ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

ENERGY CENTER

BIOGAS PRODUCTION SYSTEM DESIGN FOR CONDOMINIUM AND ITS FEASIBILITY

A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of Master of Science in Energy Technology

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ABSTRACT

The research is concerned with designing of Biogas Production System for Condominium and studying its Feasibility by crosschecking field survey and information from literatures. The field survey data support the opinion about the importance of constructing biogas plant for Condominium where the average family members' number is five with average monthly energy cost for cooking is Birr 385 per family.

The study indicates that at optimum condition $43.2\ \mathrm{m}^3/\mathrm{day}$ of biogas is obtained from the substrate collected from 10 blocks of Condominium. Based on present energy consumption, $43.2\ \mathrm{m}^3/\mathrm{day}$ biogas fulfills the cooking energy requirement for 43 households. If households use biogas instead of kerosene only, it can serve the cooking energy need for 115 households.

Compressing biogas reduces storage requirements, concentrates energy content and increases pressure to the level needed to overcome resistance to gas flow. As the result of installing compressor for this system, $43.2\mathrm{m}^3$ of biogas volume is stored in $7\mathrm{m}^3$ of pressure vessel and the pressure increased to 11bar from 1.106bar.

In this study, it was possible to see that the Biogas System Design for Condominium is financially as well as economically feasible as the NPV is positive and benefit cost ratio is greater than one. As financial analysis shows the 40 households will save annually Birr 121,175 or Birr 3,029 per family as a result of using biogas instead of other cooking energy sources & using biogas only instead of kerosene, the 115 households save Birr 1,067 per family per annual. This result is obtained if households construct a 96 m^3 biogas plant with daily loading $1.5\mathrm{m}^3$ of night soil in to digester.

ACKNOWLEDGEMENT

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I would also like to thank and express my deep regards to AMU 1998 batch of mechanical department, and friends for their continuous encouragement especially, Andualem Messay.

This thesis is dedicated to my loving mom, Habu

DECLARATION

I declare that this thesis entitled "**Biogas Production System Design for Condominium and its Feasibility"** is my original work done under the supervisor of Dr.-Ing. Demiss Alemu at Addis Ababa Institute of Technology during the year 2011 as part of Master of Science degree in Energy Technology and has not been presented for a degree in any other university and that all the sources of materials used for the thesis have been correctly acknowledged.

Name	Signature	date
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Candidate		

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Dr.-Ing. Demiss Alemu	__________________	______________
Thesis Advisor	Signature	Date

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LIST OF SYMBOLS

BCR	Benefit Cost Ratio
C/N or C:N	Carbon to Nitrogen Ratio
CMS	Consolidated Management Services Nepal (p) Ltd
CNC	Compressed Natural Gas
DLR	Digester Loading Rate
DM	Dry matter
EAEDPC	Ethiopian Alternative Energy Development and Promotion Center
EEPCO	Ethiopian Electric Power Corporation
ETB	Ethiopian Birr
FAO	Food and Agriculture Organization
G_d	Specific Gas Production per day
HRT	Hydraulic Retention Time
kPa	kilo Pascal
kWh	kilowatt hour
mmHg	Millimeter Mercury
NPV	Net Present Value
ODM	Organic Dry Matter
pH	Power of Hydrogen
PVC	PolyVinyl Chloride
RWEDP	Regional Wood Energy Development Programme
S_d	Substrate Input
TS	Total Solid
VS	Volatile Solid

CHAPTER ONE

1.1. Introduction

Problems of growing energy consumption and diminishing supplies of fossil fuels has led to researches of the use of renewable energy sources and, consequently, the development of new technological processes of energy production. One of the renewable energy resources is the biogas produced from green energy crops and organic waste matters.

Conversion technologies for the production of energy from biomass can be classified as biological or thermal (Claasen et al., 1999). The choice between the technologies depends strongly on the material properties together with the social and economic situation. Anaerobic digestion is one of the biological technologies to produces renewable and clean energy (i.e. biogas) from biomass. Besides, it conserves the fertilizer value presented originally in the waste (VanVelsenand Letting, 1980).

The production of biogas from the biomethanation process depends strongly on temperature. Anaerobic digestion can be achieved under psychrophilic (<25c^o), mesophilic (25-45c^o) or thermophilic (>45c^o) conditions. Digestion under the thermophilic condition has many advantages such as higher metabolic rates and effective destruction of pathogens and weed seeds (Van Lier, 1995).

Biogas is a mixture of gases produced during anaerobic decomposition of organic materials. The main gaseous by product is methane (CH_4), with relatively less CO_2, ammonia (NH_3), hydrogen sulphide (H_2S), nitrogen and water vapour. The composition of the gases depends on the chemical composition of the substrate (Bates, 2007).

Biogas is about 20 percent lighter than air and has an ignition temperature in the range of 650 to 750° C. It is an odourless and colourless gas that burns with clear blue flame similar to that of LPG gas (Sathianathan, 1975). Its calorific value is 20 MJ/m^3 and burns with 60 percent efficiency in a conventional biogas stove (FAO/CMS, 1996). Designing a biogas system for the condominium requires the services of a project designer experienced with these systems.

All components of a biogas system must be gas tight. Gas leaks are dangerous because certain mixtures of methane gas and air are explosive. Therefore, the design, construction, and operation of these systems should be undertaken only by experienced or carefully trained personnel. There are different types of biogas systems. Biogas plants can be classified based on:

- Feeding method
- Type of construction
- According to geometrical shapes etc.

The success of biogas plants (projects) at an area depends on: availability of organic materials, cost of constructing, found energy sources and its costs, experience, knowledge, ambient climate conditions especially temperature, and acceptability for people constructing these plants

1.2. Background

The digestion of organic matter by anaerobic microorganisms occurs naturally in the wet environments where there is no oxygen found as: - swamp, bottom of lakes, inside wastewater net pipes and landfill (British Biogen, website).The evolved gas from anaerobic digestion of organic matter was noticed and used very early by ancient Chinese by burning the gas given of when vegetables and manures were left to decompose in a closed vessel. Also other reports point to the using of biogas during 10^{th} BC century in Assyria and 16^{th} century in Persia for heating bath water (British Biogen, website).

In the last centuries many scientists appeared who interested in anaerobic digestion process by studying the evolved gases, anaerobic microorganisms, substrate and other affecting conditions and factors. From these scientists: Van Helmont, Benjamin Franklin, Volta, Beachans, Pastuer and especially Sir Humphry Davy who indicated that methane is one of the gases that generated from anaerobic digestion in 1808 (British Biogen, website).

In 1859, the first biogas plant was constructed in India, while the first plant appeared in England in1895 (British Biogen, website). The biogas production and use began in 1970s in America (Oregon Office of Energy, 2002

Biogas plant was constructed in Ethiopian, Ambo Agricultural College to generate energy required for the purpose of welding in1957/58. During the period 1980 – 2000 more than 1000 biogas plants have been constructed to government institutions, private sector and communities, where most of them were established for demonstration purposes. But the awareness and practices didn’t go beyond such places (MoguesWorku, 2009).

The Literature review discusses the benefits of using biogas that is renewable energy source. The building of biogas plant through the world is the same. In Ethiopia, for Condominium the biogas plant (system) is not design yet.

1.3. Statement of the Problem

Energy is a means for performing activities. For the humanity, energy is a vital component of development. There are two types of energy sources on the Earth:

i. Conventional energy sources and
ii. Renewable (Non-conventional) energy sources.

Conventional energy is obtained from a static storage such as fossil fuels, nuclear reactions etc. It remains static bound in position until it is released by human actions. These are finite and non-renewable. On the other hand, non-conventional energy is obtained from natural sources, which can be continuously formed. Solar energy, wind energy, Geo thermal energy and bio energy fall into this category. The following factors are driving forces for research in renewable energy resources for households use:

- The oil crisis of the 1970s due to depletion of convectional fuel,
- Cost increment of kerosene fuel,
- Health risk of using convectional fuel and
- GHG emission

The key concerns that guided searching for alternative energy sources are that such alternative energy sources are: renewable, safe, locale specific, cheap, decentralized and appropriate

1.4. Objective

The general objective of this study is to design biogas production system and ensure whether it is financial consistent or not. More specifically, the study has the following objectives:

- Biogas production System design for condominium
- Estimating biogas production
- Estimating cost of plant
- Evaluate and compare energy choice
- Ensure that installing biogas plant for condominium is socially accepted technology that will give economic benefits

1.5. Scope

The biogas production system design for condominium is not limited to the thesis, but it can extend to national domestic biogas production program to ensure energy self-sufficiency.

1.6. Methodology

To fulfill the objectives of this study, the following methodology was used.

i. Beginning phase: Desk study

- Collection of secondary data & information from Literature
- Preparation of questionnaires for primary data collection

ii. Investigation and data collection phase: field study

- The amount of energy consumed in average by household
- Floor of condominium and the average numbers of the resident in each apartment
- Households would consult to search opinions on biogas technology
- Collecting different design data of condominium from Addis Ababa Housing Development Project Office

iii. Data Analysis, Interpretation and Report Preparation

- Once the field and desk activities would complete, all the data collected from the field and secondary sources crosschecked, verified, analyzed and interpreted using appropriate theory

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Historical Background of Biogas

Biogas technology was introduced in Ethiopia as early as 1979, when the first batch type digester was constructed at the Ambo Agricultural College. In the last two and half decades around 1000 biogas plants, ranging in size from 2.5 m^3 to 200 m^3 were constructed in households, community and governmental institutions in various parts of the country. Up to 2008, approximately 40% of the biogas plants that were constructed are not operational due to a lack of effective management and follow-up, technical problems, loss of interest, reduced animal holdings, leave of ownership, water problems, etc.(NBP,2008).

Human excreta, generally known as night soil are used in biogas plants in several countries. Biogas could be generated in family sized septic tanks, but studies have indicated that night soil from 40 to 60 people would be required to produce enough cooking gas for one family (GTZ, 1999).

A few large plants using only night soil have been built in China, India, and Nepal. The largest of these is the biogas power plant at Foshan in China's Guangdong region. It uses about 170,000 kg a day of night soil in 28 connected 47m^3 digesters the plant has a total digester volume of 1316 $m^3$and produces up to 720 $m^3$of biogas daily. The gas is stored in two flexible plastic gasholders and used in two diesel generating sets to produce about 90 kW of electricity.

2.2. Human Excrements

In most cultures, handling human excrement is loaded with taboos. Thus, if night soil is to be used in a biogas system, the toilet in question should drain directly in to the system so that the night soil is fermented without pretreatment.

Human excreta are potential raw material for biogas production. One adult at ordinary diet will produce from 100-250 grams of night soil per day. On a vegetable diet, an adult will produce from 300-400grams a day. Night soil is usually neutral to slightly alkaline in pH, 24-27% TS (Dry weight) with a C/N of 6 to 10, nitrogen 4 to 6 %, VS 85% of TS (Krishna, 1987).Biogas production from human night soil is, averaging $0.02-0.03m^3/day$ from 200grams on a wet weight basis at 70% CH_4 (Krishna, 1987).

2.3. Biogas Composition & Properties

Biogas is a mixture of gases evolved from digestion process of organic matter by anaerobic bacteria at anaerobic conditions (i.e. without oxygen) (Mattocks, 1984). Most studies about biogas indicate that methane (CH_4) and carbon dioxide (CO_2) are the main components, where the ratio of methane ranged between 50 - 80% and the ratio of carbon dioxide range is 20 - 50% (EREC, 2002). Other components of biogas that may be found in small amounts (traces) are: Hydrogen (H_2), Nitrogen (N_2), Hydrogen Sulfide (H_2S), Carbon monoxide (CO), Ammonia (NH_3), Oxygen (O_2) and water vapor (H_2O) (Schomaker et al., 2000).

Table 2.1: Composition of Biogas (source: FAO/CMS, 1996)

Substance	**Symbol**	**Percentage (%)**
Methane	CH_4	50-70
Carbon Dioxide	CO_2	30-40
Hydrogen	H_2	5.0-10
Nitrogen	N_2	1.0-2.0
Water Vapor	H_2O	0.3
HydrogenSulphide	H_2S	Traces

Methane and carbon dioxide are odorless and colorless gases. Hydrogen sulfide is colorless but it has an odor of rotten eggs in addition to its toxicity (FAO/CMS, 1996). Carbon dioxide, hydrogen sulfide, ammonia and water vapor considered corrosive substances (Schomaker et al., 2000). In general; biogas with all its components is colorless, odorless and lighter than air (FAO/CMS, 1996).

2.4. Application of Biogas

Biogas is more convenient to use than traditional fuels, such as fire wood, dried dung and even kerosene. It gives a hot, clean flame that does not dirty pots or irritates the eyes, as does the smoke from other fuels. The composite from the plant can be used for fertilizer. Biogas can also be used in engine to drive machinery and water pumps. The concept of replacing wood fuel and petroleum oils by alternative fuels, such as biogas has encouraged governments in various countries to set up biogas programs. Eg. India, China and Nepal etc. for cooking, lighting, heating running engine, electricity (power) etc. (GTZ, 1999).

Normally, the biogas produced by digester can be used as it is just in the same way as any other combustible gas. But, it is possible that a further treatment or conditioning is necessary, for example, to reduce the hydrogen sulfide content in the gas.

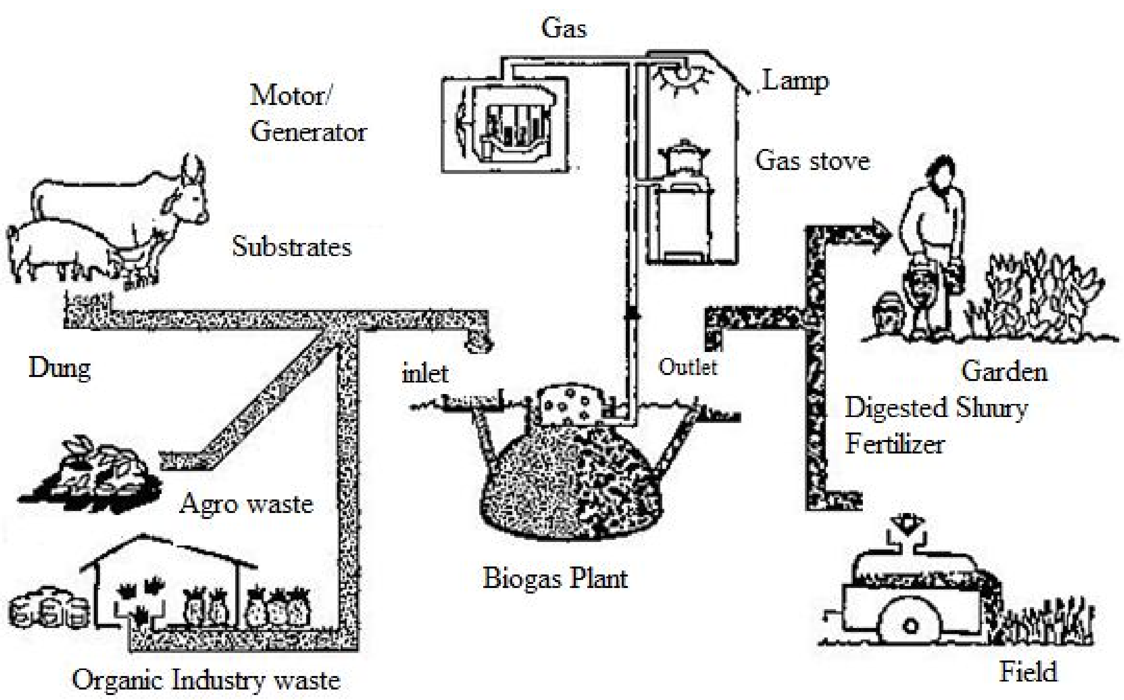

Fig. 2.1: A Typical Biogas System Configuration (Source: GTZ, 1989)

2.5. The Benefits of Biogas Technology

Well-functioning biogas systems can yield a whole range of benefits for their users, the society and environment in general:

- Production of energy (heat, light, electricity)
- Transformation of organic waste into high quality fertilizer
- Improvement of hygienic conditions through reeducation of pathogens, worm eggs and flies
- Reduction of workload, mainly for women
- Environmental advantages through protection of soil, water, air and forested vegetation
- Micro-economic benefits through energy and fertilizer substitution, additional income
- Macro-economic benefits through decentralized energy generation, import substitution and environmental protection.

2.6. Microbiological Process in Biogas

Biogas microbes consist of a large group of complex and differently acting microbe species, notable the methane producing bacteria. The whole biogas process can be divided into three steps. These are:

- Hydrolysis
- Acidification and
- Methane formation

2.6.1. Hydrolysis

In the first step (hydrolysis), the organic matter is enzymolyzed externally by extracellular enzymes (cellulose, amylase, protease and lipase) of microorganisms. Bacteria decompose the long chains of the complex carbohydrates, proteins and lipids into shorter parts. For example, polysaccharides are converted into monosaccharide. Proteins are split into peptides and amino acids (Ghaly et al., 2000).

