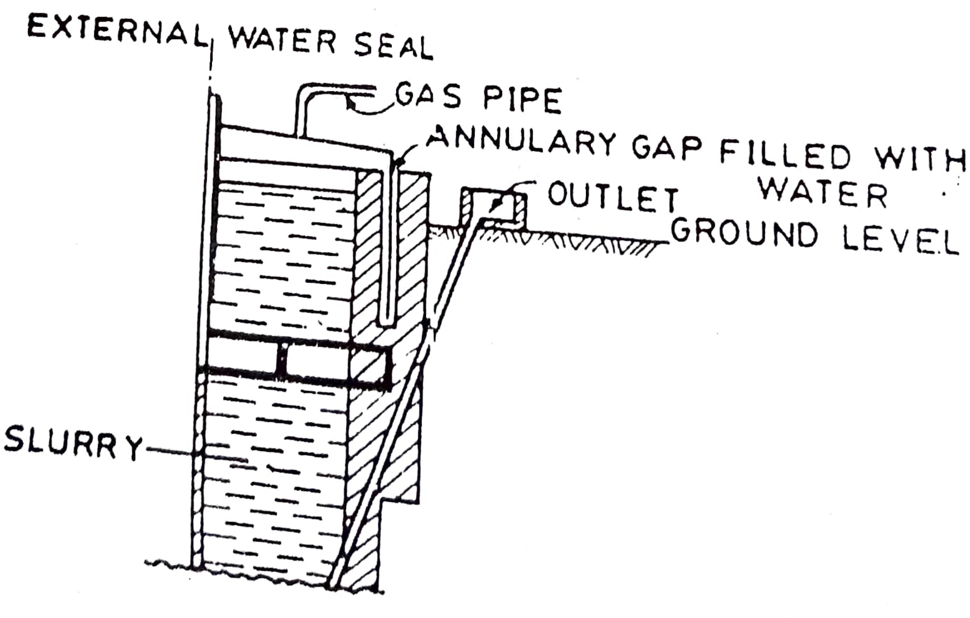


Fig. 7.9.5 (a) Digester with floating gas hold-

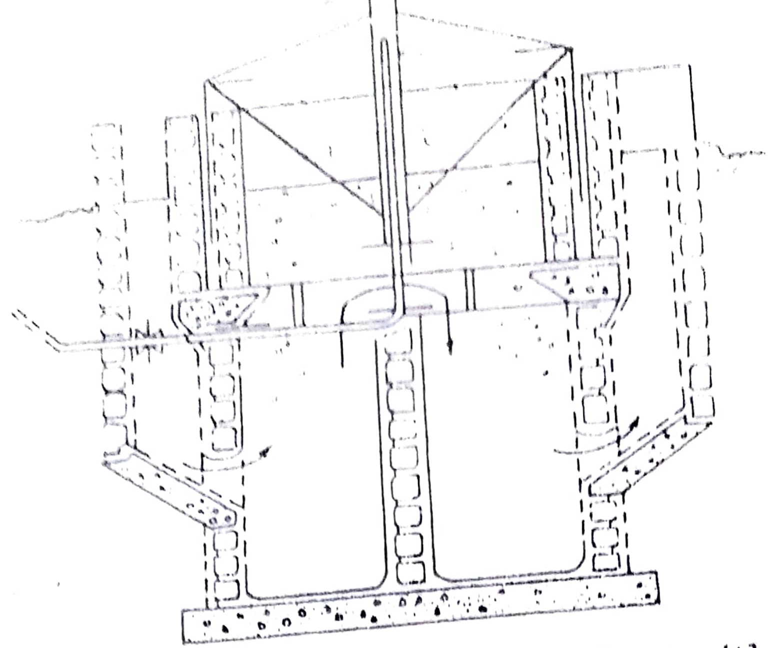


Fig. 7.9.5. (b) Cross-section of biogas plant with water-seal arrangement and gas exit through centre guide frame.

In order to avoid the depth of the digester a squa construction had also been tried. This is shown in Fig. (7.9.6) of plant did not prove successful due to clogging.

