CHAPTER TWO

Literature Review

2.1 History of Biogas

2.1.1 Period from 1970 to 1983

In the years around 1970, the first wave of installations of small self - made biogas plants started in China. These so - called “power plants at home” were attached to private rural houses. The costs for such constructions were quite significant. On average it took 17 working days for construction and a family had to invest around 5% of their annual income. But within only a few years the investment was amortized by savings on fuel costs and some additional income from selling the fermented residues as fertilizer.

About 6 millions biogas plants were set up in China, promoted by the Chinese government to provide energy, for environmental protection, and to give an improvement in hygiene. The “China dome” bioreactor became a standard construction and an example for other developing countries. Such a typical plant consisted of a concreted pit of a few cubic meters volume. The raw materials – feces, wastes from the pig fattening, and plant residuals – were introduced via a gastight inlet into the interior of the reactor. The gas resulting from fermentation collected in the storage space above the substrate. Whenever needed, a slight overpressure was applied to direct some of the gas via hoses to the kitchen. The biogas was usually not used for power supply. This practice was quite common, and about 7 million households, about 6% of all the households in the country, were applying this principle in 1978.

In a cooperative, about 90 families lived together. They cultivated sugar cane and bananas, carried on freshwater fishing, and bred silkworm. Any waste was collected and brought to a central biogas plant of 200 m3 volume, where it was transformed into fuel. The fuel was used for cooking, to heat the living rooms, and to drive electrical generators. At the same time, the process in the biogas plant killed the germs in the feces, leaving a hygienic residue for use as fertilizer. The people suffered less from parasitic infections and the nutritional value of the soils was improved, yielding large crops. The cooperative society was able to survive on its own and only imported a few small amounts of grass for feeding, some chemical fertilizer, and some liquid manure from the neighborhood. From a political and economic point of view, however, there was no pressure to continue making progress in this field. The importance and interest declined at the end of the period (around 1983), and more and more biogas plants were shut down.

2.1.2 Period from 1984 to 1991

During this period, quite a few new plants were installed, while about the same number of old plants were shut down. The biogas technology, however, gained again more importance since universities started to be engaged in the recovery of biogas and acquired new insights and knowledge.

2.1.3. Period from 1992 to 1998

Building on the new results of the latest research, more biogas plants were set up again, starting in the year 1992. This vogue was supported by the following three political slogans and campaigns.

2.1.3.1. "A pit with three rebuilding's"

The campaign named "A pit with three rebuilding's", encouraged people to build a pit serving as a bioreactor and to rebuild three rooms: the sty, the toilet facilities, and the kitchen.

The sty and the toilet room were rebuilt to have direct drainage into the 8 – 10 m^3 bioreactors. The kitchen was set up with a biogas cooker directly connected with suitable pipe work to the bioreactor. The toilet water for rinsing was withdrawn from the top of the reactor using a scoop.

2.1.3.2. "4 in 1"

Especially in the north of China, the campaign named " 4 in 1 " was strongly accepted it was based on a concept that was developed in a small city, Pulandian in the province Liaoning. This concept took into account the continental climate in the north of China, where there are huge temperature differences between summer and winter. The significant temperature drop and the cold climate during winter only allowed the common biogas plant to be run for about 5 months.

In order to operate the plant during the whole year, the following four different sections were built:

- Bioreactor with a volume of about 8 m^3.
- Greenhouse with about 300 – 600 m^2 of space.
- Sty with about 20 m^2 of space.
- Toilet.

The yield of biogas was about 0.15 to 0.25 m^3 per cubic meter of reactor volume. A volume of 8 m^3 for the bioreactor was sufficient to produce enough gas for a family of 4 members. The fermented residue from the reactor was used as a fertilizer in the greenhouse, while the biogas itself was used for cooking and to heat and light the greenhouse. Overall, the investment for such a plant and concept was usually recovered after 1 – 2 years.

2.1.3.3. "Pig - biogas - fruits"

The campaign named "Pig - biogas - fruits" was strong in the south of China. This plant, which the government promoted, was similar to the "4 in 1" concept, but, because of the milder temperatures, it was not mandatory to have all the different sections consolidated together. Further, the greenhouse was not required, and the fertilizer was used for fruit trees.

2.1.4 .Period from the year 1999 onwards

In the year 1999, the following two projects were established to fight against the worsening environmental crisis: "Energy and environment" and "Home - bio and wellbeing". Similarly to the actions taken in Germany the programs included financial aid to motivate people in the rural areas of China to build biogas plants. The concept is working and the number of plants is rapidly increasing.