2.6.2. Acidification

Acid producing bacteria, involved in the second step, convert the intermediates of fermenting bacteria into acetic acid (CH_3COOH), hydrogen (H_2) and carbon dioxide (CO_2). These bacteria are facultative anaerobic and can grow under acid conditions. To produce acetic acid, they need Oxygen and Carbon. For this, they use the Oxygen solved in the solution or bounded oxygen. Hereby, the acid producing bacteria create an anaerobic condition which is essential for the methane producing microorganisms. Moreover, they reduce the compounds with a low molecular weight into alcohols, organic acids, amino acids, carbon dioxide, hydrogen sulphide and traces of methane. From a chemical standpoint, this process is partially endergonic (i.e. only possible with energy input), since bacteria alone are not capable of sustaining that type of reaction (Schink, 1997).

2.6.3. Methane formation

Methanogenes involved in the third step, decompose compounds to low molecular weight. For example, they utilize hydrogen, carbon dioxide and acetic acid to form methane and carbon dioxide. Under natural conditions, methane producing microorganisms occur to the extent that anaerobic conditions are provided, e.g. under water (for example in marine sediments), in ruminant stomachs and in marshes. They are obligatory anaerobic and very sensitive to environmental changes. In contrast to the acidogenic and acetogenic bacteria, the methanogenic bacteria belong to the archaebacter genus, i.e. to a group of bacteria with a very heterogeneous morphology and a number of common biochemical and molecular-biological properties that distinguish them from all other bacterial general. The main difference lies in the makeup of the bacteria’s cell walls (de Mes et al., 2003).

2.7. Factors Affecting Anaerobic Process

There are many factors affecting the digestion process inside the digester and the quantity of produced biogas. These are: microbes balance, temperature, substrate type, stirring, total solids or moisture, carbon/nitrogen ratio (C/N), time remaining of organics inside the digester, acidity (pH), and the presence of activators or inhibitors (Mattocks, 1984; FAO/CMS,1996). Any drastic change in these factors can adversely affect the biogas production. So these parameters should be adjusted within the desirable range to operate the biogas plant efficiently (Chatterjee, 2007 and Marchaim, 1992).

2.7.1. Microbes Balance

Methanogenes convert simple acids and hydrogen that produced by fermentative bacteria species into methane gas and carbon dioxide; this means there should be stable ratios between the different types of anaerobic bacteria population. For example; if the acidogenic bacteria population increases more than the appropriate ratio then there will be an excess accumulation of acids inside the digester which will increase acidity (pH fall down) causing deactivation or stop acting of methanogenes and so the digestion process. In contrast; if the population of acidogenic bacteria decreases significantly, there will be no enough acids for methanogenic bacteria which will decrease biogas production (Mattocks, 1984;FAO/CMS, 1996; Schomaker et al.,2000).

2.7.2. Substrate type

Anaerobic bacteria can digest all organic materials but they differ in the time interval required for complete digestion. That is, some are easily digested and in short time (from few to many days) while others are hardly digested and in long time (months or years) and this is according to the compounds from which the organic matter is composed (Mattocks, 1984;FAO/CMS, 1996).

2.7.3. Carbon to Nitrogen ratio (C/N ratio)

C/N ratio means the ratio of carbon element amount in organic matter to its content of nitrogen element amount (FAO/CMS, 1996). The best C/N ratio is 20-30 atoms of carbon for each atom of nitrogen (20-30carbon atoms: 1 nitrogen atom) (Mattocks, 1984; FAO/CMS, 1996; EREC, 2002). High or low C/N ratio will effect negatively on the digestion of the substrate. Substrates with a too low C/N ratio lead to increased ammonia production, results in toxic effects, and inhibition of methane production. A too high C/N ratio means lack of nitrogen, from which negative consequences for protein formation and thus the energy and structural material metabolism of the microorganism result. A high carbon nitrogen ratio is likely to acidify and bring about the failure of fermentation.

Materials with high C/N ratio should be mixed with those of low C/N ratio to bring the average ratio of the composite input to the desirable level (Karki and Gautam, 1994). It is recommended that, if C: N ratio is high the gas production can be improved by adding nitrogen in the form of cattle urine or by fitting a latrine to the plant (Fulford, 1988).The carbon nitrogen ratio of pig and cattle manure is suitable, while that of human and chicken dung is low for effective digestion. The carbon nitrogen ratio of fresh vegetation is high and this ratio is getting very high in old vegetation, therefore these materials should be mixed in proper proportions in order to start the fermentation process and raise the yield of biogas. Accordingly, biogas production varies as per the carbon/nitrogen ratio of the feeding material (EAEDPC/SNV Ethiopia, 2008).

2.7.4. Temperature

Methanogenes can act on the substrate in wide range of the temperature from below freezing to above 57.2℃ (EREC, 2002). There are three ranges of temperature at which digestion process can be occurred and these ranges are (Mattocks, 1984):

- Low temperature range (Psycrophilic bacteria range): less than 35℃
- Medium temperature range (Mesophilic bacteria range): ranged between 29℃and 40℃
- High temperature range (Thermophilic bacteria range): from 50℃ to55℃.

According to another source (FAO/CMS, 1996), the optimum temperature for the digestion process is 35℃. In general the higher temperature inside the digester the less time required for completing digestion of organic materials (more production of biogas) since more methanogenic bacteria are working upon substrate and also more destruction for diseases causing microbes. The temperature inside the digester should be stable, since the methanogenic bacteria are highly sensitive toward changes and variations of temperature inside the digester especially at high temperature ranges(51.7-39.4℃) where the productivity of the biogas dropped significantly, while it drops gradually at low temperature range (35-0℃)(EREC, 2002).That is, a sudden or fast temperature changes reduces the production of biogas or may be stop its production, so temperature monitoring is essential especially for biogas plants work at high temperature range and may additional heating system or advanced digester isolation is required.

The biogas plants in Ethiopia are expected to be operated in mesophilic range because the temperature in most regions of the country is within this range (EAEDPC/SNV Ethiopia, 2008).

2.7.5. pH value

pH value is an important parameter affecting the growth of microbes during anaerobic digestion. pH value of the digester should be kept within the desired range of 6.8-7.2 by feeding it at optimum loading rate. Acetate and fatty acids produced during digestion tend to lower pH of the digester liquor. However, the ion bicarbonate equilibrium of carbon dioxide in the digester exerts substantial resistance to pH change. This resistance to the change in pH is known as buffer capacity, is quantified by amount of strong acid or alkali added to the solution in order to bring about change in pH. Thus the presence of bicarbonate helps to prevent adverse effect on the microorganisms which result from low pH caused by excess production of fatty acids during digestion. Proteins and other organic compounds, as well as bicarbonate, take part in the buffering capacity and the resistance to the changes in pH (Chatterjee, 2007).

Naturally, in the first few days the pH falls as a result of producing acids by acidogenes. After that, pH rises gradually as a result of nitrogen digestion (forming $NH4^+$). Then the pH stabilized between 7.2 and 8.2 where production process of biogas stabilized also (FAO/CMS, 1996).The characteristic of the feed night soil has pH value 6.9 to 8.4(Joon Moo Hur,2001).For adjusting pH value, acidic materials as sodium bicarbonate should be added to the digester contents (or with loaded organics) in the case of significant pH rising while lime or any other basic material can be added in the case of pH falling (Mattocks, 1984).

2.7.6. Stirring

Optimum stirring substantially reduces the retention time. Stirring is very important for completing digestion process and enhancing biogas production. Since stirring break down the scum formed on the surface of digester contents and prevent the bacteria from stagnating in their own waste products (Mattocks, 1984).

Stirring is more important for large scale biogas plants. Stirring for digester contents of small plants could be done manually by steel rods from substrate introducing pipe, or by paddles while large scale plants require more sophisticated stirring system as gas recirculation and mechanical stirrer. Good mixing of organic wastes with water before introducing the slurry into the digester enhances the digestion process (Mattocks, 1984; FAO/CMS, 1996)

2.7.7. Total Solids

Total solids mean the amount of solid particles in the unit volume of the slurry and they usually expressed in the percentage form (FAO/CMS, 1996). Mattocks (1984) pointed that the percentage of total solid should be between 5% and 12% while other source reported that the best biogas production occur when total solid is ranged from 7% to 10% because of avoiding solids settling down or impeding the flow of gas formed at the lower part of digester (FAO/CMS, 1996). Therefore; dilution of organic substrate or wastes with water to achieve the desirable total solids percentage is required.

2.7.8. Hydraulic retention time (HRT)

Most anaerobic systems are designed to retain the waste for a fixed number of days. The number of days the materials stays in the tank is called the hydraulic retention time. The required time for complete digestion of the substrate inside the digester depends on the type of the substrate, substrate particles size, stirring and mainly on the temperature of the digester (Mattocks, 1984;FAO/CMS, 1996).

In general the highest digester temperature and the finest substrate particles size the shorter retention time. According to the most reports about anaerobic digestion process the retention time of 40 to 60 days is satisfied for digesters work at temperature range between 20℃ and35℃ (EREC, 2002; Mattocks, 1984 and FAO/CMS, 1996).

2.7.9. Inhibitors and Activators

Presence of some substances in the contents of the digester below certain concentrations may activate the digestion process and so increasing the biogas production, but at higher concentrations it may become inhibitors. For example, presence of NH_4 from 50 to 200 mg/l stimulates the growth of microbes, where as its concentration above 1500mg/l produces toxicity (FAO/CMS, 1996). Results of other study pointed that adding small amount of nickel metal (as nickel chloride) to rice straw substrate stimulate its biogas production while nickel larger amount gives opposite results (TRI, website). The presences of some substances can kill anaerobic bacteria as antibiotics, drugs and other medical wastes (Mattocks, 1984).

2.7.10. Digester Loading Rate

The digester loading indicates how much organic material per day has to be supplied to the digester or has to be digested. The digester loading is calculated in kilograms of organic dry matter per cubic meter of digester volume per day (kg ODM/m^3/day).Long retention times result in low digester loading. If the digester loading is too high, the pH falls. The plant then remains in the acid phase because there is more feed material than methane bacteria.

2.8. Basic types of biogas plant

Biogas plants can be classified based on:

- Feeding Method
- Type of construction
- According to geometrical shapes
- According to orientations of inlet and outlet
- And according to buried position

Based on feed method they are classified as (FAO/CMS, 1996):

- Batch feed plants
- Semi continuous
- Continuous feed plants

Batch plants are filled completely and then emptied after a fixed retention time. The major disadvantage, their gas output is not steady. To achieve a more or less uniform rate of biogas production, several digesters must be operated in parallel i.e. filled at staggered intervals.

Batch plants are suitable for digesting straw, fibrous material with high solids content, usually in areas with low annual rainfall, and for use as simple demonstration plants (GTZ, 1989).Continuous feed plants are those in which there is a continuous through flow of biomass, resulting in a near constant volume of slurry in the digester. Such plants are feed once or twice a day.

The advantage of continuous feed plants is that the bacteria receive a regular supply of substrate and are therefore able to generate a more constant supply of biogas. The problem is that buoyant constituents tend to form a stiff layer of scum that impedes biogas production and may even plug up the plant. That drawback can be countered by installing suitable agitators and lengthening the retention time (GTZ, 1989).Continuous feed biogas plants are sized on the basis of the desired retention time for the organic material, in combination with the digester load, which in turn is a function of the existing temperature and type of substrate (GTZ, 1989). Based on the type of construction biogas is classified as:

- Fixed dome plants
- Floating drum plants
- Plastic covered bag plants

Fixed domed and floating drum biogas plants are two basic types of tested biogas plants that have gained wide spread acceptance (Mattocks, 1984).

2.8.1. Fixed dome plant

A fixed dome plant comprises a closed, dome shaped digester with an immovable, rigid gasholder and a displacement pit (expansion chamber). The gas collected in the upper part of the digester. Gas production increases the pressure in the digester and pushes slurry into the displacement pit, from where the slurry flows back to the digester as soon as gas is released. The volume of the expansion chamber is equal to the volume of gas storage.

Gas pressure is created by the difference of slurry levels between the inside of the digester and expansion chamber. When gas is extracted, a proportional amount of slurry flows back into the digester. The gas pressure does not remain constant in a fixed dome plant, but increases with the amount of stored gas. Consequently, a special purpose pressure controller or a separate floating gasholder is needed to achieve a constant supply pressure. The digesters of such plants are usually made of masonry, with paraffin or bituminous paint applied to the gas filled area in order to make it gastight (GTZ, 1989).

Fixed dome plants must be covered with earth up to the top of the gas filled space as a preventive measure (internal pressure up to 0.1-0.15 bar). As a rule, the size of the digester does not go beyond 20 m^3, corresponding to a gasholder volume of $3-4m^3$.The earth cover makes them suitable for colder climates, and they can be heated as necessary (GTZ, 1989).

The digester is filled through the inlet pipe up to the bottom level of the expansion chamber. The level of original filling is called the zero line. Under the anaerobic condition biogas is produced. The following figures (2.2, 2.3, 2.4 and 2.5) show the basic element and some models of this design (GTZ, 1989).

Advantages fixed dome plant:

- It has low cost compared to floating drum type as it uses cement and no steel.
- It has no corrosion trouble (problem)
- Heat insulation is better as construction under the beneath the ground, temperature is be constant.
- The design is compact, it saves space of construction
- Less need of maintenance

Drawback fixed dome plant:

- Gas production per cubic meter of the digester volume is less.
- Gas pressure fluctuates substantially and is often very high. This makes complicates gas utilization
- Plant often not gas light (porosity and cracking often cause irreparable leaks.)

Fixed dome plant is only recommended in cases where experienced biogas technicians are available for building them, and when the user is amply familiar with how the plant operates (GTZ, 1989).

2.8.2. Floating drum plant

The main components of this design are nearly the same as that of fixed dome design, but the difference is in the system of biogas collection. In this design, the biogas collected inside mild steel drum that adjusted over the top of the digester. This drum moves up and down according to the biogas pressure rise up under gas pressure, that is; when the quantity of biogas increases, the drum moves up and as the biogas consumed it is moved down (FAO/CMS, 1996).

Figure 2.6 shows a schematic diagram for a water jacket floating drum design show one of the applied floating drum plant.

Advantage:

- Floating drum plants are easy to understand and operate
- They provide gas at a constant pressure
- Volume of stored gas visible directly
- Few mistakes in construction

Drawback:

- High construction cost of floating drum
- Many steel parts liable to corrosion, resulting in short life(up to 15 years)
- Maintenance intensive due to the necessity of periodic painting & rust removal.
- If fibrous substrates are used, the gasholder shows a tendency to get "stuck" in the resultant floating scum.

Floating drum plants can be recommended as mature, easy to operate, functionally capable means of producing biogas, particularly when reliability is demand more than inexpensiveness. Water jacket plants are universally applicable and especially easy to maintain (GTZ, 1989).

Fixed dome design costs less than floating drum design and it is of less repair requirements. Floating drum design provides biogas with stable rate or pressure while the biogas rate in fixed dome design is variable (Mattocks, 1984; FAO/CMS, 1996).