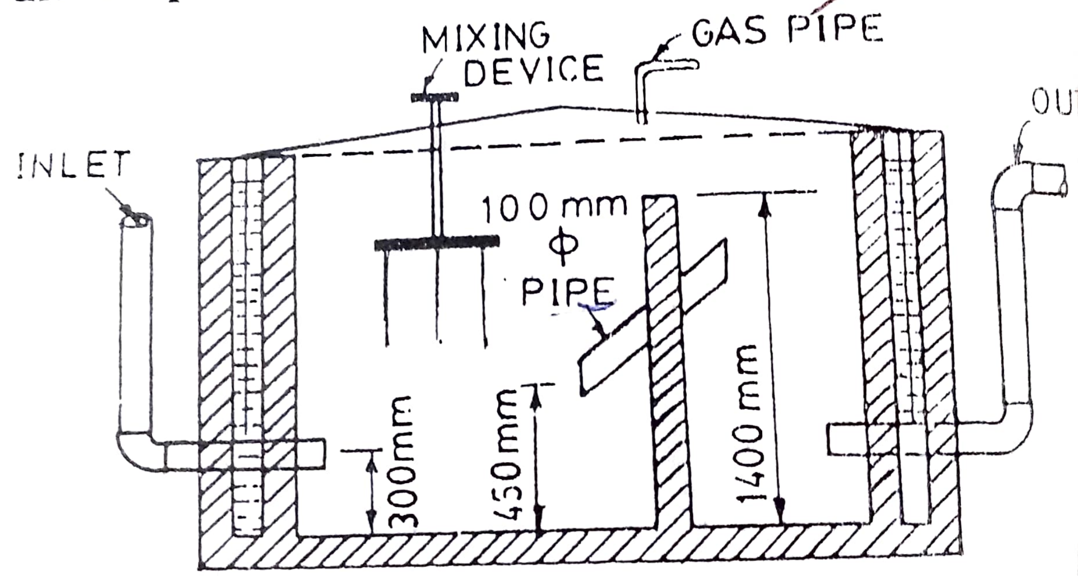


Fig. 7.9.6. Two-chamber rectangular digester with floating gas and water seal (Philippines).

A very simple type of digester using oil drums Fig. (7.9.7). These are best suited for research purposes.

In many situation separation of the gas from the been found to be advantageous. Such arrangements are sh (7.9.8) and (7.9.9). In this digesters gas is let to a separated the floating gas holder and water seal. Though there ar conveniences in this arrangement it is comparatively cos

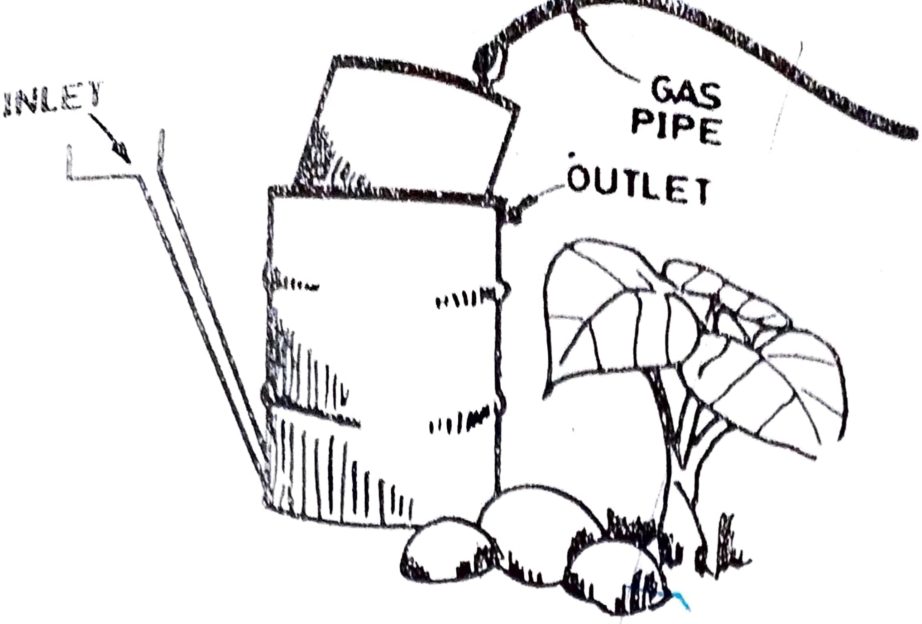


Fig. 7.9.7. Oil drum digester (Indonesia).