In the year 2003, "China's 2003 – 2010 National Rural Biogas Construction Plan" was announced. Objectives were set aimed at increasing the number of biogas plants in China to 20 million by 2005, giving 10% of all farmers ' households the use of their own biogas plant, and to 50 Mio by the year 2010. Each small biogas plant earns an award of 150 US $ from the government. China plans to supply 15% of its total energy consumption from renewable resources by the year 2020, which means that 200 millions biogas plants have to be built. An investment of 187 billion US $ is foreseen.

Near the city of Meili in the province of Zhejiang, biogas is produced from the excrement of 28000 pigs, 10000 ducks, 1000000 chickens, and 100000 hens. In Mianzhu in the province Sichuan a biogas plant closely connected to an ethanol production plant produces some MW electricity from biogas. Nanyang in the province Henan is one of the leading biogas cities in the world because of its location in the center of a rank soil area. Here, there is an abundance of corn, and 1.75 million milligram cereals of second quality can be used for the production of biogas. [4]

2.2 Biogas Concept

Biogas consists mainly of methane and carbon dioxide, but also contains several impurities. It has specific properties which are listed in Table 2.1. Biogas with methane content higher than 45% is flammable.

Table 2.1 General Features of Biogas

Composition	55 – 70% methane (CH_4) 30 – 45% carbon dioxide (CO_2) Traces of other gases
Energy content	6.0 – 6.5 kWh m^3
Fuel equivalent	0.60 – 0.65 L oil/m^3 biogas
Explosion limits	6 – 12% biogas in air
Ignition temperature	650 – 750 ° C (with the above - mentioned methane content)
Critical pressure	75 – 89 bar

Critical temperature	− 82.5 ° C
Normal density	1.2 kg m-3
Smell	Bad eggs (the smell of desulfurized biogas is hardly noticeable)
Molar Mass	16.043 kg kmol-1

Bacteria degradation of biological and organic matter in the absence of oxygen known as Anaerobic Digestion generates Biogas. The Anaerobic digestion is an effective proven technology for handling and treating biological wastes and effluents for generation of district heating and electricity supplies, as well as clean environment. Depending on the feedstock, Biogas is principally mixture of methane gas (CH_4), Carbon dioxide gas (CO_2) and minute traces of hydrogen sulphide gas (H_2S), hydrogen, nitrogen, ammonia gas (NH_3) and sulfur dioxide gas (SO_2). Methane is the only constituent of Biogas with significant fuel value. The inert diluents of Carbon dioxide gas (CO_2) and nitrogen lowers the calorific content of the gas, while hydrogen sulphide gas (H_2S), corrosive nature wears down the anaerobic digester and pipes involved in the gas distribution.

The process of anaerobic digestion is carried out in a simplified number of steps using any substrate of organic or biological origin and occurs in septic tanks, rubbish dumps, garbage refuse bins, decaying municipal waste or food waste. [4]

2.3 Biomass Sources

The sources of biomass can be classified specifically as either:

- Agricultural materials such as liquid manure, crop residues (Ley crops, maize, straw, sugar beet), Silages (grass silage, maize silage), Vegetable wastes
- Industrial residues such as Distillery wastes, and Pomace.
- Municipal wastes such as Source Separated Solid Organic Wastes.
- Municipal wastewaters and Sewage Treatment Plants.
- Animal manures and Slaughter wastes.

Methane potential fraction differs and ranges between 40%-80% do the basis of the digester type, substrate quality and digesting bacteria. A small fraction of hydrogen sulphide often is present in Biogas.

In Table 2.2 the varying percentage constituents of Biogas. [2]

Table 2.2 Varying Composition of Biogas Components Mixture

Constituents	% Composition
Methane	50-75
Nitrogen	0-1
Carbon IV Oxide	30-45
Water	0-1
Ammonia	Traces
Hydrogen Sulphide	Traces (ppm)

2.4 Biogas Commercial Analysis

Like natural gas, biogas has a wide variety of uses, but, as it is derived from biomass, it is a renewable energy source. There are many other benefits to be derived from the process of converting substrates in a biogas plant. [2]

- The economic pressure on conventional agricultural products always continues to rise. Many farmers are forced to give up their occupation, since their land no longer brings sufficient yield. However, the production of biogas is subsidized in many countries, giving the farmer an additional income. For the farmer, biogas production does not mean major reorientation, because microorganisms for methanation require similar care to that needed for livestock in the stable.
- With the present tendency for farms to become large – scale enterprises and with the widespread abandonment of agricultural areas, the cultural landscape is changing. Biogas production from corn or grass could contribute to the maintenance of the structure of the landscape with small farmyards.
- Biomasses that are not needed are often left to natural deterioration, but energy can be generated from these biomasses with aerobic degradation, the low - energy compounds CO_2 and H_2O are formed at least, i.e., much energy is lost to air – about twenty times as much as with an anaerobic process. In the case of the anaerobic degradation metabolism products of high - energy (e.g., alcohols, organic acids, and, in the long run, methane) result, which serve other organisms as nutrients (alcohols, organic acids) or are energetically used (biogas).
- Reduction of landfill area and the protection of the groundwater: the quantity of organic waste materials can be reduced down to 4% sludge when the residue is squeezed off and the waste water from the biogas plant is recycled into the waste water treatment plant.