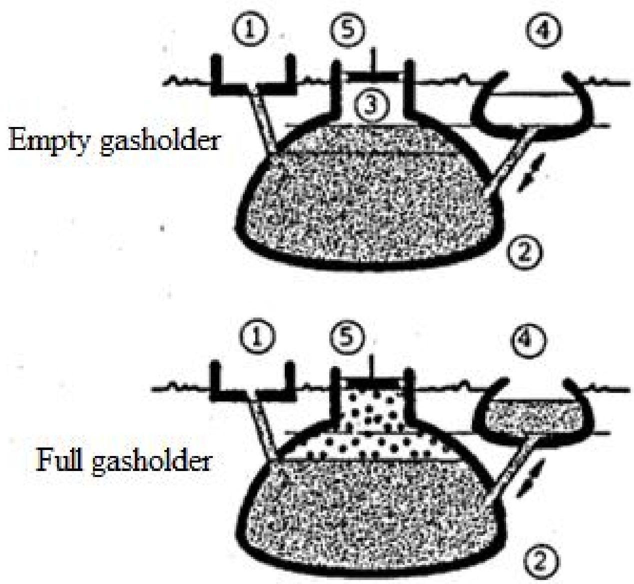

Fig.2.2: Basic function of a fixed dome biogas plant, 1 Mixing pit, 2 Digester, 3 Gasholder, 4 Displacement pit, 5 Gas pipe (Source: OEKOTOP (sited in GTZ,1989:62))

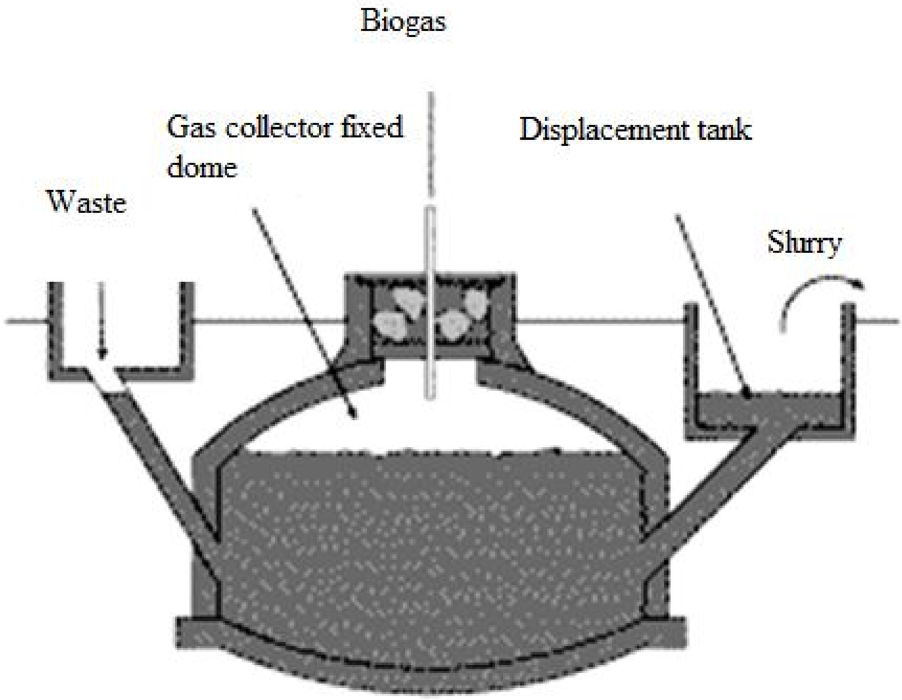

Fig.2.3. Chinese fixed dome plant (Source: Medyan, 2004)

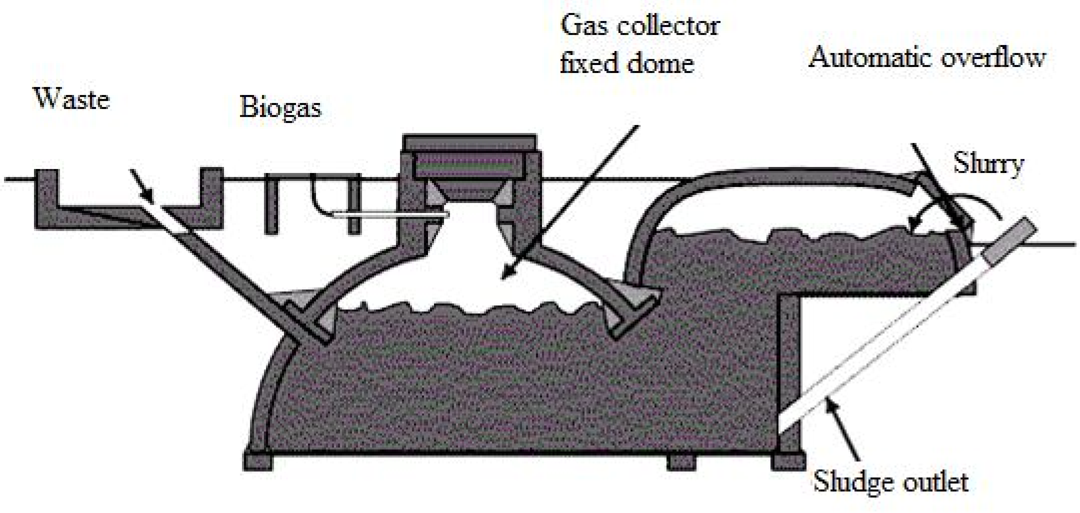

Fig.2.4.Fixed dome plant Camartec design (source:Medyan, 2004)

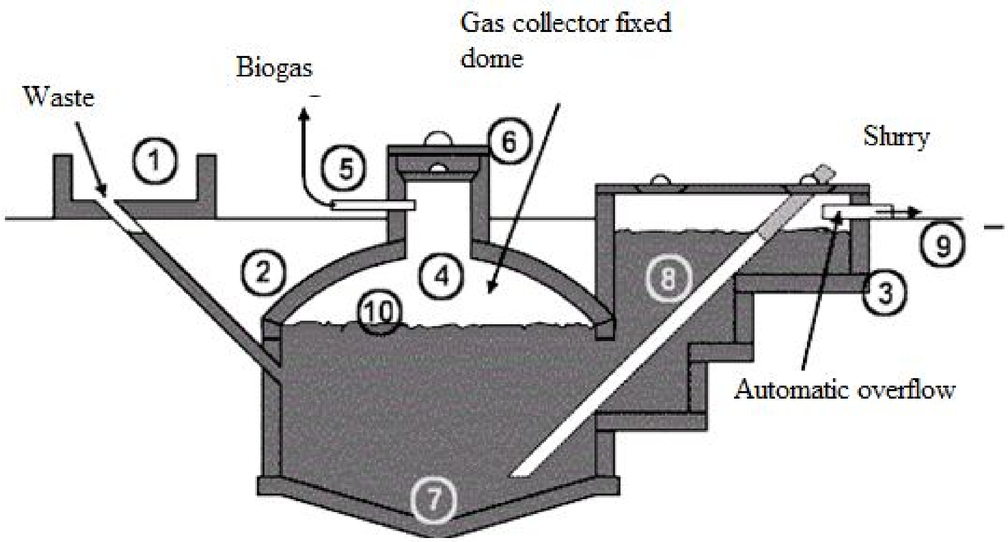

Fig.2.5. Fixed dome plant Nicarao design: 1. Mixing tank with inlet pipe and sand trap, 2. Digester, 3. Compensation and removal tank, 4. Gasholder, 5. Gas pipe, 6.Entry hatch, with gastight seal, 7. Accumulation of thick sludge, 8. Outlet pipe , 9. Reference level &10. Supernatant scum, broken up by varying level (source: Madyan Adel, 2004)

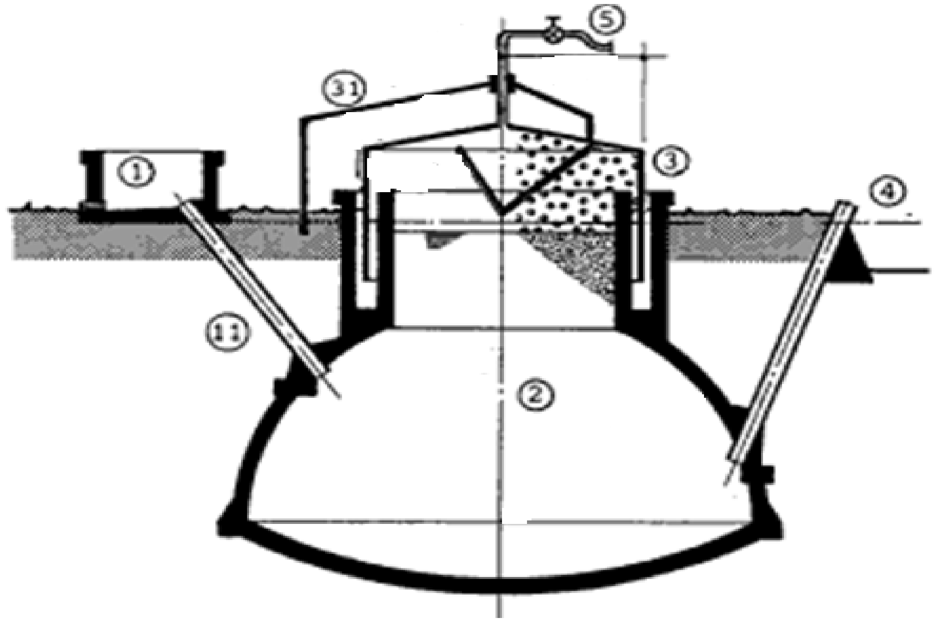

Fig.2.6: Floating drum plant 1.Mixing pit, 11.Fill pipe, 2.Digester, 3.Gasholder, 31. Guide frame, 4. Slurry store, 5.Gas pipe (Source: Madyan Adel, 2004)

CHAPTER THREE

3. BIOGAS TECHNIQUE

3.1. Design Constraint

When selecting a design, the following operating requirements need to be considered.

- Type and composition of organic material which determines the choice of process.
- Knowing demand for biogas and fertilizer, in addition to available substrate quantities, which determines the size of the biogas plant.
- Cost of material building
- Economy of labor input for building and operating the plant.
- Knowledge and experience of the organization or person promoting the biogas plant.

3.2. Sizing of Biogas plant

To calculate the size of a biogas plant, certain characteristic parameters are used. These are as follows:

- Daily fermentation slurry feed (substrate input) (S_d),
- Retention time (RT),
- Specific gas production per day (G_d), which depends on the retention time and the feed material.

The following additional concepts and parameters are also used in the theoretical literature:

Dry matter (DM): The water content of natural feed materials varies. For this reason the solids or dry matter content of the feed material is used for exact calculation.

Organic dry matter (ODM or VS): Only the organic or volatile constituents of the feed material are important for the digestion process. For this reason, only the organic part of the dry matter content is considered. Most favorable ODM value desired is 8%.

3.3. Socio Economic impacts of Biogas Plant

The following are some of the socio economic impacts that resulted from constructing biogas plants:

i. Provide new job opportunities.
ii. Using renewable energy source from materials that should be disposed of, decreasing paid money for getting energy from other sources like kerosene, natural gas etc and so saving family income.
iii. Using produced biogas reduces the quantity of imported kerosene and other energy sources which save money for government.
iv. Using digested organics for fertilizing crops reduces the used amount of manufactured fertilizers, which save money for both farmer and government. Also this using enhances crops production, which will increase the farmer income.

3.4. Constrains for Biogas Technology Dissemination

The main constrains that faces dissemination of biogas technology in most societies are:

i. Cost for constructing biogas plants and long the time period (relatively) required for pay back the capital.
ii. Instability of biogas production and fall of biogas production in cool months.
iii. Experience required for constructing biogas digesters.
iv. Found of some toxic components (usually in trace quantities) in biogas, especially hydrogen sulphide and ammonia (British Biogen, website).

3.5. Parts of Biogas Plant

Biogas plant consists of the following main components:

- Mixing pit (tank)
- Inlet and outlet
- Digester
- Gasholder
- Slurry storage(Compost tank) (detail in section 5.2.5)
- Gas pipe, valve and accessories

Depending on the available building material different variants of the individual components are possible. The following section shows the detail explanation of each component.

3.5.1. Mixing Pit (tank)

In the mixing pit, the substrate is diluted with water and agitated to yield homogeneous slurry. The fibrous material is raked off the surface, and any stones or sand settling to the bottom are cleaned out after the slurry is admitted to the digester

The useful volume of the mixing pit should amount to 1.5-2 times the daily input quantity. In the case of a biogas plant that is directly connected to animal housing, it is advisable to install the mixing pit deep enough to allow installation of a floating gutter leading directly into the pit. Care must also be taken to ensure that the low position of the mixing pit does not result in premature digestion and resultant slurry formation (GTZ, 1989). For reasons of hygiene, toilets should have a direct connection to the inlet pipe. Therefore in case of this design the diameter of inlet pipe should be equal to the diameter of safety tank tube that comes out from the Condominium. No need to design mixing tank for this case.

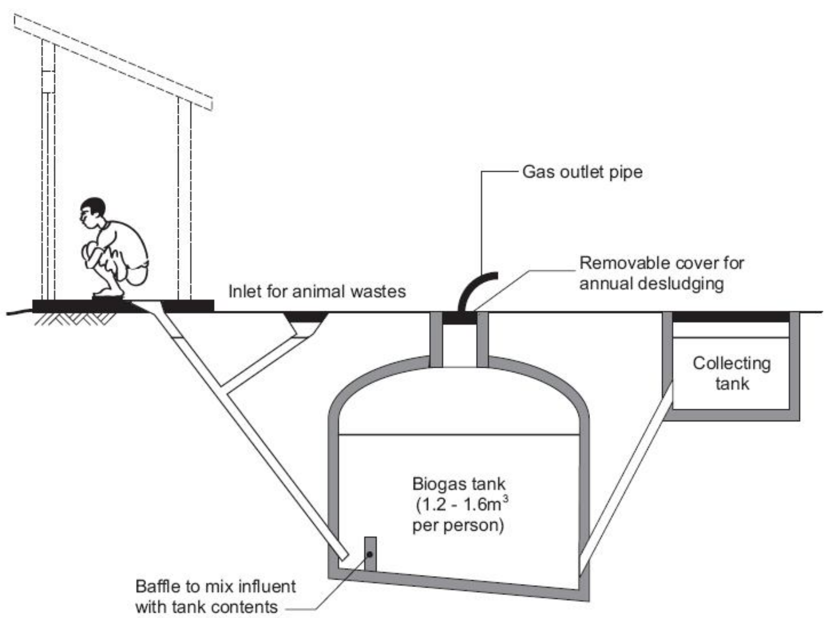

Fig.3.1. Biogas digester with Latrine (Reed and Shaw)

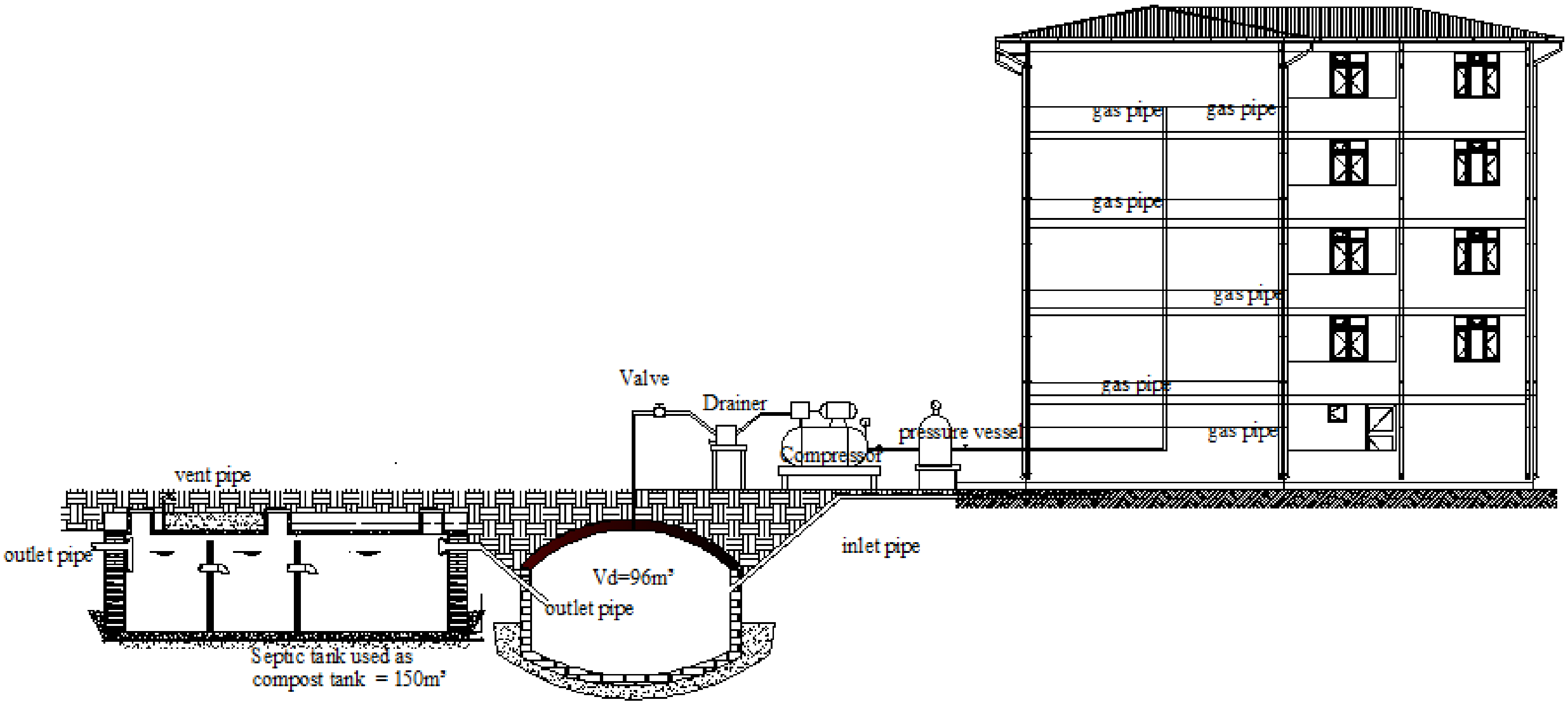

Fig.3.2. Schematic diagram of Biogas Production, Compression, Bottling and Gas pipe System

3.5.2. Inlet and Outlet

The inlet (feed) and outlet (discharge) pipes lead straight into the digester at a steep angle. For liquid substrate, the pipe diameter should be 10-15 cm, while fibrous substrate requires a diameter of 20 - 30 cm. Plastic or concrete pipes are preferred (GTZ, 1989).

Both the inlet and the outlet pipes must be freely accessible and straight, so that a rod can be pushed through to eliminate obstructions and agitate the digester contents. The pipes should penetrate the digester wall at a point below the lowest slurry level (i.e. not through the gas storage). The points of penetration should be sealed and reinforced with mortar.