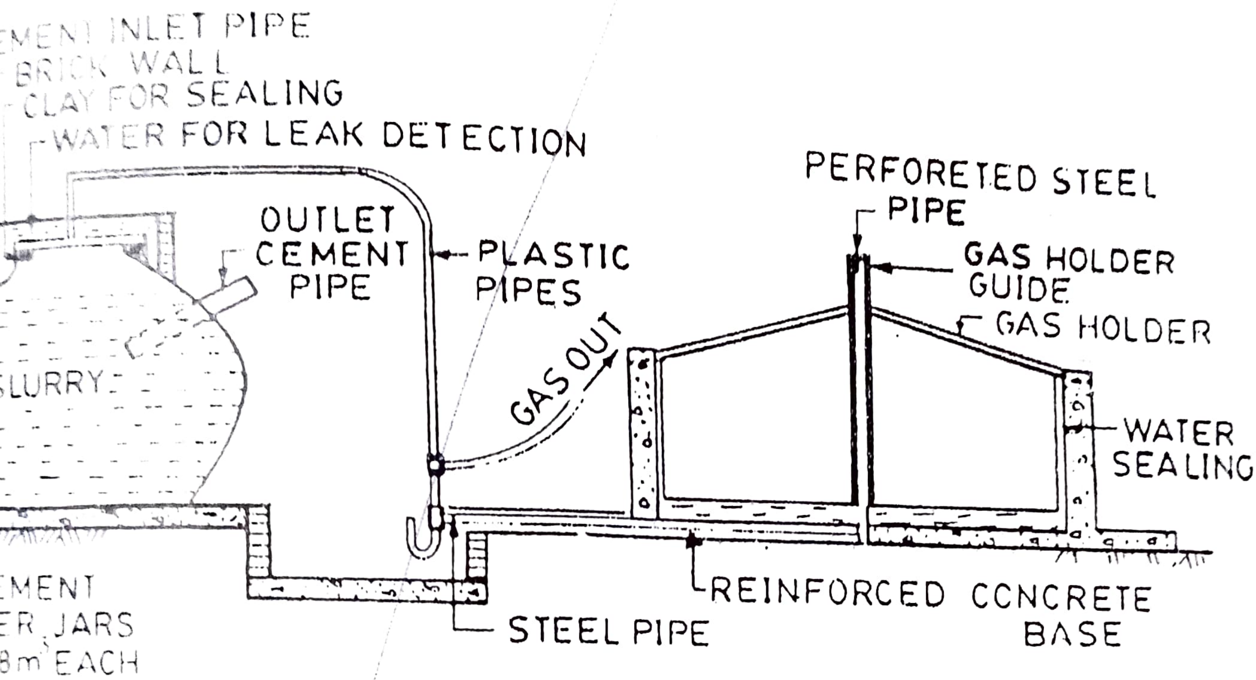
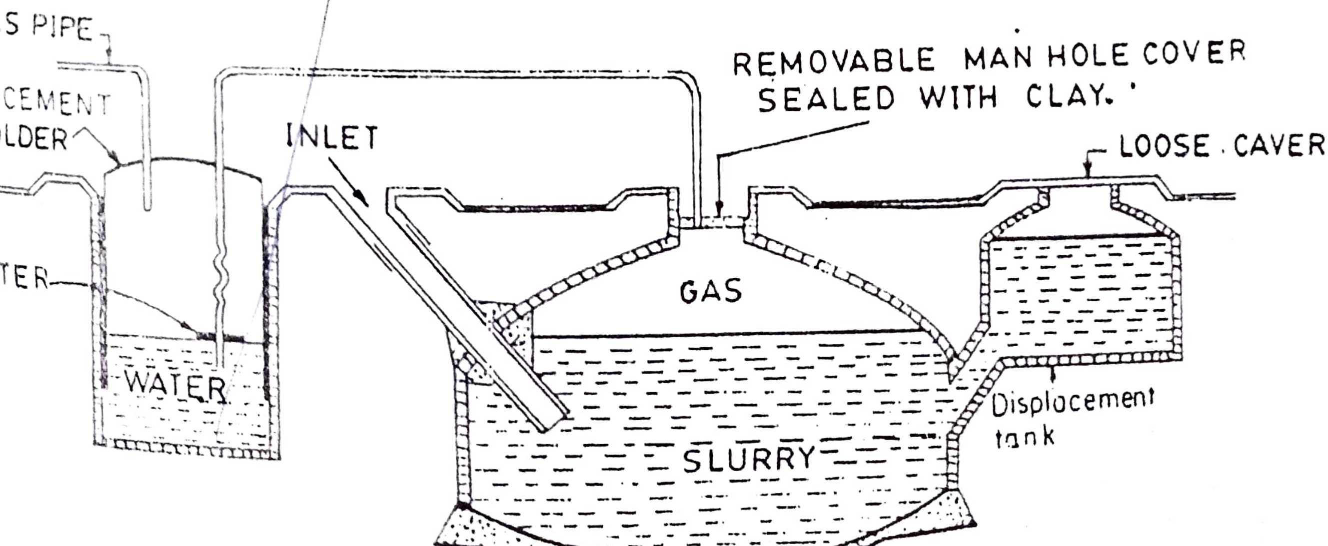


Fig. 7.9.8. Jar digester with separate gas holder (Thailand).



Gas removing system, the pipe arrangement and gas holder support system are shown in Figs. (7.9.10) and (7.9.11).