- ❖ Substantial reduction of the disposal costs of organic wastes, even including meaningful re-use (e.g., as fertilizers), because the quantity of biomass decreases so significantly.
- ❖ If plants are used as co-substrates for biogas production and the residues are recycled to agriculture, no mineral fertilizer need be bought. A cycle of nutrients is reached. Nitrate leaching is reduced. Plant compatibility and plant health are improved.

2.5 Biogas Plant Types

Biogas digester can be classified on the basis of m^3 of gas yield/day/unit volume of the digester as:-

- Low yield digester: -

These can be constant gas volume or, constant gas pressure or plug flow types. They are manually operated, unheated and uninsulated and work generally in mesophilic fermentation phase with conversion efficiencies of 20-30%. They are simple and mostly used in developing countries and can be continuous, simi-contenuous or batch feed types. Yield per m^3 of digester is generally 0.3 to $0.4m^3$/day with a maximum value of $0.7m^3$/day. These are generally for individual decentralized users in rural areas. Long retention time is necessary. They are used for farm size below than $25m^3$ capacity and are widely propagated in India, China, and South East Asia.

- High yield digester

Relatively these are cost and energy intensive and complex. Works on thermophilic phase in addition to mesophilic phase. Conversion efficiencies are 50% to 80%. Gas yield per m^3 of digester volume is always greater than 1m3/day/m^3 and goes up to $3m^3$/day/m^3 of digester volume. They use heating, insulation, stirring and pumping auxiliaries. They are suitable for large scale application like urban waste systems, sewage systems, etc. short retention time is used. Characteristics of low and high yield digesters are given in table 2.3.

Table 2.3 Characteristics of Low and High Yield Digesters

No	Parameter	Low yielding digester	High yielding digester
1	users	Decentralized unit in developing countries and china.	Centralized and decentralized unites in developing countries.
2	Task performed	Direct use for cooking, water heating, lighting and diesel engine.	Gas is stored, purified and piped, compressed for use as automotive fuel and converted to electricity.
3	Principle of digester	Plug flow, constant gas pressure and constant gas volume types.	i. Complete mix stirred tank digester. ii. Two phase digester. iii. Integrated two phase plug flow digester. iv. Fixed film up flow digester. v. Anaerobic attached film expanded digester.
4	Type of	i. Earth embedded	i. Skid mount digester.

	digesters	type with movable gasholder (with/without water seal). ii. Earth embedded type with fixed dome. iii. Plastic bag digester. iv. Batch digester. v. Horizontal digester.	ii. Bio funnel –and expanded radial overflow digester. iii. Vertical and horizontal cylindrical digester with single/double chambers.
5	Size of digester(m^3)	0.25-6000	2-25000
6	Feed input rate before slurry formation(kg)	4-12500	2-340000
7	Biogas output(N m^3/day)	0.1-3500	2.5-28000
8	Biogas yield, Nm^3/kg of feed	0.02-0.05	0.1-0.3
9	Biogas yield, N m^3/m^3 of	0.1-0.3(China) 0.3-0.5(India)	1-1.85

	digester volume		
10	Water to feed ratio	0.8:1-1:1	1:1
11	Retention time ,days	30-150	5-25
12	Conversion efficiency ,%	20-35	50-85
13	Heating of digester	Slurry at ambient temperature:- i. Natural sun heating. ii. Sometimes in winter, hot water is added for feed heating.	i. Solar active/passive heating. ii. Heat by burning part of biogas produced. iii. Auxiliary electrical heating.
14	Insulation	i. Digesters embedded into earth. ii. Compact hay insulation used sometimes. iii. Gasholder covered with gunny sacks or plastic sheet.	i. Expanded foams like urethane. ii. Multilayered insulators. iii. Gas filled powders and fibrous material. iv. Evacuated powders.
15	Additives	Animal urine, poultry	Activated carbon, cellulose

		droppings dried straw powder, compacted grasses, algae, molasses.	enzymes, lactobacillus culture, and gamma radiation.
16	Mechanical power	Manual-scum breaking, mixing of slurry.	i. Stirring of digester. ii. Premixing of feed. iii. Pumping of effluent. iv. Pumping of gas. v. Compression and cleaning of gas.
17	Gas processing	Moisture removal	i. CO_2 purification. ii. H_2S purification. iii. Moisture removal.

2.5.1 Constant Pressure or Floating Dome Digester

This type also known as the Indian digester, consist of a deep circular shape pit built form bricks, mortar and plaster, it's preferred to be under ground to minimize the heat loss from the system also its butter to be cylindrical for structural strength purposes.