The inlet pipe ends higher in the digester than the outlet pipe in order to promote more uniform flow of the substrate. In a fixed dome plant, the inlet pipe defines the bottom line of the gas holder (Fig.3.2 (1)). In a floating drum plant, the end of the outlet pipe determines the digester's slurry level (Fig.3.2 (2)) (GTZ, 1989).

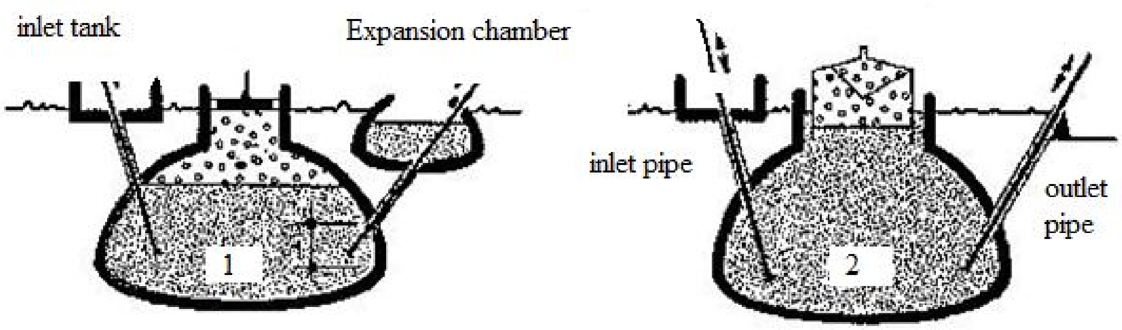

Fig.3.3: Inlet and outlet for fixed dome (1) and floating drum plants (2) (Source: OEKOTOP (sited in GTZ, 1989:71))

3.5.3. Digester

Digester tank is an area where the biomass is stored and fermentation takes place. When the biomass ferments with sufficient retention time, it will produce a biogas. Digesters shape can be in different form. The digester of a biogas plant must accommodate the substrate and bacterial activity, as well as fulfill the following structural functions (GTZ, 1989):

- Accept the given static forces
- Provide impermeability to gas and liquids
- Be durable and resistant to corrosion

As a rule, the digesters of simple biogas plants are made of masonry or concrete. Such materials are adequately pressure resistant, but also at risk to cracking as a result of tensile forces. The following forces act on the digester:

- External active earth pressures (p_E), causing compressive forces within the masonry
- Internal hydrostatic and gas pressures (p_W), causing tensile stress in the masonry

Thus, the external pressure applied by the surrounding earth must be greater at all points than the internal forces (p_E>p_W)(GTZ,1989).

3.5.3.1. Sizing digester

The size of biogas plant depends on the quantity, quality and kind of available biomass and on the digesting temperature. The size of the digester, i.e. the digester volume (V_d), is determined on the basis of the chosen retention time (RT) and the daily substrate input quantity (S_d)

$$V_d = S_d \times RT \qquad 3.1$$

$$S_d = m_{biomass} + m_{water}$$

Where, V_d = Volume of digester

S_d = Daily substrate input

RT = Retention time

$m_{biomass}$ = Mass of biomass

m_{water} = Mass of water

3.5.3.2. Fixed dome gasholder

A fixed dome gas holder can be either the upper part of a hemispherical digester or a conical top of a cylindrical digester (e.g. Chinese fixed dome plant). In a fixed dome plant the gas collecting in the upper part of the dome displaces a corresponding volume of digested slurry. The following aspects must be considered with regard to design and operation:

- An overflow into the compensation tank must be provided to avoid overfilling of the plant.
- The gas outlet must be located about 10 cm higher than the overflow level to avoid plugging up of the gas pipe.
- A gas pressure of 1mwc or more can develop inside the gas space. Consequently, the plant must be covered sufficiently with soil to provide an adequate counter pressure.

3.5.4. Gas pipe, valve and accessories

Galvanized steel water supply pipes are used most frequently, because the entire piping system (gas pipe, valves and accessories) can be made of universally applicable English/U.S. Pipes with nominal dimensions of (1/2") or (3/4") are adequate for small to midsize plants of simple design and pipe lengths of less than 30 m. The diameters of the pipes are depending on the required flow rate of biogas through the pipe line and the distance between biogas digester and gas appliances. Long distances and high flow rates lead to decrease of the gas pressure. The longer the distance and the higher the flow rate, the higher the pressure drops due to friction. The pipe should be laid straight as far as possible with minimum joints and bends.

Table 3.1: Appropriate pipe diameter for different pipe lengths and flow rate (maximum pressure loss < 5 mbar) (Source: GTZ, 1999)

	Galvanized steel pipe			PVC		
Length [m] → **Flow rate[m^3/hr]** ↓	20	60	100	20	60	100
0.1	$1/2''$	$1/2''$	$1/2''$	$1/2''$	$1/2''$	$1/2''$
0.2	$1/2''$	$1/2''$	$1/2''$	$1/2''$	$1/2''$	$1/2''$
0.3	$1/2''$	$1/2''$	$1/2''$	$1/2''$	$1/2''$	$1/2''$
0.4	$1/2''$	$1/2''$	$1/2''$	$1/2''$	$1/2''$	$1/2''$
0.5	$1/2''$	$1/2''$	$3/4''$	$1/2''$	$1/2''$	$1/2''$
1.0	$3/4''$	$3/4''$	$3/4''$	$1/2''$	$3/4''$	$3/4''$
1.5	$3/4''$	$3/4''$	$1''$	$1''$	$3/4''$	$3/4''$
2.0	$3/4''$	$1''$	$1''$	$3/4''$	$3/4''$	$1''$

The values in this table show that a pipe diameter of (1") is suitable for flow rates up to1.5m^3/h and distances up to 100 m (Galvanized steel pipe). Therefore one could select the diameter of (1") as single size for the hole piping system of small biogas plants. Another option is to select the diameter of l" for the main gas pipe and (1/2") for all distribution pipes to the gas appliances. When installing a gas pipe, special attention must be paid to:

- Gas tight, less friction type joints
- Line drainage, i.e. with a water trap at the lowest point of the sloping pipe in order to empty water accumulation
- Protection against mechanical impact

The biogas coming from the digester is saturated with water vapor. This water vapor will condense at the walls of the pipeline. If this condense water is not removed regularly, it will ultimately clog the pipeline. Hence, a water drain has to be placed in the pipeline. The position of the water drain should be vertically below the lowest point of the pipeline so that water will flow by gravity to the trap. Water can be removed by opening the drain. This has to be done periodically (GTZ, 1999).

3.6. Estimation of Soil/Earth Pressure and Hydraulic Forces

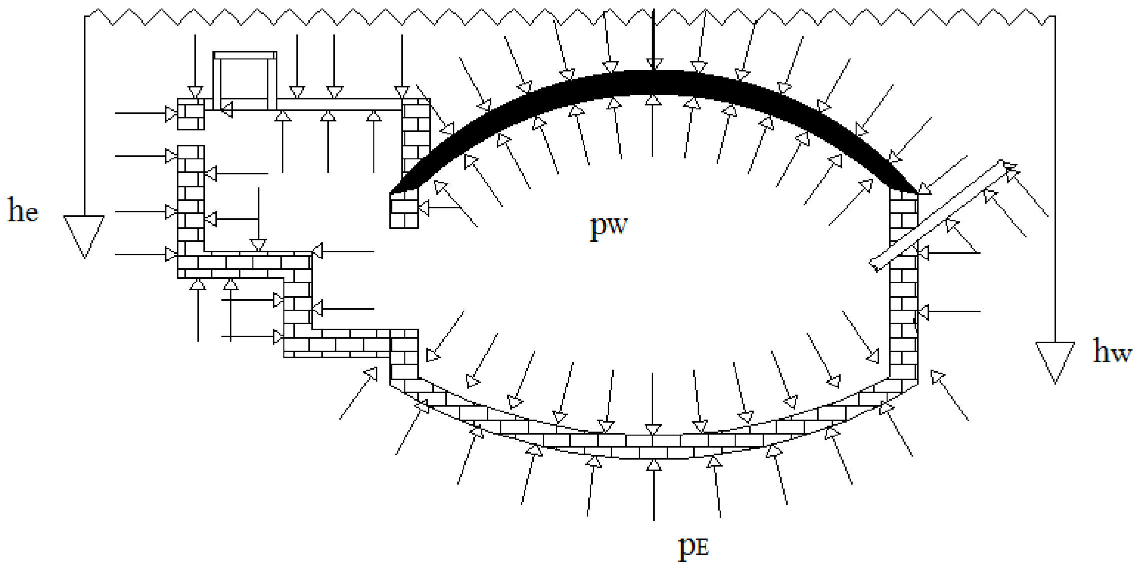

Fig.3.4. Schematic diagram of Soil Pressure and Hydraulic Pressure Forces

In depth forces, h $_{(e, w)}$:

$$p_W = w_W + h_w \qquad 3.2$$

Where, p_W = Hydrostatic pressure at depth h_w

w_W = Specific weight of water $= 1000\, kp/m^3$

Active earth pressure is given by:

$$p_E = w_E \times c \times h_e \qquad 3.3$$

Where, p_E = Active soil pressure, i.e. force of pressure of dry, previously loose (not firmly fixed in place) but now compact column of earth on a solid vertical wall

w_E = Specific weight of dry backfill soil $= 1800 \ldots 2100\, kp/m^3$

h_e = Height of earth column

c = Coefficient of soil pressure for the earth column = 0.3 . . . 0.4

$$p_W = 1000 \times 5 = 5{,}000 \frac{kp}{m^2}, 1000N \approx 100kp$$

$$= 50kPa$$

$$p_E = 1950 \times 0.4 \times 6.5$$

$$= 50.7kPa$$

Therefore masonry should overcome the 50kPa tensile pressure and 50.7kPa compression pressure.

3.6.1. Determination of masonry thickness

Force analysis on the gasholder:

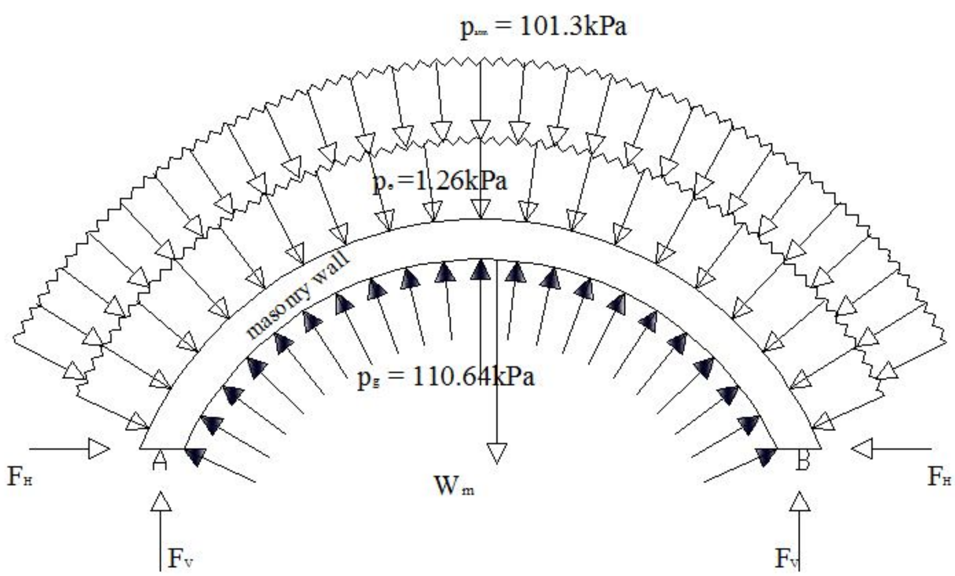

Fig.3.5. Force Analysis on Gasholder

Where, $F_{v,A}$= Vertical force at A

$F_{H,A}$ = Horizontal force at A

$F_{V,B}$ = Vertical force at B

$F_{H,B}$ =Horizontal force at B

p_g= Pressure due to biogas

p_e= Active earth pressure

W_m = Weight of masonry

p_{atm}= Atmospheric pressure

At static equilibrium, uniformly distributed forces:

$$p_g A_s = W_m + p_e A_s + p_{atm} A_S \qquad 3.4$$

$$W_m = \rho_m A_s t$$

Where, A_s = Surface area of upper dome

ρ_m = Density of masonry

t = Thickness of masonry

$$p_g A_s = W_m + p_e A_s + p_{atm} A_S$$

$$110.64 \times 32.8 = 24 \times 32.8 \times t + 1.26 \times 32.8 + 101.3 \times 32.8$$

$$t = 0.34\text{m}$$

The thickness of masonry or concrete should be support shall not exceed 0.34m.

3.6.2. Force Analysis Digester under Empty Condition

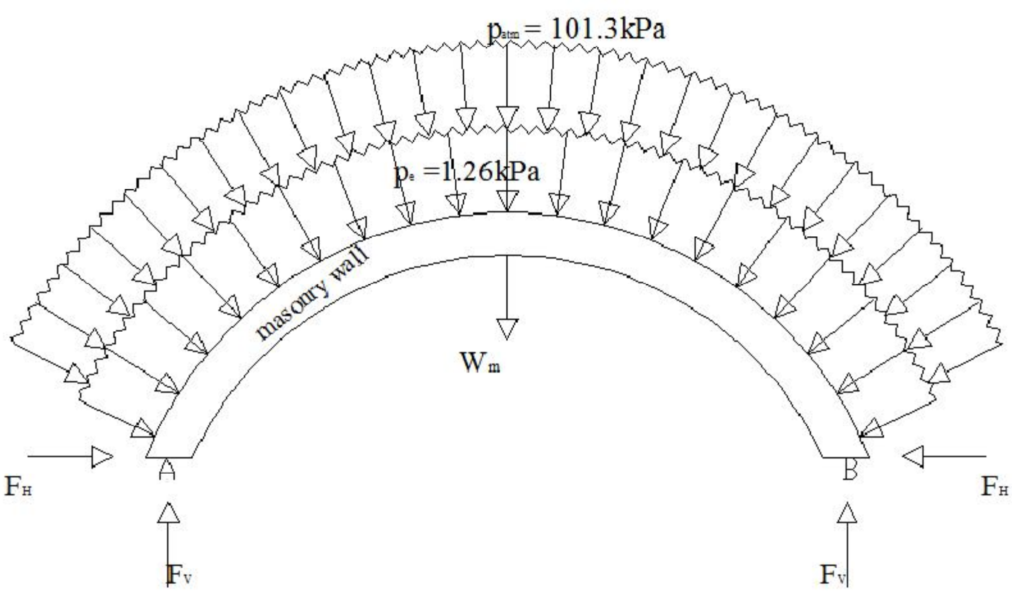

Fig.3.6. Force Analysis under Empty Condition.