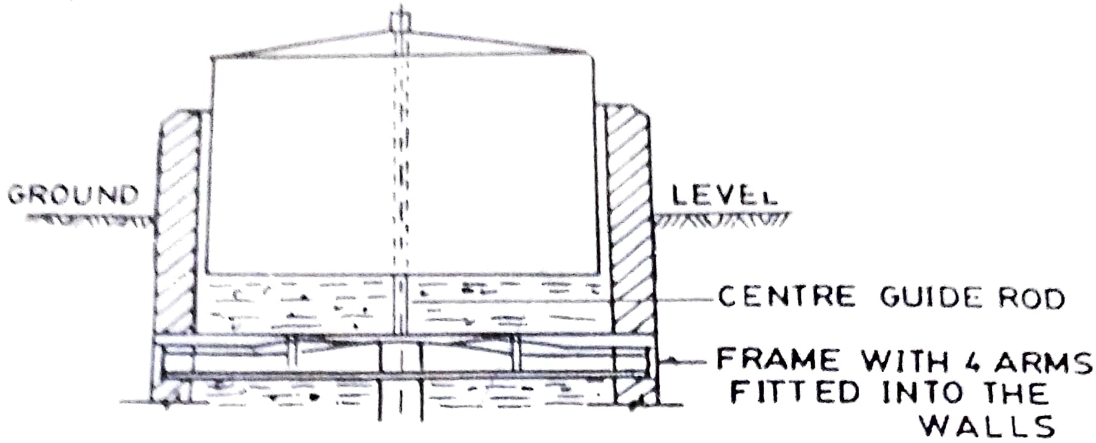
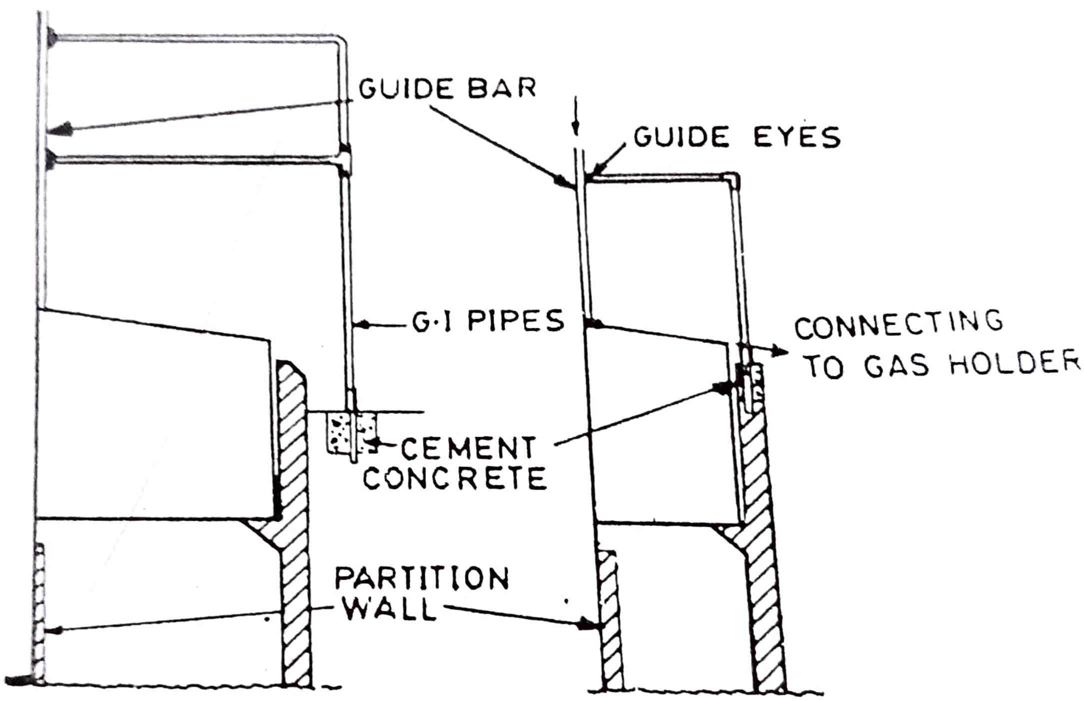


Fig. 7.9.10. Gas holder internal guide system.



Gas holder external guide system fixed to the earth (for large sizes)

Gas holder external guide system fixed to digester wall.

Fig. 7.9.11.

The different design variations of family type biogas plants available at present in our country include :

1. KVIC (Khadi and Village Industries Commission) design.

2. PRAD (Planning, Research and Action division) design (modification of Chinese design).

3. ASTRA (Application of Science and Technology to Rural areas) design.

4. Murugappa Chettiar Research Centre design.

5. Tamil Nadu Agricultural University dome type design.

7.11. Bio-gas from

The subject of biogas production from fresh plant at all new Biogas production was a common feature on many European Farms. The biogas was used in kitchen, hatching, washing machine, automobiles and other heating devices, refrigerators etc. These plants were fermentation plants which had heating systems.