The pit is provided with partition wall made of masonry to prevent of short circulation of the fresh slurry, which makes plant as tow stage digester.

The input slurry mixed in a small masonry tank and fed through pipe to a point near the bottom of digester.

The slurry enters in one portion and rises to the top, while in the other portion the slurry goes down and finally enters the outlet collection chamber through a pipe.

The gas holder is a bell-shaped steel drum that floats either direct on fermentation slurry or in a water jacket of its own, In earlier it was suspended on the counter weighted pulleys hanging from several poles around the digester, but these led to tilting and loss of gas pressure, most plants now have a pair of central guide pipes, the inner pipe is connected to a steel frame embedded in the wall of digester , the outer pipe is a part of the structure of the gas holder which is free to rise or fall depending on the production and the use of gas. This single pair of pipes permits the circular motion of gasholder as well as axial motion. [2]

2.5.1.1 Advantages of Floating Dome Digester

i. Simple.
ii. Easily understood in operation.
iii. Volume of stored gas is visible directly.
iv. The weight of the steel gasholder provides almost a constant level of gas pressure which is usually about 10cm column of water.
v. Because it normally uses only cow or pig manure diluted to less than 10% of total solids, sludge formation is slow and frequent cleaning is not necessary. [2]

2.5.1.2 Disadvantages of Floating Dome Digester

i. The steel gasholder is expensive.
ii. Plant life is short due to steel gasholder corrosion problems.
iii. The uninsulated steel gasholder is a good heat conductor and is thus not well suited for cold weather.
iv. The plant has very little potential for digesting the fibrous plant material like plant stalks.
v. Regular maintenance costs due to painting are high. [2]