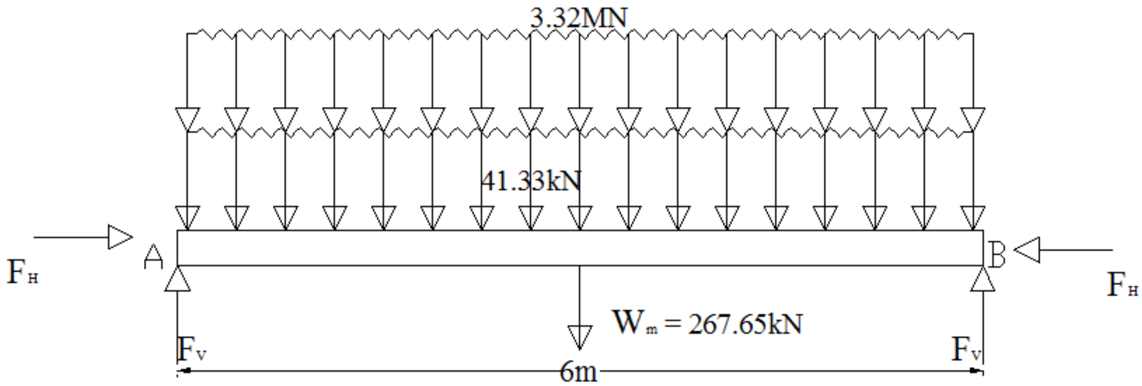

Fig.3.7.Free Body Diagram of Masonry

Considering the upper dome as supported beam:

Calculating reaction force by equation of static equillibrium:

$$\sum F_H = 0 \quad (3.5)$$

$$\sum F_V = 0 \quad (3.6)$$

$$\sum M = 0 \quad (3.7)$$

$$\sum F_V = 0$$

$$F_{V,A} + F_{V,B} = 267.65 + 41.33 + 3.32$$

$$= 3.63MN$$

Taking moment at point A:

$$\sum M_A = 0$$

$$267.65 \times 3 + 41.33 \times 3 + 3.32 \times 3 - 6F_{V,B} = 0$$

$$\mathrm{F_{V,B}} = 1.814\mathrm{kN}$$

From equation 3.4

$$\sum F_V = 0$$

$$F_{V,A} + F_{V,B} - 3.63 = 0$$

$$\mathrm{F_{V,A}} = 1.814\ \mathrm{kN}$$

Analysis of deflection:

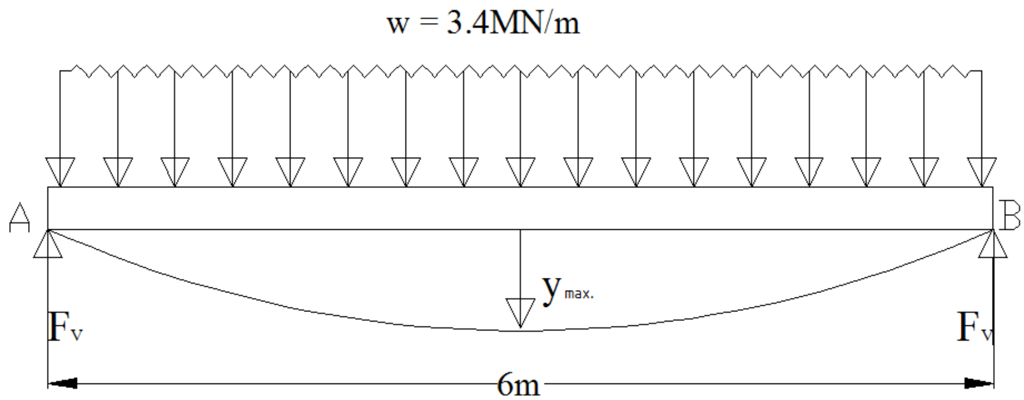

Fig.3.8. Masonry deflection Analysis

The equation of deflection of fixed supported beam is given by:

$$y = \frac{-wx\left[x^3 - 2Lx^2 + L^3\right]}{24EI} \qquad 3.8$$

Where, y = Deflection (m)

w = Distributed force per unit length (N/m)

E = Modulus of Elasticity (GPa)

I = Moment of inertia (m^4)

The maximum deflection occur at $x = \frac{L}{2}$

$$y = \frac{-5wL^4}{384EI} \qquad 3.9$$

Minus sign is due to right down.

E = 25Gpa for middle strength of concrete material

$$I = \frac{Lt^3}{12}$$

$$y_{\max} = \frac{-5wL^4}{384EI}$$

$$y_{\max} = \frac{5 \times 3.4 \times 10^6 \times 6^4}{384 \times 25 \times 10^9 \times 0.02}$$

$$= 0.115\text{m}$$

The masonry (concrete slab) deflects at center 116mm which is around the half of its thickness. In nature the concrete is weak in tension so this indicates that the concrete slab should be reinforced.

3.7. Pressure Developed in the Digester

The pressure of a gas mixture is equal to the sum of the pressure each gas would exert if it existed alone at the mixture temperature & volume. Dalton's law

$$p_m = \sum_i^k p_i(T_{m,} V_m) \qquad 3.10$$

The partial pressure of a gas is the pressure exerted by a particular component of a mixture of gases. It is given by(W.Z.Black& J.G. Hartley,1985)

$$p_i V_i = n_i RT \qquad 3.11$$

Where, P_i = Pressure developed by each gas of mixture

V_i = Volume of particular component of gas

T = Temperature of mixture in Kelvin

R =Ideal gas constant

n = number of moles of component

Based on the maximum volume of biogas produced per a day it is possible to find the maximum gas pressure developed in the digester dome. 43.2m^3 of biogas can be produced per a day (section 5.1). Based on their composition, it is possible to find particular volume & molar number of gas.

Table 3.2: Night soil base biogas composition (Daisy &Kamaraj, 2011)

Composition	**Percentage (%)**
Methane	65-66
Carbon dioxide	32-34
Hydrogen Sulphide	1
Nitrogen Oxide	Trace
Ammonia	Trace

According to their composition the volume of each gas in the mixture can be determined.

The volume of methane:

$$V_{CH_4} = \%\ CH_4 \times V_{Tb}$$
$$= 0.655 \times 43.2$$
$$= 28.3\, m^3/day$$

The volume of Carbon dioxide:

$$V_{CO_2} = \%\, CO_2 \times V_{Tb}$$
$$= 0.33 \times 43.2$$
$$= 14.26\, m^3/day$$

The volume of Hydrogen Sulphide:

$$V_{H_2S} = \%\, H_2S \times V_{Tb}$$
$$= 0.01 \times 43.2$$
$$= 0.432\, m^3/day$$

Table 3.3: Densities, molecular weight and chemical formulas of some gases at normal Temperature and Pressure (20 ℃ and 1atm) (Source: www.engineeringtoolbox.com)

Gas	**Formula**	**Molecular Weight**	**Density - ρ -** kg/m^3
Air	-	29	1.205
Ammonia	NH_3	17.03	0.717
Carbon dioxide	CO_2	44.01	1.842
Hydrogen Sulfide	H_2S	34.076	1.434
Methane	CH_4	16.043	0.668
Water Vapor	-	18.016	0.804

Density is given by:

$$Density = \frac{mass}{volume} \qquad 3.12$$

$$\rho_{CH_4} = \frac{m_{CH_4}}{V_{CH_4}}$$

$$m_{CH_4} = 0.668 \times 28.3 = 18.90\, kg/day$$

$$mole = \frac{mass}{Molecularweight} \qquad 3.13$$

$$n_{CH_4} = \frac{m_{CH_4}}{M_{CH_4}}$$

$$= \frac{18.91}{16.01} = 1178\,mol/day$$

$$m_{CO_2} = \rho_{CO_2} \times V_{CO_2}$$

$$= 1.842 \times 14.26 = 26.26\,kg/day$$

$$n_{CO_2} = \frac{m_{CO_2}}{M_{CO_2}}$$

$$= \frac{26.26}{44.01} = 596.68\,mol/day$$

$$m_{H_2S} = \rho_{H_2S} \times V_{H_2S}$$

$$= 1.434 \times 0.432 = 0.619\,kg/day$$

$$n_{H_2S} = \frac{m_{H_2S}}{M_{H_2S}}$$

$$= \frac{0.619}{34.076} = 18.165\,mol/day$$

The partial pressure of a methane gas:

$$p_{CH_4} = \frac{n_{CH_4} \times R \times T_m}{V_m}$$

$$= \frac{1178 \times 8.31 \times 306}{43.2 \times 10^3} = 69.34kPa$$

The partial pressure of a carbon dioxide gas:

$$p_{CO_2} = \frac{n_{CO_2} \times R \times T_m}{V_m}$$

$$= \frac{596.8 \times 8.31 \times 306}{43.2 \times 10^3} = 35.12kPa$$

The partial pressure of a hydrogen sulphide gas:

$$p_{H_2S} = \frac{n_{H_2S} \times R \times T_m}{V_m}$$

$$= \frac{18.165 \times 8.31 \times 306}{43.2 \times 10^3} = 1.07kPa$$

The biogas saturates with water vapor and now the total pressure inside the digester is the sum of two pressures the dry gases and the water vapor.

Table 3.4: Water vapor pressure at specific temperature (http://hyperphysics.phy-astr.gsu.edu)

Temp (^oC)	**Vapor Pressure (mmHg)**	**Temp (^oC)**	**Vapor Pressure (mmHg)**
-10	2.15	40	55.3
0	4.58	60	149.4
5	6.54	80	355.1
10	9.21	95	634
11	9.84	96	658
12	10.52	97	682
13	11.23	98	707
14	11.99	99	733
15	12.79	100	760
20	17.54	101	788
25	23.76	110	1074.6
30	31.8	120	1489
37	47.07	200	11659

At 33℃ temperatures, we can obtain by interpolation:

At $30^{\circ}C$ $p_1 = 31.8 mmHg$

At 37℃ $p_2 = 47.07 mmHg$

$$\Delta T = 7°C, \Delta p = 15.27\, mmHg$$

$$\Delta T = 3°C, \Delta p = x = 6.54 mHg$$

At $33°C$ temperature, $p_{H_20} = 31.8 + 6.54 = 5.11 \text{kPa}$

Total pressured developed in gasholder:

$$p_{total} = p_{CH_4} + p_{CO_2} + p_{H_2S} + p_{H_2S} + p_{H_2O}$$

$$= 69.34 + 35.12 + 1.07 + 5.11 = 110.64 \text{kPa}$$

3.8. Pressure drop in a gas pipe

The pressure system of the gas must be controlled whenever designed gas distribution system. Biogas is available at a gauge pressure of about 981pascal in conventional biogas plants and for efficient use in burners and lamps it should be available at the point of use at a pressure of not less than 785-981pascal.

Due to friction effect when gas flows through pipe there is loss. So properly designed pipe line is one which does not cause pressure drop of more than 196-294pascal under any circumstances. For determining the proper size of the pipe line, the gas is considered as incompressible fluid during the flow its density changes to a very small extent. For an incompressible fluid through a pipe:

$$Q = VA \qquad 3.14$$

Where, Q = Discharge (m^3/s)

V = Gas velocity (m/s)

A = Cross sectional area (m^2)

Pressure drop of the gas is computed using Bernoulli's equation

$$\frac{p}{\rho g} + \frac{v^2}{2g} + z = const \qquad 3.15$$

Where, p = Biogas pressure (N m^{-2}),

ρ = Biogas density (kg m^{-3}),

v = Biogas velocity (m s^{-1}),

g = Acceleration due to gravity (9.81 m s^{-2}) and

z = Head (m).

Bernoulli's theorem essentially states that for an ideal gas flow, the potential energy due to the pressure, plus the kinetic energy due to the velocity of the flow is constant. In practice, with gas flowing through a pipe, Bernoulli's theorem must be modified. An extra term must be added to allow for energy loss due to friction in the pipe:

$$\frac{p}{\rho g} + \frac{v^2}{2g} + z + h_f = const \qquad 3.16$$

Where, h_f = head loss due to friction

3.8.1. Head Loss

The head loss in a pipe circuit falls into two categories:

a) That due to viscous resistance extending throughout the total length of the circuit
b) That due to localized affects such as valves, sudden changes in area of flow and bends. The overall head loss is a combination of both these categories.

3.8.1.1. Head loss in straight pipes

The head loss due to friction in pipes may be obtained by using the Darcy-Weisbach's equation

$$h_f = \frac{fLV^2}{2gd} \qquad 3.17$$

Where, h_f = head loss due to friction

f = Friction factor depending upon the surface of the pipe (dimensionless)

L = Length of the pipe in meters

V = Velocity of gas

d = Diameter of pipe

Friction factor for pipe:

The value of friction, for smooth pipes, may be obtained by using the following expression:

i. For laminar flow $(R_e < 2300)$

$$f = \frac{64}{R_e} \tag{3.18}$$

ii. For turbulent flow $(R_e > 2300)$

$$f = \frac{0.3164}{R_e^{0.25}} \tag{3.19}$$

Where, $R_e = \frac{VD}{\gamma}$

V = Velocity of gas

D = Diameter of pipe

γ = kinematic viscosity

At p = 1.013bar, and T = 300K Assuming the biogas kinematic viscosity equal to air

$$\gamma = 1.568 \times 10^{-5} \frac{m^2}{s}$$

From continuity equation

$$Q = AV \tag{3.20}$$

Eight hours usage time, discharge is $5.4\, m^3/hr$ section (5.1)

$$5.4 = 5.07 \times 10^{-4} \times V$$

$$V = 2.96\, m/s$$

$$R_e = \frac{0.0254 \times 2.96}{1.568 \times 10^{-5}} = 4794.89$$

$R_e \geq 2300$, Implies turbulent flow

$$f = \frac{0.3164}{4795^{0.25}} = 0.038$$

$$h_f = \frac{fLV^2}{2gd} = \frac{0.038 \times 25 \times 2.96^2}{2 \times 9.81 \times 0.0254} = 16.7m$$

3.8.1.2. Head loss Due to Sudden Changes in Area of Flow

1. Sudden Expansion: The head loss at a sudden expansion is given by:

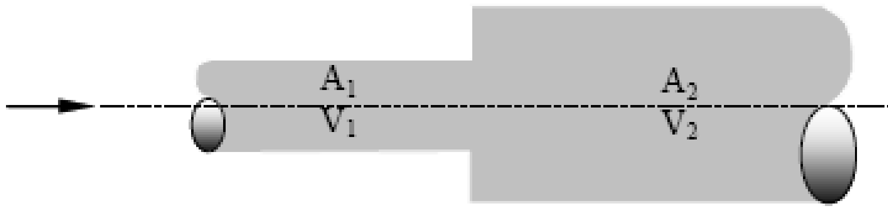

Fig.3.9. A sudden expansion

$$h_{mE} = \frac{V_1^{\ 2} - V_2^{\ 2}}{2g} \qquad 3.21$$

Where, h_{mE} = minor loss due to expansion

V_1 = Velocity at cross sectional area 1

V_2 = Velocity at cross sectional area 2

g = gravity

In this design there is no sudden expansion of pipe. Since the main gas pipe is divided in to the appliance gas pipe.

2. Sudden contraction - The head loss at a sudden contraction is given by

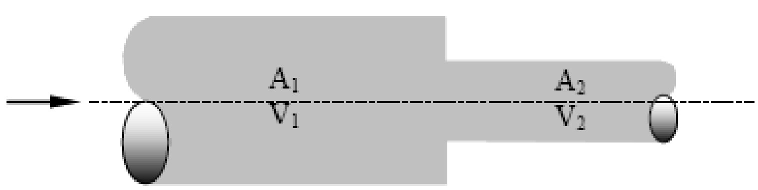

Fig.3.10. A sudden contraction

$$h_{mC} = \frac{K\, V_2^{\ 2}}{2g} \qquad 3.22$$

Where, h_{mC} = minor loss due to sudden expansions

K= loss coefficient

Table 3.5: Loss Coefficient for Sudden Contractions (Beek, W.J. and Muttzall, K.M.K. ,1975)

$\frac{A_2}{A_1}$	0	0.1	0.2	0.3	0.4	0.6	0.8	1.10
K	0.50	0.46	0.41	0.36	0.30	0.18	0.06	0

From continuity equation:

$$A_1V_1 = A_2V_2$$

$$\frac{0.0254^2 \times \pi \times 2.96}{4} = \frac{0.0127^2 \times \pi \times V_2}{4}$$

$$V_2 = 11.84\, m/s$$

$$h_{mC} = \frac{KV_2^{\,2}}{2g}$$

$$= \frac{0.385 \times 11.84^2}{2 \times 9.81}$$ By interpolating the value of K since area ratio is 0.25

=2.75m

3.8.1.3. Head loss due to Bends

The head loss due to a bend is given by expression

$$h_{mB} = \frac{K_B V^2}{2g} \qquad 3.23$$

Where, $h_{mB} =$ minor loss due to bending of pipe

K_B = a dimensionless coefficient which depends on the bend radius/pipe radius ratio and the angle of the bend.

K_B = 0.5 for elbow connection and considering the average number elbow 20.

$$h_{mB} = \frac{K_B V^2}{2g}$$

$$= \frac{0.5 \times 2.96^2}{2 \times 9.81} \times 20 = 4.46m$$

3.8.1.4. Head loss due to Valves

The head loss due to a valve is given by expression

$$h_{mV} = \frac{K_V V^2}{2g} \qquad 3.24$$

h_{mV} = Minor loss due to valve

K_V = Loss coefficient depends upon the type of valve and degrees of opening

Table 3.6: Typical valves of loss coefficients for gate and globe valves(Beek, W.J. and Muttzall, K.M.K. ,1975)

Valve type	$\mathbf{K_V}$
Globe valve, fully open	10.0
Gate valve, fully open	0.2
Gate valve, half open	5.6

For gate value, fully open K_V = 0.2 average number of valves = 50

$$h_{mV} = \frac{K_V V^2}{2g}$$

$$= \frac{0.2 \times 2.96^2}{2 \times 9.81} \times 50 = 4.46m$$

Total head loss

$$h_{fT} = h_f + h_{mE} + h_{mC} + h_{mB} + h_{mV}$$

$$= 16.7 + 0 + 2.75 + 4.46 + 4.46 = 28.37m$$

Total pressure loss in pipes

$$p_{fT} = \frac{\rho f L V^2}{2d} = \rho g h_{fT}$$

$$= 1.2 \times 9.81 \times 28.37 = 0.33\text{kPa}$$

CHAPTER FOUR

4. COMPRESSION OF BIOGAS

Compressing biogas reduces storage requirements, concentrates energy content, and increases pressure to the level needed to overcome resistance to gas flow. Sometimes the production pressure of a biogas source does not match the pressure requirements of the gas utilization equipment. Compression can eliminate the mismatch and assurance the efficient operation of the equipment. Moreover, large biogas systems rely on compression to reduce the size of the gas storage facility or to transport the biogas to a pipeline. The choice of either a blower or compressor depends on the amount of pressure increase needed (James L. Waish et al., 1988).