The process of biodigestion as already described generally in following two recognized systems :

(1) Batch fermentation and

(2) Continuous fermentation.

In batch fermentation, the feeding is between plant is emptied once the process of digestion is comple

In continuous fermentation the feeding is done gested slurry equivalent to the amount of feed overfl plant.

The continuous process may be completed in a separated into two stages.

(a) *Single stage process*. The entire process of complex organic compounds into biogas is completed in a ber. This chamber is regularly fed with the raw materials spent residue keeps moving out. Serious problems are enco a single stage continuous process. This subject is discussed

(b) *Double stage process*. The acidogenic stage and stage are physically separated into two chambers. This the of acid-production is carried out in a separate chamber and diluted acids are fed into the second chamber where bio-meth takes place and the biogas can be collected from the second Considering the problems encountered in fermenting fibrou waste materials the two stage process may offer higher success. However appropriate technology suiting to rural needed to be developed based on the double stage process.

...mentation. In this case the digester is largely filled ... that the dry matter generally remains less than 10%. The ... similar to cow dung ferment very well in this process. However, ... plant materials being light, float on water forming a scum. This ... be broken and the materials are submerged every few hours ... continuity of the process. This is the major problem en... while fermenting agricultural waste by this process.

...fermentation. In order to prevent floatation of the plant ... water, the amount of water in the digester is kept to its ... which is just sufficient to keep the raw materials wet for its ... fermentation. The total solids may be 25-30% with no free water. ... is called dry fermentation. The problem of floatation and ... formation may not arise, but the accumulation of acids and ... of the gas in plant materials is likely to occur. The plug flow ... movement of the plant material in the digester may also not take place. ... the problem of pH regulation, proper uniform culture, development and movement of the material pose serious problems in this process. Some of these problems may be less severe when dry fermentation is carried out in the batch fermentation process.

Problems in Straw Fermentation

1. *Scum Formation.* When cow dung is mixed with equal amount of water it forms a smooth slurry which is self-buffered flows smoothly from inlet to outlet and ferments well in any simple digester. The straw material floats on water. Water is essential for fermentation but it also helps in scum formation. Even after the submergence of the straw material in the biogas digester the rising gas bubbles increase the buoyancy of the straw particles, thereby it further helps in floatation. This scum become more compacted as the time progresses and may become sufficiently strong. When a family size plant is fully loaded with straw material, the freshly submerged scum may reappear within a few hours during summer months. This phenomenon poses the greatest problem in successful straw fermentation in continuous fermentation system. Thus suitable manual stirring device which one man (or a house wife) can operate is needed to be developed.

2. *Movement in digester.* Automatic movement of the charge material inside the digester from its inlet to outlet due to the density gradient would be essential. While cow dung slurry moves smoothly allowing the gas bubbles to escape, the straw materials remain floating and may trap the gas. However it may move away from the feeding point as the slurry fed is daily pushed in. Since stirring (to break the scum) is essential, there is a chance that unfermented material may pass through the outlet, if the outlet is near the digester top. Howeve...

the density of the straw material approaches unity as it undergoes fermentation. It becomes less and less prone to floatation and tends to remain suspended in water. However, it does not settle down at the bottom.

Pilot Plants Using Plant Wastes. There are many wastes such as paddy straw, or wheat straw, or water hyacinth etc. which can be utilized to generate biogas. A domestic biogas plant of 0.4 m^3 capacity was developed and fabricated at Jyoti Solar Energy Institute Vallabh Vidyanagar (Gujarat), which could be placed inside the kitchen and save 50% LPG requirements of a family. This plant uses *water hyacinth* (Echhonia Gassipes), a water weed, available in many parts of India. It is a very fast growing aquatic weed. Its annual productivity is about 1050 tonnes per hectare of water surface. This waste can be fed into biogas generator to generate biogas.

Physico-chemical characteristics of water hyacinth

Physical characteristics	*Percentage*
(*i*) Moisture	92.87
(*ii*) Total solids	7.13
(*a*) Volatile solids	5.82
(*b*) Residue	1.31
Chemical characteristics	
(*i*) Carbon	32.51
(*ii*) Hydrogen	4.22
(*iii*) Nitrogen	1.78
(*iv*) Cellulose	25.00
(*v*) Lignin	10.99
(*vi*) Carbon to nitrogen ratio	18.26
(*vii*) Specific gravity	0.25

Moisture and total solids are on wet weight basis and all other ıalysis are on dry wt. basis. From the above, we see that water ⁄acinth has a very high content of moisture and 83 per cent of its total lids are volatile. Its carbon to nitrogen ratio is 18.26 and cellulose ntent is 25%. Which shows that it has a good potentiality for biogas oduction.