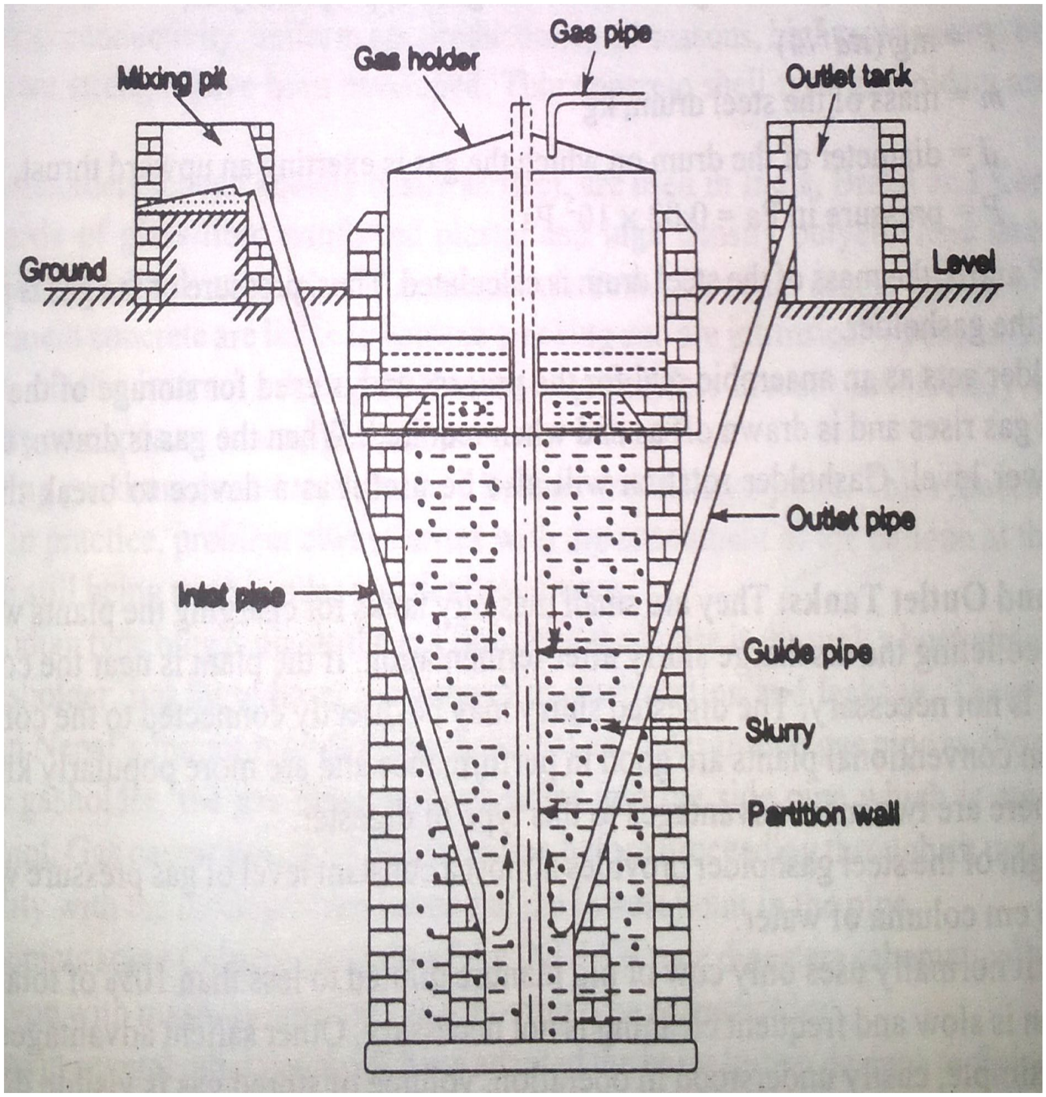

Figure 2.1 Schematic Diagram of Floating Drum Digester

2.5.2 Constant Volume or Fixed Dome Digester

This type also known as the Chinese digester, their design is slightly different from the Indian design in having a fixed dome instead of floating gasholder, also termed as fed batch plants, they are classified under semi-continuous digesters due to the continuous gas production and discontinuous flow of the digested slurry. Mainly use all of agricultural, animal, and human wastes. [2]

The digester is completely underground for butter thermal insulation, avoiding cracking of dome frequently due to the difference in temperature and moisture. The main digester is composed of a cylindrical shell wall with dome and bottom being segments of spherical thin shells. Shallow burial reduces excavation work and keep away from ground water. The digester has a twofold function:-

i. Accommodating digestible material.
ii. Storage of gas.

Since all wastes are used for biogas production, the slurry is not homogeneous mixture. Sedimentation takes place. Hence, the solids content of the daily input settles at the bottom, while the liquid effluent only will be taken out daily, thus the process becomes semi continuous. The detention time is so adjusted to meet the fertilizer requirement for agriculture. Since it accommodates this settled sludge, the volume will be 2.0-2.5 times more than the Indian plant of the same capacity. Usually the digester volume is limited to $15m^3$, another reason for providing longer periods is to provide sufficient time to destroy parasites present due to the usage of human excreta.

A straight inlet is provided to feed the charge without any clogging. The rush of the feed acts as a stirring force to promote gas production. The effluent goes out from the middle layer of the digester. The parasitic ova due to their own weight sink to the bottom of the digester. About 96.6% of the ova will settle at the bottom, while only 3-4% remains floated on the surface of the liquid. The middle layer will not contain any parasitic ova. That is the reason why the out let starts from the middle height of the digester. This effluent can be safely applied to the fields. The volume of the outlet is about 10% of the digester.

The upper portion of the digester right under the dome is the space to store the gas. When gas is produced, it rises and gets collected in the dome. The pressure of the gas displaces the slurry into the outlet into the outlet tank .the fluctuation of the liquid surface control the pressure within a definite range. The normal pressure in this digester is 50-100cm of water column.

The mouth of the dome is enclosed by a removable cover for easy access during maintenance and cleaning settled sludge which use as manure for agriculture.

The removable cover is fitted into the manhole and sealing it with clay paste. The water on top of this will be used for sealing to:-

i. Maintain the clay paste in moist condition.
ii. Detect gas leakage if any through bubbling. [2]

2.5.2.1 Advantages of Fixed Dome Digester

i. Less expensive due to no steal gas holder.
ii. Can be built from locally available materials.
iii. The underground digester is less affected by colder ambient winter temperatures.
iv. Due to the wide inlet, the design permits the use of plant material as a feed stock and facilitates cleaning which is necessary when such materials are used. [2]

2.5.2.2 Disadvantages of Fixed Dome Digester

i. Persistent leakage and seepage problems.
ii. When the gas pressure is very high there is a possibility of gas leaking through the pressure relief valve.
iii. The gas yields are too low (about 0.1 to 0.15m^3/m^3 digester per day).