4.1. Parameters for Selection of Compressor

In order to determine what type of compressor system is needed to accomplish the job, a variety of detailed data is needed to be discerned. As a minimum, a precise understanding of the following data is required:

- Gas being handled
- Flow rate
- Suction and discharge pressure
- Site elevation (or local barometric pressure)
- Suction temperature
- Capacity

Capacity: To size a compressor the capacity must be stated as the volume of gas flow at the compressor's suction condition. This volume is normally referred to as inlet cubic meters per hour (Nm^3/hr).

4.2. Calculating Compression ratio

Compression ratio (R) is the ratio of discharge pressure to suction pressure:

$R = \frac{p_d}{p_s}$ (Remember p_d & p_s must be "absolute" values)

A single stage compressor has only a single R value. A two stage compressor has three R values.

R = Total compression ratio for the compressor

R_1 = Compression ratio for the first stage

R_2 = Compression ratio for the second stage

$$R = \frac{p_d}{p_s}\ , R_1 = \frac{p_i}{p_s}\ , R_2 = \frac{p_d}{p_i}$$

p_s = Suction pressure

p_d =Discharge pressure

p_i =Inter stage pressure- the pressure between the1st and 2nd stage of the compressor.

4.3. Choosing One stage or Two stage Compressor

The choice of the proper number of compression stages is largely based on the compression ratio. Here are some guidelines for choosing the proper number of stages:

Table 4.1: Compression ratio vs. Proper number of Stages (Source: NPC, 1993)

R value	**No of Stages**
1-3	Single stage
3-5	Single stage, occasionally two stage
5-7	Two stage, occasionally single stage
7-10	Two stage
10-15	Usually two stage, occasionally three stage
15 +	Three stage

In this work, the Compressor fulfills the following criteria might be selected form catalogue for compression purpose.

- The gas being handled is biogas
- Flow rate = $120.96\frac{m^3}{hr}$ for compressor selected from catalogue
- Suction pressure: The pressure at the compressor inlet expressed p_s = 1.106 bar
- Discharge pressure: The pressure at the compressor discharge expressed p_d=11 bar
- Suction temperature =33℃
- Power =11kW
- $R = \frac{p_d}{p_s}$

  P_s = 1.106bar + 1.013bar =2.12bar-a

  P_d = 11bar +1.013bar =12.013bar-a

  $R = \frac{12.013}{2.12} = 5.67$, the two stage compressor is best suited

4.4. Biogas compressor

Compressing biogas requires a gas compressor suitable for flammable gases. These differ from regular compressors in several respects (James L. Waish et al., 1988).

- The cylinder is located further from the crankcase
- Free of non-ferrous metal
- Condensate control
- Condensate washed out on suction side,
- Passageways are provided to vent leaks away from the crankcase and prevent explosions
- Inlet and exhaust ports are designed to let contaminants pass through instead of collect in the compressor.

4.5. Energy Density and Storage Volume

As biogas is compressed to higher pressures, its mass is pushed into smaller volume. This raises the energy density of the gas and reduces the required storage volume. Note that the energy densities are much higher for biogas that has the H_2S**,** CO_2 and water vapor removed (100% methane). The higher compression ratio, the costs associated with compressing biogas will increase. For adiabatic compression, with no heat transfer across the system boundary (Q = 0), the thermodynamic relation is given by (W.Z.Black & J.G.Hartley, 1995):

$$p_1 V_1^{\,k} = p_2 V_2^{\,k} \qquad 4.1$$

Where, k = Adiabatic ratio C_p / C_v = 1.3 for biogas

V_1 = Initial volume of biogas that the plant produce per day.

P_2 = Compressed raw biogas pressure (11bar) selected from catalogue

V_2 = Compressed volume

Substituting the values

$V_1 = 43.2 \dfrac{m^3}{day}$, p_1 = 110.64kpa, p_2 = 1100kpa, $V_2 = ?$ $k = \dfrac{c_p}{c_v} = 1.3$ for biogas

$$p_1 V_1^{\,k} = p_2 V_2^{\,k}$$

$$110.64 \times 43.2^{1.3} = 1100 V_2^{1.3}$$

$$V_2 = 7.38 \frac{m^3}{day}$$

Therefore, to ensure steady supply of compressed raw biogas to the households, it is first stored in a pressure vessel which has storage capacity of 7m^3 since other volume is stored in compressor.

4.6. Power Needed for Compression

The energy required for compression represents a major operating cost of a biogas system. Accordingly, estimating the energy requirement becomes an important component of the system design effort. Estimates are usually based on adiabatic compression process (compression without cooling) since such a calculation estimates the maximum energy required for compression in a frictionless compressor (James L.Waish et al., 1998).

Mathematically, the relationship between the system pressures, the compressor capacity, and the energy required for compression in a frictionless, adiabatic compressor can be stated as:

$$W = C_1 R T_1 \left[\left(\frac{p_2}{p_1} \right)^{C_2} - 1 \right] \qquad 4.2$$

Where, W = Shaft work required for compression (horsepower)

$$C_1 = \frac{k}{k-1}$$

$$C_2 = \frac{k-1}{k}$$

$k =$ Ratio of specific heats of the biogas $C_p / C_v = 1.3^*$

R = Gas constant for the biogas

$T_1 =$ Initial temperature (K)

$p_1 =$ Initial pressure (psig)

$p_2 =$ Final pressure (psig)

Values for 60% CH_2, 40%CO_2 biogas

The value of "W" represents the amount of energy required to compress biogas of a known composition adiabatically**.** However, compressors are never 100% efficient because of friction and heat transfer that occur during the compression process and therefore the actual energy required will be greater than computed using the preceding equation. It should be noted that manufacturers' literature will indicate different efficiencies for almost every compressor. Confusion can be avoided by asking the manufacturer of the compressor being analyzed for the actual energy consumption of the equipment.

4.7. Purification and bottling of biogas

There are different techniques through which carbon dioxide from biogas can be removed to enhance methane content in it. Some of widely used techniques are:

- Absorption in water (water scrubbing) ,
- Absorption by chemicals,
- Pressure swing adsorption,
- Membrane separation & cryogenic separation can be used under varying conditions.

Table 4.2: CO_2 & H_2S Removal Processes from Biogas

No	**Method**	**Advantage**	**Disadvantage**
1	Absorption in water	One of the easy and cheap methods for CO_2 removal.	Water pumping load is high.
2	Absorption by chemicals	The chemical absorbents are more efficient in low pressure and can remove CO_2 to low partial pressures in treated gas.	Regeneration of the solvent requires are relatively high energy input. Disposal of by-product formed due to chemical reactions is a problem.
3	Pressure swing adsorption	By proper choice of the adsorbent, this process can remove CO_2, H_2S, moisture and other impurities.	Adsorption is accomplished at high temperature and pressure. It is a costly process.
4	Membrane separation	Modular in nature and separate CO_2 and CH_4 effectively.	Suitable to Small capacity, cost is high. Also life of membranes is less.
5	Cryogenic separation	Allows recovery of pure component in the form of liquid, which can be transported conveniently	High cost involved makes it impractical for biogas applications.

Absorption of CO_2 in water is simple, cost effective, eco-friendly and practical method for CO_2 removal from biogas. It is a continuous process and simultaneously removes H_2S also. High purity biogas (> 95%) methane content can be obtained using this technology (Wellinger, A. & Lindeberg , A., 1999).

A CO_2 scrubbing and bottling technology has been designed and developed at Indian Institute of Technology Delhi and University of Balochistan, Queta, Pakistan based on physical absorption of CO_2 in water at elevated pressure (Syed Zafar Ilyas, 2006 &Virendra K. Vijay, 2006).

4.7.1. Water Scrubbing

Water scrubbing involves the physical absorption of CO_2 and H_2S in water at high pressures. It is simple method involving use of pressurized water as an absorbent. The raw biogas is compressed and fed into a packed bed absorption column from bottom and pressurized water is sprayed from top. The absorption process is, thus a counter-current direction through packing material (resching rings), so that maximum absorption of carbon dioxide in water takes place. Purified gas is stored in cylinder and the dissolved CO_2 and H_2Sin water are collected at bottom of tower (Nonhebel g.,1964 and Wellinger A. &Linderg A., 1999).

The design of water scrubbing system depends on the solubility of carbon dioxide in water as solubility is governed by pressure and temperature as given in Table 4.3. It is clear from the table that as the pressure increases solubility of CO_2 in water increases but decreases as temperature increases.

Table 4.3: Approximate solubility of CO_2 in water (Source: VirendraK.Vijay, 2006).

Pressure (atmospheric)	**Solubility, in kg of CO_2 per kg of water at different temperature**			
	0℃	10℃	20℃	30℃
1	0.40	0.25	0.15	0.10
20	3.15	2.15	1.30	0.90
50	7.70	6.95	6.00	4.80

4.8. Comparison Biogas with Natural gas

Natural gas has 75-98 % methane with small percentages of ethane, butane, propane while biogas has about 60 % methane and40 % carbon dioxide. It is possible to improve the quality of biogas by enriching its methane content up to the natural gas level. After methane enrichment and compression it can be used as vehicle fuel just like CNG (Dubey A. K., 2000).Over and above, it has lower emission than natural gas and diesel as shown in Table 4.4

Table 4.4: Comparison of gaseous emissions for heavy vehicles (source: Report on biogas, 2000)

g/kg	CO	HC	NO_x	CO_2	Particulates
Diesel	0.20	0.40	9.73	1053	0.100
Natural gas	0.40	0.60	1.10	524	0.022
Biogas	0.08	0.35	5.44	223	0.015

CHAPTER FIVE

5. BIOGAS SYSTEM DESIGN

Fig.5.1. Layout of Gerji V Condominium

Basic input data (Field survey: Addis Ababa Housing Development Project Office, 2011).

- Number of households in one block in average are 30
- Number of blocks in average are 10
- Number of people are 5 persons per household in average
- Number of people in one block in average are 150
- Size of septic tank is 90 – 180m^3
- Inlet pipe diameter is 110 – 150 mm
- Distance of septic tank from the nearest block is 2.5m the minimum distance

Daily substrate input can be taken as

S_d= 0.4kg / person-day

Total discharge for the ten blocks is determined

$TS_d = 10 \times 0.4 \times 150 = 600\, kg/day$

Therefore, the daily biomass input is 600kg.

Total solid content of night soil is, TS = 0.2

Volatile solid content of night soil is, VS = 0.15

The underground temperature is assumed to be 33℃ for Addis Ababa which is found in tropical zone. The amount of biogas generated each day is calculated on the basis of the specific gas yield of the substrate and the daily substrate input. The estimation can be based on (GTZ, 1989):

a) **Volatile Solids Content (VS)**

$$G_d = VS \times G_y \qquad 5.1$$

b) **Weight of Moist Mass**

$$G_d = W_{biomass} \times G_{y(moist)} \qquad 5.2$$

c) **Standard Gas yield values per Livestock Unit**

$$G_d = n_{LSU} \times G_{y(species)} \qquad 5.3$$

Where, G_d = Daily biogas generated

G_y =Specific biogas yield

n_{LSU} = Number of Livestock Unit

As a rule, it is advisable to calculate according to several different methods, since the available basic data are usually very imprecise, so that a higher degree of sizing certainty can be achieved by comparing and averaging the results.

5.1. Daily Gas Production

a) $G_d = VS \times G_y$

$$= 0.2 \times 600 \times 0.38$$

$$= 45.6\, m^3/day$$

b) $G_d = W_{biomass} \times G_{y(moist)}$

$$= 600 \times 0.07$$

$$= 42\, m^3/day$$

c) $G_d = n_{LSU} \times G_{y(species)}$

$$= 1500 \times 0.028$$

$$= 42\, m^3/day$$

Averaging the daily biogas yield:

$$G_d = \frac{45.6 + 42 + 42}{3}$$

$$= 43.2\, m^3/day$$

5.2. Sizing Digester

Digester volume is determined on the basis of the chosen retention time and daily substrate input quantity. The retention time, in turn, is determined by the digesting temperature. Practical experience shows that retention times is 60-80 days. For a night soil biogas digester, a longer retention time (70-80 days) is needed so that the pathogens present in human feces are destroyed (Lagrange, 1979). Extra-long retention times can increase the gas yield by as much as 40 %(GTZ, 1989).Since Addis Ababa found in hot tropical region and to ensure complete degradation of slurry, retention time of 80 days is assumed.

There is 600kg weight of moist biomass

Dry matter (D_m) of fresh discharge:

$$D_m = W_{biomass} \times TS$$
$$= 600 \times 0.2$$
$$= 120\, kg/day$$

To make favorable condition for fermentation the concentration of organic dry matter should be 8% i.e. 8kg Organic dry matter should be available in 100kg influent.

$$8 = 100$$
$$120 = x$$
$$x = \frac{120 \times 100}{8} = 1500\,\frac{kg}{day}$$

Water should be added to make the discharge 8% concentration of organic dry matter is:

$$m_{water} = 1500 - 600$$
$$= 900\, kg/day$$

Assuming the density of slurry approximately to 1000 kg/m^3 ,the volume of daily discharge of substrate is:

$$V_s = \frac{m_{slurry}}{\rho_{slurry}}$$
$$= \frac{1500}{1000} = 1.5\frac{m^3}{day}$$

Hence, volume of digester:

$$V_d = S_d \times RT$$
$$= 1.5 \times 80 \; = 120 m^3$$

Since the biogas will be stored in pressure vessel outside digester as mentioned in section 4.5, the volume required for digester can be as small as possible. Therefore, the digester volume is:

$$V_d = 120 - 43.2$$
$$= 77\, m^3$$

5.3. Inlet and Out let pipe

Size of inlet and outlet pipe is equal to the diameter of the tube that directly connected to the septic tank i.e. (110 – 150mm) by making some stepped angle to make turbulence to avoid scum formation in digester.

5.4. Expansion Chamber

Size of expansion chamber is equal to the volume of gasholder in fixed dome biogas plant, but biogas stored in pressure vessel out of digester. However, the design of expansion chamber is in order to avoid over flow of raw substrate (unfermented substrate) $4.2m^3$ expansion chambers is coupled to the digester.

5.5. Compost Tank

Compost tank is an integral part of the biogas plant; no plant is complete without it. Enough earth body must exist, at least one meter, between the compost tank and the outlet chamber to avoid cracking of the chamber walls. The volume of the compost tank must be at least equal to the plant volume (BSP, 1994). Therefore, the size of compost tank should be equal to the size of septic tank in this case.

5.6. Selecting the Type of Fixed Dome Plant

Part of digester below the ground level is subjected to heavy compressive load due to the earth pressure, which increases with depth. In this design due to hydrostatic pressure cylindrical digester was selected. Deenbandhu fixed dome plant with a little modification is best suited. Deenbandhu, the successor of the Janata plant in India, with improved design, is more crack proof and consumes less building material than the Janata plant with a hemispherical digester (FAO/CMS, 1996 and Mattocks, 1984).

Other reasons that support this choice are:

- Constructing the digester underground reduces the negative impacts resulted from atmospheric temperature changes,
- Raw substrate from the latrine (toilet) has odour, hence it should be beneath under earth.

- Availability of construction materials such as: cement, sand, small stones etc. with reasonable prices.
- It distributes forces uniformly on surface area
- Deenbandhu fixed dome plant application is well disseminated in Ethiopia.