The results of experiments on water hyacinth for bio-gas producn are :

(*i*) Biogas production per kg of Wet water hyacinth	53.50 litres
(*ii*) Biogas production per kg of dried water hyacinth	750.61 litres

7.20. Fuel Properties of Bio-gas

Biogas generated by anaerobic fermentation of organic wastes, essentially contains Methane and carbon dioxide in large proportion and has traces of other gases. The importance properties are as follows :

Composition	*(% volume)*
Methane	50—60
Carbon dioxide	30—45
Hydrogen	5—10
Nitrogen	0.5—0.7
Hydrogen Sulphide and oxygen	Traces.

Calorific value

60% Methane : 22.350 to 24.22 MJ/m^3

without CO_2 : 33.525 to 35.390 MJ/m^3

Octane rating without CO_2 : 130

" " with CO_2 : 110

Ignition temperature : 650°C

Air to methane ratio for complete combustion (by volume) : 10 to 1

Explosive limits to air (by volume) : 5 to 15

7.21. Utilization of Bio-gas

The main products of the bio-gas plant are fuel gas and orga manure. Biogas is a flammable gas. Methane is the only combust portion in the gas and hence around 60 percent by volume is only usa for combustion.

The biogas can be utilized effectively for household *cooki lighting, operating small engines, utilizing power for pumping wa chaffing fodder* and *grinding flour* by using the already kno technology.

The utility of the gas in burners is well established. There millions of homes today using this gas as fuel solely for cooking p poses. The burning of cattle dung has not only led to national wast of organic manure but has also caused health hazard problems. It been estimated that 30 million *chullas*, besides consuming 133 mill tonnes of wood, are amongst the major causes of high incidence respiratory diseases and trachoma of eyes of the women folk. The o way of saving the house wife from the irritating smoke of the dung ca and wood is to popularise the use of biogas as far as possible.

Low cost burners have been designed by engineers. A nozzle needed for lamp and stove, which consists of hole in the size of nee point (0.5 mm dia.) and the other end of the nozzle is connected to gas supply hose from the digester. After the biogas enters the stove lamp, it will spray out from the nozzle at a very high velocity and air surrounding this gas streams becomes a low pressure area. The fore air is drawn into the mixing chamber through the air inlets to n with the biogas. From the mixing chamber the bio-gas air mixtu rushes to the openings at the fire sieve plate for combustion. T brightness and force of combustion of the stove and the lamp depend the biogas pressure, the mixing ratio of biogas with air (approx. 1 : 1

...nditions of mixing between biogas and air. A biogas lamp ... mantle, which is made of a Ramic fibre (the same fibre from ... grass cloth and linen is made). The Ramic fibre turns to ashes ... burned and forms a layer of thorium oxide, which emits a dazzling light at high temperatures. As biogas is almost half as light as ... and as hot air flows upward, the brightness of the standing biogas ... is greater than that at the hanging lamp. A biogas lamp of a ... intensity of about 60 watts equivalent electrical light can function for seven hours if one cu. metre gas is available.

One horse power engine can work for two hours roughly with a ... metre of gas. This quantity of gas can cook three meals for a family ... about five. It may be noted that gobar gas can not be bottled into ... cylinders like L.P.G.

It is highly economical to build power houses at the places of ...eration of biogas so that electricity can be produced and the same ...nected to the grid. This certainly will avoid the power cut situations ...ily. Electricity could be produced directly by using bio-organic ...tter as the source of fuel in a bio-chemical fuel cell. Air is injected at ...cathode as an *oxidiser* and bio-organic matter at the anode as the ... The electrolyte is usually an organic solution or an acqueous ...dium such as potassium hydroxide. The bacteria create new losses ...consuming about half of the fuel. The consumption is necessary for ...eir nutritional requirements. The electrical power output of a bio-...emical fuel cell is proportional to the bacterial metabolism rate. It is ...ssible to scrub the biogas by treating with sodium carbonate and ...ethane. An experiment at IIT, Madras has shown that the flame ...emperature of the gas can be increased upto 1000°C. This may be ideal ...or using the gas for *brazing* in workshop.

Biogas can be used to operate both Cl (diesel) and SI (petrol) engines. C.I. engines can run on dual fuel (biogas + diesel) and pilot injection of diesel is necessary for igniting the mixture of air and biogas inside the cylinder. However the initial starting of diesel engine is done on pure diesel. Spark ignition (SI) engine can be operated on biogas after initially starting on petrol. The quantity of gas required for running oil engines must be sufficient on an average 425 litres of gas is required per horse power per hour. Water pump or Generator can be connected to the engine. If a 5 HP engine is to be used for say 8 hours atleast 18 cubic metres of gas would be required per day. That means at least 30 to 35 animals are required for this purpose only. Over and above this gas required for cooking or lighting etc. shall also have to be provided for.