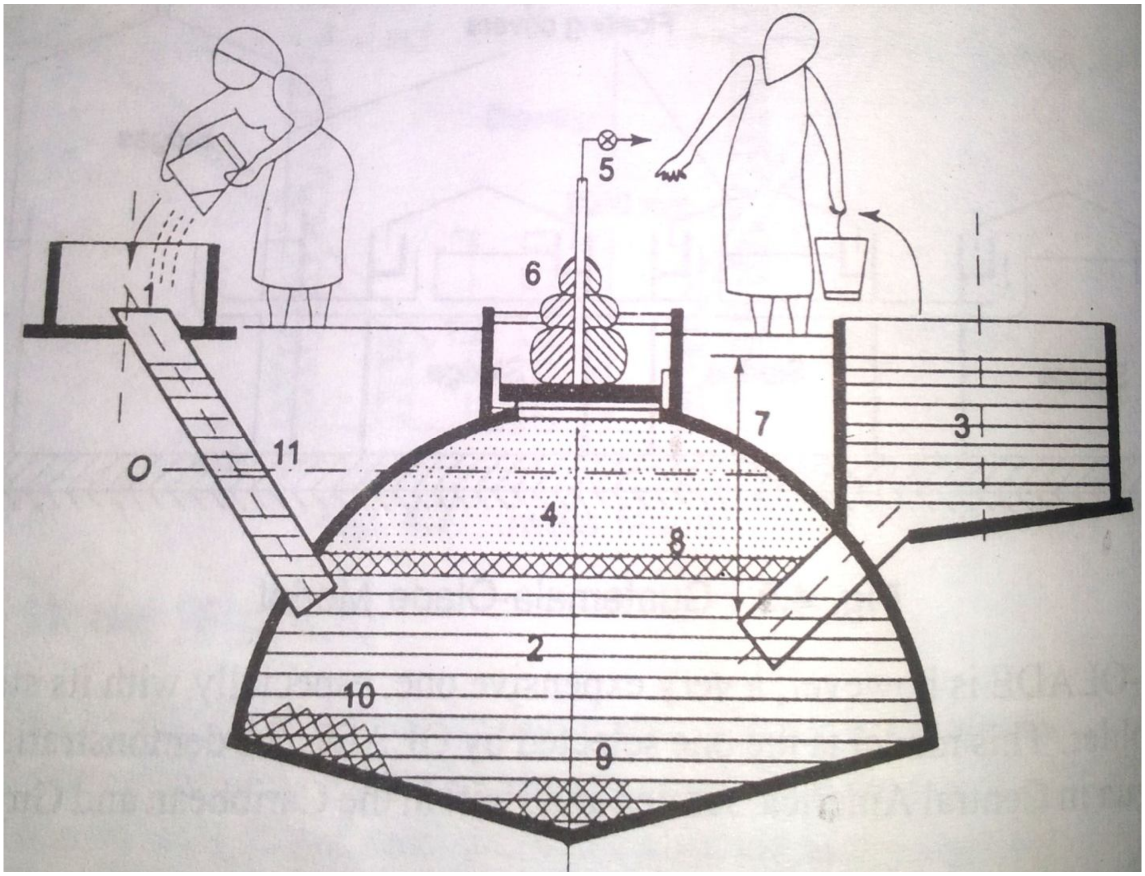

Figure 2.2 Fixed-Dome Plant

1. Mixing tank with inlet pipe.
2. Digester.
3. Compensating and removal tank.
4. Gas holder.
5. Gas pipe.
6. Entry hatch, with gas tight seal and weighted.
7. Difference in level=gas pressure in cm WC.
8. Supernatant scum; broken up by varying level.
9. Accumulation of thick sludge.
10. Accumulation of grit and stones.
11. Zero line filling height without gas pressure.

2.5.3 Comparison between floating dome digester and fixed dome digester

Table 2.4 contains comparison between floating dome digester and fixed dome digester. [2]

Table 2.4 Comparison between Floating Dome Digester and Fixed Dome Digester.

NO	floating dome digester	fixed dome digester
1	Capital investment is high.	Capital investment for the corresponding size of biogas unit is low.
2	Steel gasholder is common and need to be replaced after few years due to corrosion damage.	Steel gasholder is not required.
3	Cost of maintenance is high.	As there is no moving part, the maintenance cost is low.
4	Life span of the digester is expected to be 30 years and that of gasholder is 5 to 8 years.	Life span of the unit is expected to be comparatively more.
5	Movable drum does not allow the use of space for other purposes.	As the unit is an underground structure, the space above the plant can be used for other purposes.
6	Effect of low temperature during winter is more.	Effect of low temperature is less.

7	It is suitable for processing of dung and soil slurry. Other organic material will clog the inlet pipe.	It can be easily adapted for use of other materials along with dung slurry.
8	Supply of gas is at constant pressure.	Supply of gas is at variable pressure which may cause slight reduction in the efficiency of gas appliances. To operate diesel engine, attachment of a gas pressure regulator in the pipe line is a must.
9	Construction of digester is known to masons but fabrication of gasholder requires workshop facility.	Construction of the dome portion of the unit is a skilled job and requires through training of masons.
10	Location of defects in the gasholder and repairing are easy.	Location of defects in the dome and repairing are difficult.
11	Requires relatively less excavation work.	Requires more excavation work.
12	In areas having a high water table, horizontal plants could be installed.	Construction of the plant is difficult in high water table areas.