The following section shows the design calculation and dimension relationship:

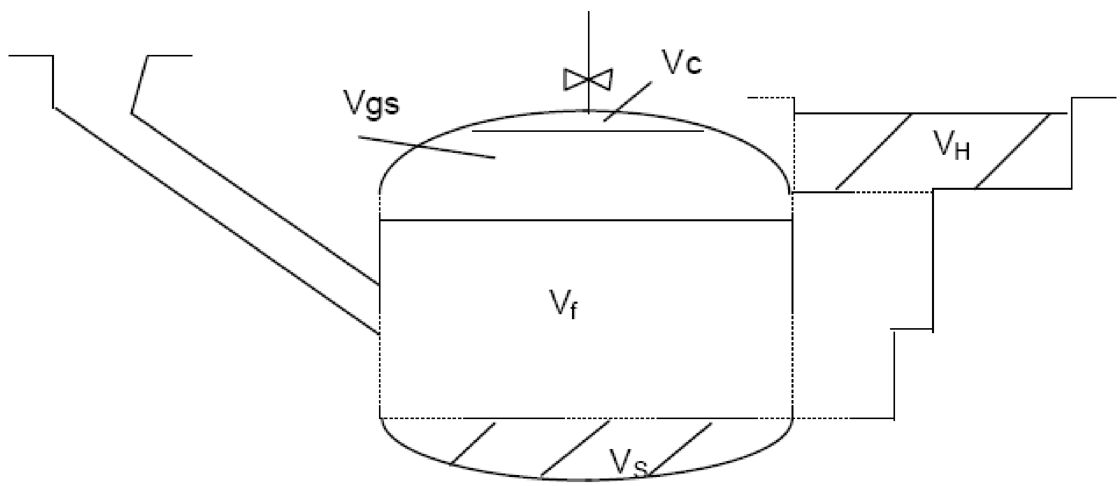

Fig.5.2. Cross-section of a Digester (Chengdu, 2006)

Where, V_c = Volume of gas collecting chamber

V_{gs} = Volume of gas storage chamber

V_f = Volume of fermentation chamber

V_H = Volume of hydraulic chamber

V_s = Volume of sludge layer

Total volume of digester:

$$V = V_c + V_{gs} + V_f + V_s$$

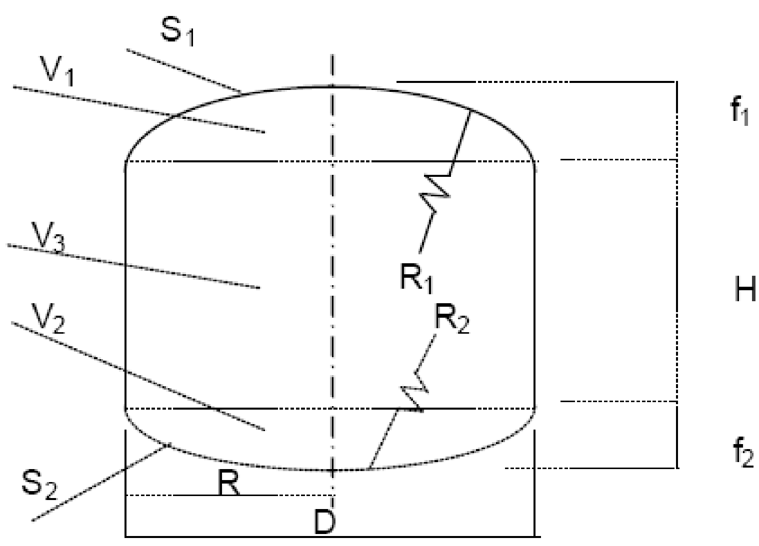

Fig.5.3. Geometrical dimensions of the cylindrical shaped biogas digester body (Chengdu, 2006)

Where, V_1 =Volume of gasholder

V_2 =Volume of sludge layer

V_3 =Volume of fermentation

S_1 =Surface area of top dome

S_2 =Surface area of bottom dome

D = Diameter of the cylinder

Table 5.1: Assumptions of Volume and Geometrical dimensions (Source: Chendu, 2006)

Volume	**Geometrical dimensions**
$V_c \leq 5\%$ V	D=1.3078 * $V^{1/3}$
$V_s \leq$ 15% V	V_1=0.0827* D^3
$V_{gs} + V_f$ = 80% V	V_2 = 0.05011 *D^3
$V_{gs} = V_H$	V_3 = 0.3142 *D^3
V_{gs} = 0.5 ($V_{gs} + V_f + V_s$) K	R_1= 0.725 *D
Where K = Gas production rate per m^3 digester volume per day. K= 0.4	R_2= 1.0625 *D
	f_1 = D/5
	f_2 = D/8
	S_1 = 0.911 D^2 & S_2 = 0.8345 D^2

Working volume of digester

$$W_V = V_{gs} + V_f \qquad 5.4$$

From geometrical assumptions:

$$V_{gs} + V_f = 0.8V$$

$$V_{gs} + V_f = 77m^3$$

$$V = \frac{77}{0.8} = 96m^3$$

$$D = 1.308 \times V^{1/3} = 1.308 \times 96^{1/3} = 6m$$

$$V_1 = 0.0827 \times D^3 = 0.0827 \times 5.99 = 18m^3$$

$$V_2 = 0.05011 \times D^3 = 0.05011 \times 5.99^3 = 11m^3$$

$$V_3 = 0.3142 \times D^3 = 0.3142 \times 5.99^3 = 68m^3$$

From V_3 we can calculate the value of 'H'

$$V_3 = \frac{\pi D^2 H}{4}$$

$$H = \frac{4 \times 68}{\pi \times 6^2} = 2.4m$$

$$f_1 = \frac{D}{5} = \frac{6}{5} = 1.2m$$

$$f_2 = \frac{D}{8} = \frac{6}{8} = 0.75m$$

$$R_1 = 0.725D = 0.725 \times 6 = 4.4m$$

$$R_2 = 1.0625D = 6.4m$$

$$V_c = 0.05V = 0.05 \times 96 = 4.8m^3$$

The detail drawing of each component is found in Appendix IV

CHAPTER SIX

6. FINANCIAL AND ECONOMIC ANALYSIS OF BIOGAS PLANT FOR CONDOMINIUM

6.1. Introduction

Biogas is a renewable energy which is eco-friendly and minimizes expenditure on the foreign exchanges on the import of fossil fuels.

The primary reason that biogas plant is not yet used for Condominium is due to lack of awareness and availability of resources such as firewood, Charcoal, Kerosene, Electricity and etc. even though they are expensive. The biogas plant demands a relatively high capital investment. The economics of various different alternatives available for the households need to be analyzed, so that the best one can be chosen.

Any decision for or against the construction and operation of a biogas plant depends on various technical criteria as well as on a number of economic and utility factors. Users want to know what the plant will offer in the way of profits (cost benefit analysis) and advantages like reduced work load, more reliable energy supplies or improved health.

There are many ways to approach economic analysis, depending on the point of view from which plant is considered. The simplest approach is, look at the cash flow position of the households.

6.2. Determining Biogas demand

There are different approaches to estimate gas demand for cooking. The following alternative methods of calculation are useful (GTZ, 1989).

a) **Determining biogas demand on the basis of present consumption**: This involves measuring the present rate of energy consumption in the form of Fire Wood, Charcoal, Kerosene, Electricity etc.

b) **Calculating biogas demand by means of comparable use data**: such data may consist of

- Empirical values from neighboring systems, for example biogas consumption per person & day.
- Reference data taken from literature, although this approach involves considerable uncertainty, since cooking energy consumption depends on local culture eating habits; therefore differ substantially from case to case.

c) **Estimating biogas demand by way of appliance consumption data and assumed periods of use**: - This approach can only work to the extent that the appliances to be used are known in advance.

6.2.1. Determining biogas demand on the basis of present energy consumption

Basic data:

Five person family size

Site specification: Gerji, Addis Ababa

Table 6.1: Present energy consumption (Source: field survey, 2011)

Source of Energy	**Monthly fuel consumption per family**	
	Unit	price(averagely) in Birr
Fire wood	(30-50)kg	50
Charcoal	(40-80)kg	120
Kerosene	(8-10)liter	135
Electricity	~	80
Total = Birr 385		

6.3. Equivalence of biogas demand

The equivalent demand of biogas can be determined using the following factors for the fuel to be substitute

1 kg of Fire Wood ≅ 0.2m^3biogas

1 kg of Charcoal ≅ 0.5m^3 biogas

0.6liter of kerosene ≅ 1m^3 biogas (Source: GTZ, 1989)

Table 6.2: Some biogas equivalents (Kristoferson & Bokalders, 1991)

Application	**1 m^3 biogas equivalent**
Lighting	Equal to 60 – 100 watt bulb for 6 hours
Cooking	Can cook 3 meals for a family of 5 – 6
Fuel	0.7kg of petrol
Electricity	Can generate 1.25kilowatt hours of electricity

Hence, the biogas to be produced $43.2m^3$ per day can serve the cooking energy requirement for 43 households per day. This indicates that the substrate collected from the seven households can serve the cooking energy requirements for a single household.

6.4. Construction Materials and Costs

After asking many experienced people those who are working in Rural Energy Development and Promotion Center of Ethiopia, the costs for constructing the proposed design (i.e.96m^3) biogas plant may be estimated as follows.

Table 6.3: Requirements and Costs for constructing the proposed design based on current basis.

No	**Requirements**	**Qty**	**Price /cost in Birr**	
			Unit price	Total price
1	Digging operations	$120m^3$	28	3,360
2	Cement bags/pieces	150	450	67,500
3	Gravel	$45m^3$	400	18,000
4	Rigid plastic pipes	20m	75	1,500
5	Gas pipe	250m length & 1/2" diameter	50	12,500
6	Main gas pipe (galvanized steel)	1" diameter & 20m	75	1,500
7	Gas valve and connectors.	100pcs	80	8,000
8	Mold/cast	$15m^3$	3200	48,000
9	Paint	10 gal	420	4,200
10	Brick	12500	2.50	31,250
11	Mason (skilled labor)	3person 60days	150	27,000
12	Installation work	2person 14 days	150	4,200
13	Biogas stove	43	500	21,500
14	Biogas burner	43	100	4300
15	Biogas Compressor	1	10,000	10,000
	Total (Birr)			262,810
	Contingency 5%			13,141
	Total money in Birr			275,951

a) Construction Materials

The construction materials to be used in the plant construction such as cement, sand water, etc., should have good quality. In order to select these materials of best quality, their brief description and the following specification has been given (BSP, 1994)

i. **Cement:** The cement to be used in the plant construction has to be of high quality with standards sand (of ratio 1:3). It must be fresh without lump and stored in dry place. Bags of cement should never be stacked on the floor or against the walls but wooden planks should be placed on the floor to protect cement from dampness.

ii. **Sand*:* -** Sand for construction purpose must be clean. Dirty sand has a very negative effect on the strength of the structure if the sand contains 3% or move impurity, It must be washed. The quality of impurity especially the mud in the sand can be determined by a simple last using bottle. This is called the "*bottle test*" For this test; small quantity of sand is put in the bottle. After this water is poured in and allow the sand to settle down. The particle of sand are heavier than that of mud so it settles down quickly after 20-25 minutes; the layer of mud verses sand inside the bottle is measured. Course and granular can be used for concreting work but fine sand will be better for plastering work.

iii. **Gravel:** -Gravel should not big or very small (i.e. it is medium). It should not be bigger than 25% of the thickness of concrete product when it is used in furthermore, the gravel must be clean. If it is dirty, it should be washed with clean water

iv. **Water: -**It is mainly used for preparing the mortar for masonry work, concreting work and plastering. It is also used to soak bricks (stones before using them). Beside these, water is also used for washing sand and aggregates. It is advised not to use water from ponds and irrigation channels for these purposes, as it is usually too dirty. Dirty water has an adverse effect the strength of the structure; hence water to be used must clean.

v. **Bricks: -** Bricks must be of the best quality locally available. When hitting two bricks, the sound must be clear; they must be well backed and regular in shape. Before use, bricks must be soaked for few minutes in clean water.

vi. **Stones: -**If stones are to be used for masonry work, they have to be clean, strong and of good quality. Stones should be washed if they are dirty.

6.5. Financial Analysis

Projects are assumed to be economically feasible if the Net Present Value (NPV) is positive, the internal rate of return (IRR) is$\geq$ 20% and a pay back period of $\leq$ 7years(Government of Georgia, 2003*)*.The major parameters that need to be considered for the financial feasibility, of biogas plants are:

a) Project life

A fixed dome type plant could last for more than 40 years depending on the quality of construction and the materials used. However, the economic life of a plant is taken as 20 years mainly because any cost or benefit accrued after 20 years will have insignificant value when discounted to the present worth.

b) Benefits and Cost

All benefits of a biogas plant cannot be readily priced or even compared with the price of similar products or services in the market. For example, it is difficult to put a money value for the benefit of decrease environmental population. This indicates that even if the financial analysis shows zero net benefit of constructing a biogas plant, it should be interpreted as having positive net benefits owing to the unpriced factors.

The biogas plants produce both biogas and organic fertilizer. The biogas could be used mainly instead of firewood, charcoal, kerosene and etc. while organic fertilizer used to improve crops yield, and so could be used instead of manufactured fertilizers. Therefore; the annual direct financial benefits for biogas plants could be estimated as follows:

$$B_a = B_{ab} + B_{af} - C_a \qquad 6.1$$

Where, $B_a =$ Annual benefit

$B_{ab} =$ Annual benefit from biogas

$B_{af} =$ Annual benefit from organic fertilizer

$C_a =$ Annual cost

6.5.1. Benefit from Biogas

The proposed biogas system designed to produce biogas quantity could cover the monthly consumption of households from charcoal, kerosene, firewood and electricity. So the annual sum saving expected from using biogas is Birr 4,620 (Table 6.1) per household.

6.5.2. Organic Fertilizer

Amount of organic matter gets out from digester into compost tank is:

$$O_m = L_a - C_b \tag{6.2}$$

Where, $O_m =$ Organic matter gets out from digester

$L_a =$ Loaded amount of substrate

$C_b =$ Organic matter converted in to biogas

$$O_m = L_a - C_b$$

$$= 0.2 \times 600 \times 30 \times 12 - 0.15 \times 600 \times 30 \times 12$$

$$= 10{,}800 \text{ kg per year}$$

Manufactured fertilizer of the lowest price available in the local markets is Urea fertilizer which sales to farmer by about $888\text{Birr}/100\text{kg}$ .By selling the organic matter gets out of the digester by 5% Urea price, and then the price of 900kg:

$$O_{fp} = 0.05 \times 888 \times 9 \times 12$$

$$= \text{Birr } 4{,}795 \text{ per year}$$

6.5.3. Annual Cost

Annual cost for operating a biogas plant may come from replacing some used equipment (mainly gas valve, gas transporting pipe and etc.), i.e. is maintenance cost & operational cost. The main operational cost is the cost of compressor power for the system. The power required for compressor is 11kW for selected compressor (Appendix III). If this compressor is operates for 24 hour, it will come 264kWh.This amount of energy has provided from Ethiopia Electric Light and Power Authority (EEPCO) or the plant itself. We know that 1m^3 biogas can generate 1.25kilowatt hours of electricity (Table 6.2). To use the power obtained from the plant, it needs a lot of preliminary things which lead us to additional cost due to raw biogas, is not ready use.

Therefore, it is better to use the power of EEPCO.Currently, EEPCO charges for power as follows:

a) For less than 50 kWh it charges 0.273 $Birr/kWh$

b) 50 to 100 kWh it charges 0.354 $Birr/kWh$

c) For greater than 100 kWh it charges 0.4993 $Birr/kWh$

Accordingly:

$$C_{op} = 264 \times 30 \times 12 \times 0.4993$$

$$= \text{Birr } 47{,}453 \text{ per year}$$

As the result, the annual income:

$$B_a = B_{ab} + B_{af} - C_a$$

Where, B_{ab} = Birr 184,800 for 40 households

$$C_a = 47{,}453 + 20{,}967 = \text{Birr } 68{,}420 \text{ (Table 6.4)}$$

$$B_a = 184{,}800 + 4{,}795 - 68{,}420$$

$$B_a = \text{Birr } 121{,}175$$

6.5.4. Cash Flow Analysis

Basic procedure of a cash flow analysis is to enter all the year-by-year income to be received over the estimated life of the project as inflows. Similarly, yearly expenditures are entered in the analysis as outflow. Finally, for each year, expenditure is deducted from the income. Generally, in the initial year(s) of the project, the net cash flow or net benefit tends to be negative, because of the expenditures incurred to meet the establishment costs (Gittinger, 1982).

6.5.5. Time Value of Money and Discount Ratio

Real value of money changes over time. The reasons for such changes are:

- Money of today can be invested to earn a return in the future; and
- People have time preference, i.e. they prefer now to the future.

6.5.6. Net Present Value

As the costs and benefits of a project are spread over the useful years of project life, they need to be expressed in terms of one common denominator to make the comparison possible. Once the annual cash flow of a project is derived, it needs to be discounted so that all values could be compared to the value of a single year. This discounted net cash flow provides a widely used criterion for measuring the profitability of a project. For this purpose, all future values are discounted to make them equivalent to the present value and is expressed as Net Present Value (NPV).

The NPV technique measures the worthiness of a project by converting the annual cash flow to a single present value. A positive NPV indicates that the benefits are higher than the costs that accrue over the project life. The process of relating future amount to the present value is known as discounting and is expressed by the following equation:

$$P = \frac{F}{(1+r)^n} \qquad 6.3$$

Where, P = present sum of money

F = Future sum of money

r = Rate of interest

n = Number of years

The commonly used discount rate is the rate of interest that a bank charges on loans and the opportunity cost of capital in situations where private capital is being committed. The NPV is calculated in Table 6.2.

Series present worth is given by

$$P = A\left[\frac{\left((1+r)^n - 1\right)}{r(r+1)^n}\right] \qquad 6.4$$

Where, A = annual worth (value)

6.5.7. Benefit Cost Ratio

Benefit-cost ratio (BCR) is another tool for assessing the profitability of a project. If the ratio is greater than unity (i.e. B/C > 1.0) the project is profitably.

6.5.8. Simple Payback Period

Simple payback period is time period required to recover the original investigated for the construction of a plant. It represents the number of years in which the investment is expected to pay for itself. It is given by:

$$SPP = \frac{I_c}{A_s} \qquad 6.5$$

Where, SPP = Simple payback period

I_c = Initial cost

A_s = Annual saving (benefits)

6.6. Economic Analysis

Some of benefits and costs of biogas plants are not limited to the users. If a large number of biogas plants are installed in a community, the non-users will also be benefited avoidance of environmental pollution and conservation of forest in area. Such benefits and costs that increase even outside of the user households is a subject matter of economic analysis and not of financial analysis. A single biogas plant does not significantly affect the economy as a whole. Economic analysis measures the effect of biogas programme on the fundamental objectives of the whole economy.