The existing diesel engines can be directly converted to use biogas, with a slight modification, saving thereby about 80% of diesel oil. It is possible to reduce the diesel oil consumption by further research. Biogas can be solely used in SI engine by suitably modifying the carburettor.

Modification of SI engine : SI engines can run completely on biogas, however, the engines are required to be started on petrol at the beginning, conversion of SI engine for operation on biogas includes provisions for the entry of biogas, throttling of intake air and advancing the ignition timing.

Biogas can be admitted to a stationary SI engine through the intake manifold and air flow control valve can be provided on the air cleaner pipe connecting the air cleaner and carburettor for throttling the intake air, as shown in Fig. 7.21.1. In this case the intake air is required to be manually throttling in the initial stage.

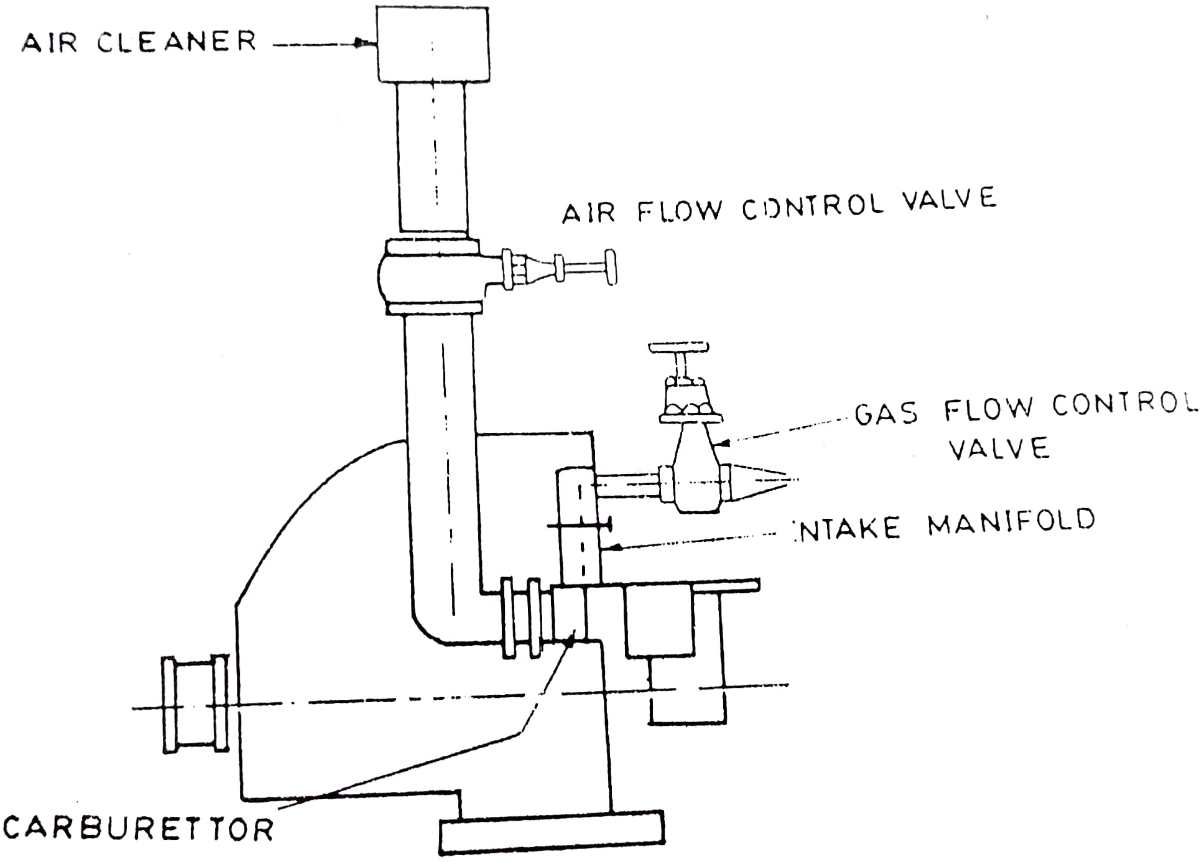


Fig. 7.21.1. Modification required for operating a stationary SI engine on Biogas.

Modification of CI engine : CI engine can operate on dual fuel and the necessary engine modifications include provision for the entry of biogas with intake air, advancing the injection timing and provision of a system to reduce diesel supply.