2.6 Chemical Reaction Process

The formation of methane from biomass follows in general the equation: [4]

$$C_cH_hO_oN_nS_s + yH_2O \rightarrow x\ CH_4 + n\ NH_3 + s\ H_2S + (c\text{-}x)CO_2$$

$$x=1/8.\ (4c+h-20-3n-2s)$$

$$y=1/4.\ (4c-h-20+3n+3s)$$

The products include, for example, the following:

Carbohydrates: $C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$

Fats: $C_{12}H_{24}O_6 + 3H_2O \rightarrow 4.5CO_2 + 7.5CH_4$

Proteins: $C_{13}H_{25}O_7N_3S + 6H_2O \rightarrow 6.5CO_2 + 6.5CH_4 + 3NH_3 + H_2S$

Because the sulfur remains in the residue and part of the CO_2 binds to NH_3,

The result in general is a biogas composition of

CH_4: CO_2 = 71%: 29%

2.7 Measuring and Test Program

The goal of a measuring and test program is to determine the specific gas production obtained at specific retention times. Since digester temperature affects gas production, the measured should be taken at both the coldest and hottest time of the year. The program consists of a set of at least four biogas plants of different sizes (Figure2.3). A given filling volume results in different retention times, in turn yielding different amounts of gas production for one and the same filling volume. [2]

Example (Figure 2.3)

Filling volume: 30kg manure and 30liter water; 60liter/day

Retention time (RT) Chosen: 30, 45, 60 and 90 days

Required digester volume (VD):

RT (30): VD=30×60=1800liter (1.8m^3)

RT (45): VD=45×60=2700liter (2.7m^3)

RT (60): VD=60×60=3600liter (3.6m^3)

RT (90): VD=90×60=5400liter (5.4m^3)

The length of the retention time (RT) has the greatest effect on digester size (VD); test plants may have any shape, however, they should all be identical and should preferably conform to the type to be used later in biogas program, the test plants must be filled regularly for at least three months before gas production is measured.

Specific gas production is determined by dividing the daily volume of gas measured by the amount of slurry loaded into the plant, the results are plotted in a carve and are used for the scaling and calculation of the digester and gas holder volumes.

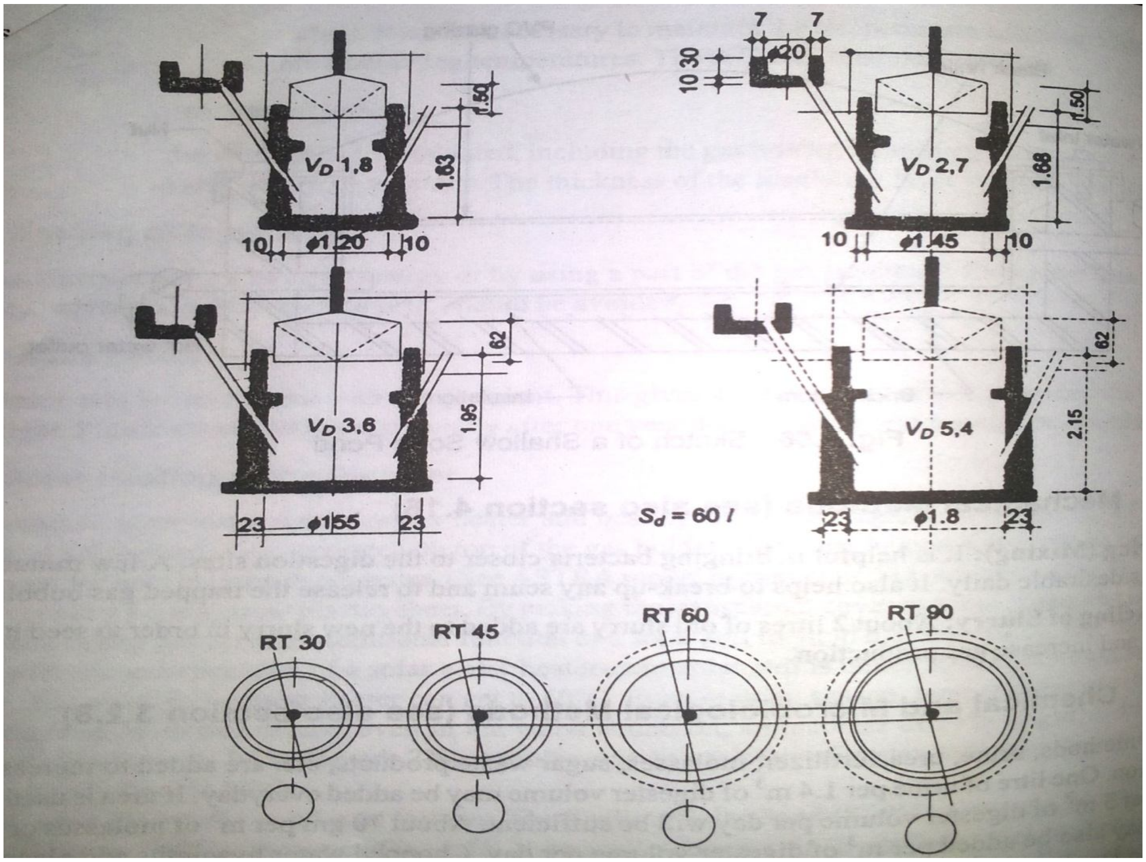

Figure 2.3 Biogas Plant for Test Program for Determination of Gas Production

The actual gas production values can also be derived from the results of measurement of a number of existing plants, for this purpose, the volume of gas stored must be measured before and after each consumption(Figure 2.4).