Table 6.4: Financial analysis of a 96 m^3 biogas plant (in Birr) for 40 households

Year	**1**	**2**	**3**	**4**	**5 to 15**
Benefits(in Birr) Indirect Priced Saving Charcoal	57,600	57,600	57,600	57,600	57,600
Saving Firewood	24,000	24,000	24,000	24,000	24,000
Saving kerosene	64,800	64,800	64,800	64,800	64,800
Saving Electricity	38,400	38,400	38,400	38,400	38,400
Selling organic fertilizer	4,795	4,795	4,795	4,795	4,795
Total	189,595	189,595	189,595	189,595	189,595
Costs(in Birr)					
Investment	275,951				
Maintenance	20,967	20,967	20,967	20,967	20,967
Operation cost	47,453	47,453	47,453	47,453	47,453
Total	344,371	68,420	68,420	68,420	68,420
Net Benefit in Birr	-154,776	121,175	121,175	121,175	121,175

The net present value, benefit cost ratio and simple pay back period are given as follows. The present costs during the lifetime of the project are determined as

$$P_c = I_c + A\left(\frac{P}{A}, r, n\right) \qquad 6.7$$

I_c = Initial cost

A = Annual cost

r = Discount rate

$$P_c = 275{,}951 + 68{,}420\left[\frac{\left((1+0.12)^{15} - 1\right)}{0.12(1+0.12)^{15}}\right] \text{at r=12\%}$$

= Birr 741,943

The present value of benefits or saving during the life time of the project

$$P_b = A\left[\frac{(1+r)^n - 1}{r(r+1)^n}\right]$$

A = Annual benefits

P_b = Total benefits during the lifetime of the project

$$P_b = 189{,}595\left[\frac{(1+0.12)^{15} - 1}{0.12(1+0.12)^{15}}\right]$$

= Birr 1,279,766

The Net Present Value is determined as

$$NPV = P_b - P_c$$

$$= 1{,}279{,}766 - 741{,}943$$

= Birr 537,822

The annual saving is

$$A_s = A_b - A_c$$

$$= 189{,}595 - 68{,}420$$

= Birr 121,175

The simple payback period is

$$SPP = \frac{I_c}{A_s} = \frac{275{,}951}{121{,}175}$$

$= 2.27\text{years}$ .This means the households will get back the capital of constructing biogas plant with in a time of less than three years.

The benefit cost ratio

$$BCR = \frac{P_b}{P_c}$$

$$= \frac{1{,}279{,}766}{741{,}943} = 1.7 \geq 1$$

6.7. Comparing Kerosene vs. Biogas

In order to compare Kerosene and Biogas the following data are essential.

- Calorific value of kerosene
- Calorific value of biogas
- Efficiency of kerosene stove
- Efficiency of biogas stove

Efficiency of a stove could be categorized as combustion efficiency and overall efficiency. Ability of the stove to change the energy from fuel to heat energy is related with combustion efficiency. The ability of the stove to change the energy from fuel into the energy gained by the specimen such as water, rice, milk etc. is termed as overall efficiency of the stove. Generally efficiency of stove is indicated by overall efficiency.

Overall efficiency of stove depends upon different conditions such as temperature, pressure, wind speed, specific heat capacity of the vessel, bottom and overall shape of vessel, weight of vessel, size of vessel and amount of specimen. Thus different tests for efficiency could yield different results of the same stove.

Table 6.5: Efficiency of different types of stoves (Source: Kirk R. et al., 1998, Nijaguna, 2002 and TERI)

Types of stove	Combustion efficiency (%)	Overall efficiency (%)
Biogas stove	99.4	55
Kerosene stove	97.7	43
Wood stove	90.1	22.8

Table 6.6: Density and net calorific value (Heat of combustion) of some fuels (Source: RWEDP, 1997 & Nijaguna, 2000)

Fuel	Density(kg/m^3)	Calorific value (MJ/kg)
LPG	560	45.3
Gasoline(petrol)	720	44.0
Kerosene	750	43.1
Biogas	1.2	22.1MJ/m^3

The potential energy content of the night soil feed into the digester on an annual basis is calculated as follows:

$$UE_1 = S_d \times VS \times n_d \times EF \times CV \times \eta \qquad 6.7$$

Where, UE_1 = Useful energy measured through quantity of night soil feed into the digester (MJ/year)

S_d = Night soil feed into the digester (kg)

VS = Volatile Solids produced/kg of night soil

n_d = Number of days night soil feed into the digester

EF = CH_4 production capacity/VS

CV_{CH_4} = Calorific value of methane

η = Efficiency of the stove

Table.6.7: Data used to derive the energy produced by the quantity of night soil feed.

Data	**Value**
Daily Night Soil(S_d)	600kg
Total Solid content (TS)	20%
Volatile Solid content	15%
Calorific value of Methane CH_4	35MJ/m^3
Efficiency of Stove	55 %
Biogas production capacity / TS kg	0.38m^3/kg
CH_4 production capacity /TS kg	0.25m^3/kg

Based on the above data the useful energy:

$$UE_1 = S_d \times VS \times n_d \times EF \times CV_{CH_4} \times \eta$$

$$= 600 \times 0.2 \times 365 \times 0.25 \times 35 \times 0.55$$

$$= 210{,}788\, MJ/yr$$

The potential energy content of biogas generate on an annual basis is calculated as follows:

$$UE_2 = B_p \times CV \times n_d \times \eta_{bs} \qquad 6.8$$

Where UE_2 = Useful energy measured (MJ/year)

B_P = Biogas produced (m^3/day)

n_d = Number of days (365)

CV = Net Calorific Value of biogas (MJ/m^3)

η_{bs} = Efficiency of the biogas stove (%)

Energy content of biogas generate on an annual basis:

$$UE_2 = B_P \times CV \times n_d \times \eta_{bs}$$

$$= 43.2 \times 365 \times 22.1 \times 0.55 = 191{,}660\, MJ/a$$

Energy available in kerosene

$$UE_t = L \times CV_k \times \eta_k \quad 6.9$$

Where, UE_t = useful energy delivered to the cooking pot (MJ/yr)

L = liters of kerosene used (liter/yr)

CV_k = calorific value of kerosene

η_k = Efficiency of the kerosene stove

Table 6.8: Data useful for calculation of energy delivered to the cooking pot

Data	**Units**	**Value**
Family kerosene consumption/annual	l/a	120
Density of kerosene	$\frac{kg}{l}$	0.75
Net calorific value of kerosene	$\frac{MJ}{kg}$	43.1
Efficiency of kerosene stove	%	43

The energy available in kerosene:

$$UE_t = L \times CV_k \times \eta_k$$

$$= 120 \times 0.75 \times 43.1 \times 0.43 = 1{,}668\,\mathrm{MJ/a}$$

As we can see the energy available from biogas units is approximately 191,660MJ/yr. This is able to completely replace the energy obtained from kerosene for around 115 households. When biogas substitutes kerosene more benefits will be obtained due to prevailing cost of kerosene.

CHAPTER SEVEN

7. CONCLUSION AND RECOMMENDATION

7.1. Conclusion

The research was conducted on biogas system design and its feasibility for Condominium. In this study it was observed that the proper working of biogas digester can be achieved if the operating & process parameters are kept at optimum condition for the designed 96m^3 biogas digester. It is necessary to feed with $1.5\,m^3/day$ for 80 days of retention time to avoid pathogenic effect on the environment.

At optimum condition $43.2\,m^3/day$ of biogas is obtained from the substrate collected from 10 blocks of Condominium which possesses ground plus four. Based on present energy consumption, $43.2\,m^3/day$ biogas fulfills the energy requirement for 43 households. This indicates the slurry from seven households serve the energy requirement of one household. But the feasibility study has taken place for 40 households; this is to ensure the continuous gas supply for the households. The reason for this was, biogas production is affected by different factors and there is pressure drop through gas pipe.

Compressing biogas reduces storage requirements, concentrates energy content and increases pressure to the level needed to overcome resistance to gas flow. Accordingly by applying biogas compressor for the system, the 43.2m^3 volume biogas is stored in $7m^3$ of pressure vessel. Also compressor increases pressure from 1.1bar to 11bar to overcome the problem of mismatch of pressure requirements of gas utilization equipment.

Financial study has shown that net present value of the plant is Birr 537,822 which is positive if the households use for all cooking energy demand and benefit cost ratio is 1.7 which is greater than one and the simple payback period is 2 years and four months.

7.2. Recommendation

The following recommendations are made to make the implementation of the project. To be sure about the loading substrate content, the actual flow of substrate should be measured and checked. If the composition of the dry organic matter in the influent is not between 7 to 10 % the following measure has to be taken.

a) Water from shower and bath room completely divert from the drainage of toilet
b) To increase the biogas production pretreated kitchen waste should be added to the digester
c) Night soil and pretreated kitchen waste should be fed with the feed rate $1.5\,m^3/day$ having 8% total solid organic matter
d) The necessity of a pump has to be checked

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APPENDIX

Appendix-I Questionnaires form for Addis Ababa Housing Developmental Project Office, and Households of Condominium.

Informed consent / Permission

Greeting! My name is ___________. I am here on behalf of the Energy Center department from Addis Ababa University to know the design type of Condominium to design biogas plant for Condominium and study its feasibility. I would like to ask some questions related to the design of Condominium.

The information you provide will be confidential the information will be used to prepare general reports, but will not include any specific names. There will be no way to identify that you are the one who gave this information.

You are kindly requested to provide genuine response to the questions accordingly for the success of the research. If you have any question about the survey, you can ask me.Please put the symbol √ or write in the space provided according to your choose. Thank you for your cooperation!

a) **Form for Addis Ababa Housing Development Project Office**

1. Are there different types Condominium design?

   Yes ☐ No ☐

2. If your answer is yes what is/are its/their basic difference?

   1. Size wise ☐ 3. Size and shape both ☐
   2. Shape ☐ ____________ 4. Other (specify)

3. Averagely how many floors are present in Condominium?

   ____

4. Averagely how many apartments/a set of rooms for living in, on one floor of a Condominium?

   ____

5. Averagely what is their resident holding capacity of each apartment/room?

   ____

6. Averagely what is the total holding capacity of one condominium?

   ____

7. What is the size of septic tank?

   ____

8. Is there direct connection of water tube for each toilet room?

   ____

9. What is the diameter of the tube that directly connected to the septic tank?

   ____

10. What kinds of location /map are selected for construction of condominium?

    ____

11. What kinds of soil type are selected for construction of Condominium?

____

12. Would you give me the design structure of Condominium?

____

13. Is there ample (enough) water in your Condominium?

____

b) Questionnaire for resident of Condominium

1. How much fuel is required for cooking per month?
   a) Fuel Wood …………..kg
   b) Kerosene …. ………..Liter
   c) LPG …………………Cylinder
   d) Electricity ……….…..unit(kW)
   e) Dried dung …………..…...kg
   f) Agricultural wastes …….kg
   g) Charcoal ………………..kg
   h) Other (specify)______________________
2. Do you buy fuel wood, dried dung or agricultural wastes or collect it from forest /source? If you buy estimate the costs in birr per month?
   a) Buy fuel wood ………….in Birr
   b) Agriculture wastes ……..in Birr
   c) Charcoal………………..in Birr
   d) Other ……………….......in Birr
3. What is the best source of energy for you as a tool for cooking?
   a) Fuel Wood ……...….kg
   b) Kerosene …….…… Liter
   c) LPG ………………..….Cylinder
   d) Electricity ………….unit(kW)
   e) Dried dung ………....kg

f) Agricultural waste …………..kg

g) Charcoal…………..…………kg

4. How many stoves do you have installed?

☐ 0/1/2/3….stoves

5. How long the stove is burnt in a day?

a) ___________am to _____________am (….hrs in the morning)

b) ___________ pm to _____________pm(…hrs in the afternoon)

c) ___________am to ______________am(…hrs in the evening

6. How much average time required transporting your energy source such as Kerosene or others from market to the house?

a) Less than o.5 hr

b) 0.5 to 1hr

c) 1 to 2 hrs

d) 2-4hrs

7. How much you cost for transportation when you buy your energy such as kerosene, charcoal, Fuel wood and others

____

8. Do you have the concept of biogas technology?

____

9. Will you like to adapt (become accustomed) technology of biogas?

____

10. If you use before for what purpose you want to use biogas?

a) Cooking

b) Lighting

c) Cooking and lighting both

d) Heating and cooling

e) Other (specify)____

11. What problem you face when you use kerosene, electricity charcoal or other as energy source of cooking?

    ____

Appendix-II Questionnaires for Rural Energy Development Promotion Center

1. Which type of biogas plant is famous/ on practice in Ethiopia?
    a) Fixed dome biogas plants
    b) Floating dome biogas plants
2. What are the main criteria for choosing the type biogas plant in Ethiopia?

    ____

3. For night soil substrate which type of biogas plant is favorable /suitable?

    ____

4. Which type of fixed dome biogas plant familiar in Ethiopia?
    a) Cylindrical fixed dome plants
    b) Spherical fixed dome plant
5. Is it economical feasibly the plants which are constricted?

    ____

6. What is the reason behind for biogas plants not well spread in Ethiopia?

    ____

7. What are future strategies for biogas plantation in Ethiopia?

    ____

8. How much will it cost to construct $100m^3$ digester volume fixed biogas plant?

    ____

9. Averagely what is the diameter of gas pipe?

    ____

10. Is there mostly used geometrical dimension relationship of biogas plant parts in Ethiopia?

    ____

Appendix - III Compressor Specification

BV8900										
Model	**Code**	**Pump**	**Tank Lt**	**Air displace l/min**	**Power**		**Max press**		**Size mm**	**Weight kg**
					HP	**kW**	**bar**	**Psi**		
BV800/1000 FT15	7PV9X5*	BV8900	1000	2016	15	11	11	160	2430x930x1770	584
BV800/1000 FT20	7PVB9Y5*	BV8900	1000	2400	20	15	11	160	2430x930x1770	584
BV800/1000 FT25	7PVB9W5*	BV8900	1000	2770	25	18.5	11	160	2430x930x1770	584

Technical data - 60Hz, GA30-90C (source: http://www.atlascopco.com)

Compressor type 60Hz	**Max .Compressor working press.**		**Compressor capacity m^3 /hr**	**Motor power**		**Dimension Mm**			**Weight kg**
	Bar(g)	Psi(g)		kW	Hp				
GA30-100	7.4	107	335	30	40	1713	903	1670	830
GA30-125	9.1	132	306	30	40	1713	903	1670	830
GA30-150	10.8	157	259	30	40	1713	903	1670	830
GA30-175	12.5	181	238	30	40	1713	903	1670	830
GA37-100	7.4	107	421	37	50	1713	903	1670	970
GA37-125	9.1	132	374	37	50	1713	903	1670	970
GA37-150	10.8	157	335	37	50	1713	903	1670	970
GA37-175	12.5	181	299	37	50	1713	903	1670	970
GA45-100	7.4	107	504	45	60	1713	903	1670	970
GA45-125	9.1	132	454	45	60	1713	903	1670	970
GA45-150	10.8	157	410	45	60	1713	903	1670	970
GA45-175	12.5	181	364	45	60	1713	903	1670	1035
GA55C-100	7.4	107	569	55	75	1713	903	1670	1035
GA55C-125	9.1	132	518	55	75	1713	903	1670	1035
GA55C-150	10.8	157	475	55	75	1713	903	1670	1035
GA55C-175	12.5	181	450	55	75	1713	903	1670	1400
GA55-100	7.4	107	630	55	75	2055	1028	1949	1400
GA55-125	9.1	132	562	55	75	2055	1028	1949	1400
GA75-100	7.4	107	864	75	100	2055	1028	1949	1500
GA75-125	9.1	132	763	75	100	2055	1028	1949	1500
GA75-150	10.8	157	695	75	100	2055	1028	1949	1500
GA75-175	12.5	181	630	75	100	2055	1028	1949	1600
GA90C-100	7.4	107	947	90	125	2055	1028	1949	1600
GA90C-125	9.1	132	871	90	125	2055	1028	1949	1600
GA90C-150	10.8	157	799	90	125	2055	1028	1949	1600
GA90C-175	12.5	181	731	90	125	2055	1028	1949	1600

Appendix - IV Discharge per day, TS value of fresh discharge and water to be added to make favorable TS condition (Source: At Information, website*)*

Kinds	Body weight (kg)	Discharge per day (kg)	TS value of fresh discharge % by wt	Water to be added with fresh discharge to make the TS value 8%(kg)
Human	50	0.5	20	0.75
Cow	200	10	16	10
Chicken	1.5	0.1	20	0.15
Pig	50	5	20	7.5

Appendix – V Detail Drawing and Site Layout of Condominium