The entry of biogas and mixing of gas with intake air can be achieved by providing a mixing chamber below the air cleaner which facilitates through mixing of biogas with air before entering into the cylinder. The arrangement as shown in Fig. 7.21.2 is largely used in stationary engines commercially available in India. The capacity of mixing chamber may be kept equal to the engine displacement volume. The pilot injection of diesel in the cycle is required to be advanced for smooth and efficient running of engine on dual fuel. The admittance of biogas into the engine at the initial stage increases engine speed and therefore, a suitable system to reduce the diesel supply by actuating the control rack needs to be incorporated.

It is concluded that

(i) Biogas is a substitute for conventional engine fuels with little modification in both SI and CI engines. Petrol replacement of the order of 100% and diesel replacement of about 80% is possible using biogas.

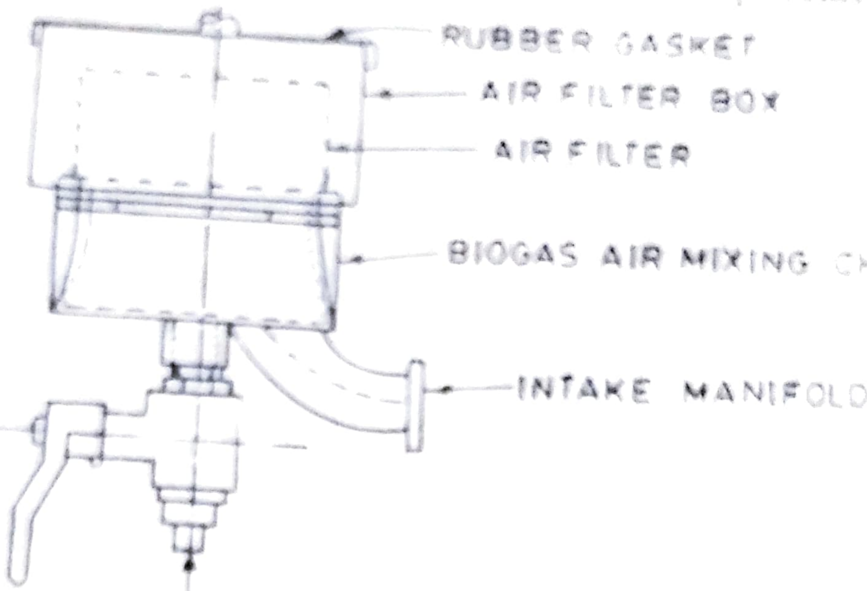


Fig. 7.21.2 Details of mixing chamber and air filter box

(ii) SI engines develop 85% of rated power whereas CI engines develop full power on biogas. Thus application of biogas in CI engine is a better alternative.

(iii) By reducing the CO_2 content in biogas, the engine performance is improved.

(iv) The ignition timing of SI engine using biogas a fuel shall be advanced by 4-5 degrees for better engine performance.

(v) The injection timing CI engines operating on dual fuel (biogas + diesel) shall be kept between 31-33° before TDC for better performance.

(vi) It is economical to use biogas in engine keeping in view the present trend of increase in prices of conventional fuel and their shortage.

In sewage treatment plants the gas is utilized as fuel for the boilers that supply hot water for heating the digesters, for running gas engines which may be coupled to pumps, blowers or generators. The hot water boilers are fired with biogas through natural-gas burners. In view of the characteristics of biogas, the gas engine in which it is used, must be specially adapted to it. If more than 0.25 to 1.0% of hydrogen sulphide is present in the biogas, the gas should be scrubbed before being burnt in a gas engine, since hydrogen sulphide make the biogas corrosive. For scrubbing the gas should be passed through a chamber filled with ferric oxide sponge.

The other main product of the biogas plant in the *organic manure*. This comes out at outlet as slurry which is quite rich in nitrogen and humus. It is in fully digested condition and is in a finely divided condition. It can be applied directly to the farm by mixing with irrigation water. This way maximum benefit is derived from the manure because nitrogen content of fresh slurry is over 2% and it is in a condition which mixes with the soil very well.

When the slurry can not be used with irrigation water it can be used for rapid fermentation of compost. The outlet slurry is led into channels which connects a number of pits. The vegetable refuse like grass, leaves, corncobs and all kind of waste material is dumped in the pit in a layer on top of which the outlet slurry is allowed to spread on top of it, again further waste material could be piled and the proces repeated until the pit is full. Another pits are also filled in the sam manner. It is found that the large content of bacteria and the nutrien material in the gas plant slurry accelerate the process of compostin By providing number of pits, the disposal of the manure becomes eas

The gobar gas manure can also form a good organic base f enriched manure, *i.e.* by enriching the manure with chemical fertiliz like ammonium sulphate, superphosphate etc. a very fine organic ba manure mixture could be produced.)