Measurement must be affected for at least three consecutive days and nights, in a floating drum plant the height of the gas holder is measured (top left). In a fixed-dome plant, the height of the slurry level is measured (top right). The manure is either weighed or measured in liters before introduction to plant.

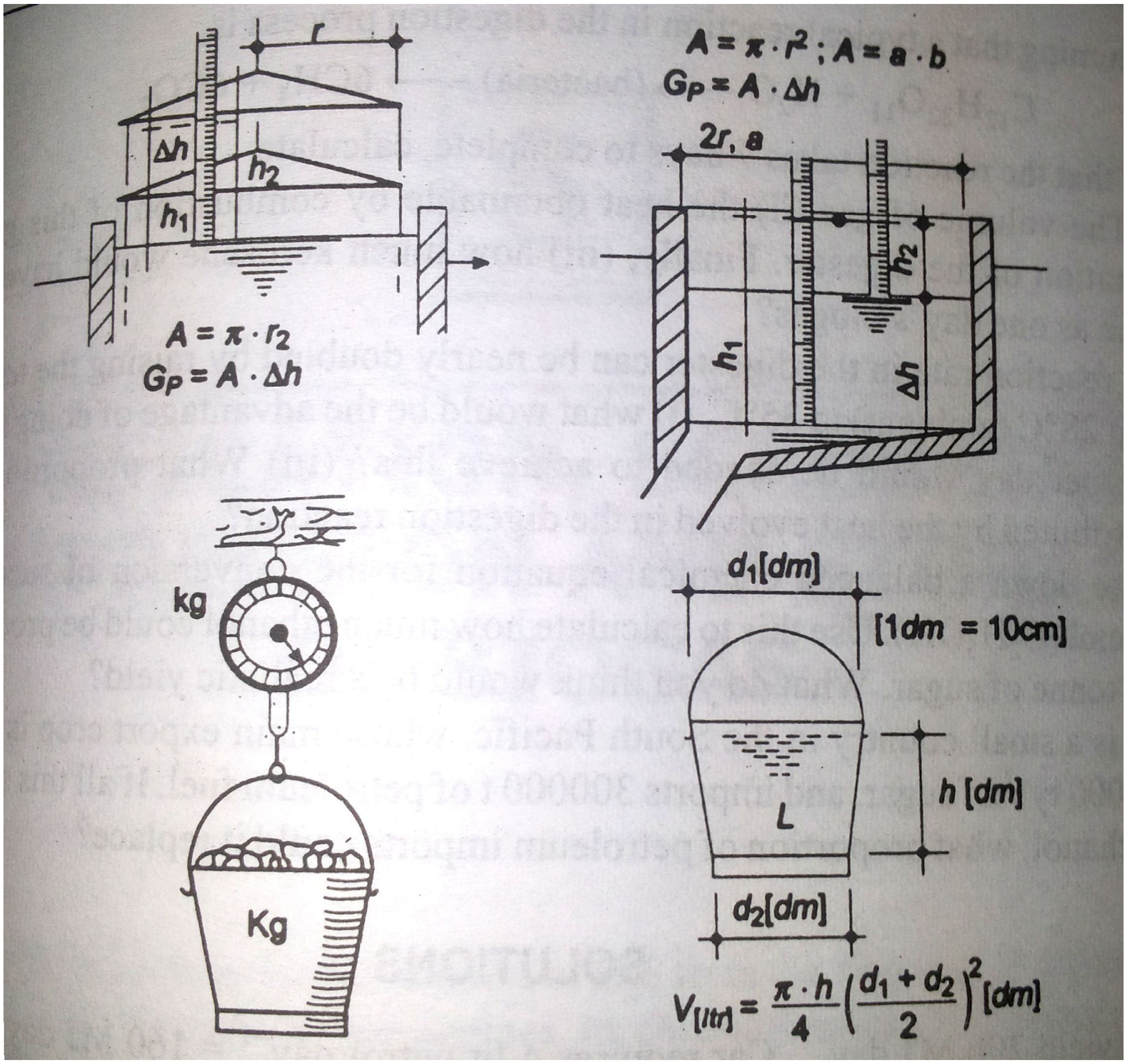

Figure 2.4 Measuring Gas Production on the Plant