Production of Biogas From Food Waste

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DEDICATION

We dedicate this thesis to our beloved parents who worked hard and made efforts to make our academic career a successful one and to all of our class fellows for their support. Thank you very much.

Firstly all praise is upon Allah, the Almighty on whom ultimately we depend for sustenance and guidance, for giving us strength and his blessings in the completion of this thesis. Secondly, we would like to express our sincere gratitude to our supervisor professor ***Prof. Dr. Muhammad Anwar Baig***, who supported us throughout our process. We attribute the level of our research to his encouragement and effort and without him this thesis, too, would not have been completed or written. One simply could not wish for a better or friendlier supervisor.

Besides our supervisor we would like to thank ***Mr.Majidul Hassan***, for his guidance and assistance throughout the research.

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In current scenario, due to depleting natural gas reserves and lack of infrastructure, it seems impossible for the Government to provide natural gas facility to the residents of rural areas. Biogas Technology, in this situation, can act as a useful tool to facilitate the residents of these rural areas.

This research was conducted to observe production of biogas through vegetable waste. Two batches were run at parallel, one for thermophilic condition and the other for mesophilic condition. During the research a careful relation between temperature, pH and biogas production was observed

For this purpose, food waste was collected from Sabzi Mandi of Islamabad located in I-11. After segregation of vegetables they were shredded and left for hydrolysis for a week before adding to the digester. In the digester feed was homogeneously mixed and conditions were maintained. The production of gas started in the second week. Gradually increased; reaching a peak; sustained, and then declined. Certain parameters like pH, temperature, moisture content, and total volatile solids were monitored. Both the batches worked successfully and gave optimum gas production. A serious problem that was faced during the research was, scum formation that resisted the release of biogas from digester through the gas nozzle.

1 INTRODUCTION

1.1 Background

Roughly 1.3 billion tons of food, about one third of the global food production, are lost or wasted annually. Loss and wastage occurs on all steps in the food supply chain. In low-income countries, most loss occurs during production, while in developed countries much food is wasted at the consumption stage. (Jenny Gustavsson 2011)

Generating food waste has significant economic as well as environmental consequences. Not only does this wasted valuable resource have huge economic impacts, it also has huge and immediate environmental impacts. When food is disposed in a landfill it quickly rots and becomes a significant source of methane a potent greenhouse gas with 21 times the global warming potential of carbon dioxide. Landfills are a major source of human-related methane in the United States, accounting for more than 20 percent of all methane emissions. (U.S. Environmental protection agency)

One effective way to avoid these problems is to produce biogas from it and use it as a renewable source of producing energy. Individual biogas systems are already benefitting several million households in Nepal, India, China and elsewhere. Larger systems are also used, for instance to process farm waste in Germany, and at sewage treatment works in the UK.

1.2 Solid Waste Management in Pakistan

Pakistan's population has increased up to 180 million; lack of adequate infrastructure is creating environmental hazards. In Pakistan, sources of waste include households, commercial areas, institutions, construction and demolition sites, industrial areas and agricultural disposals. Factors that affect waste generation in the country are size and type of the community and level of communities' income.

Composition of solid waste generally comprises of plastic and rubber, metal, paper and cardboard, textile waste, glass, food waste, animal waste, leaves, grass, straws, fodder, bones, wood and stones.

According to various studies conducted on waste management in the country, about 54,888 tons of solid waste is generated daily in urban areas of Pakistan and 60 percent of it is collected by the municipal authorities. However, according to official estimates, 30 percent to 50 percent of the solid waste generated within most cities is not collected. Solid waste generation in Pakistan ranges between 0.283 to 0.612 kg/capita/day and the waste generation growth rate is 2.4% per year (Draft Environmental Assessment Report, Stockholm, November 1993). The projected population of the country for the year 2014 is 197.77 million on the basis of current annual growth rate of 2.6 percent resulting in an estimated projection of solid waste of 71,018 tons per day/ 25.921 m tons per year.

In Pakistan there is no proper system of solid waste management. Solid waste management system does not exist in most of the rural areas of Pakistan. Solid waste generated mostly ends up in empty plots, place of generation, in drains causing blockages in sewage system or on road sides. We can see open dumping on road/street sites which is a very common practice and local sanitation departments have least interest in waste management and open dumping.

According to different studies, 40-50 % of the total solid waste is constituted of organic content. This content when put to landfill, not only generates toxic leachate; contributing towards the depletion of ground water quality, but also releases methane gas in the atmosphere during the biological degradation process. But if we want to look for a solution to this environmental problem, we can say that this major chunk of solid waste is an enormous resource and there is an opportunity of producing energy and quality organic manure. In the later stages of this study you will see that how this waste can be used to produce energy and fertilizer.

1.3 Biogas in Pakistan

Pakistan has low forest cover. About 4% of total area is covered by forest, in which only 5% area is protected. 90% of country's wood production is used as fuel. About 7000 ha of land is reforested in Pakistan every year. (Abdul Rauf 2007)

The energy crisis in Pakistan is getting worse day by day. Biogas plants in rural areas can play a major role in decreasing the burden on the national energy grids and deforestation. Biogas plants are being built and encouraged with the help of government funds and many other incentives. In our neighboring country India, there are almost two millions biogas plants.

Pakistan's 70 percent population lives in the rural areas. Most farmers have two or more cows/buffalos. The dung from these cattle mixed with an equal proportion of water can be used to produce biogas in a biogas plant. This biogas can then be used for cooking purposes or to generate electricity through a gas fired engine whereas the residue from this plant can be used as a fertilizer. Typically, 50 kg cow dung is required to produce 100 cubic feet of biogas that is sufficient to fulfill the daily requirements of a family of five or six members. (Akhter, 2004)

About 4,137 biogas plants were installed in Pakistan with the help of the government in the period 1974 to 1987. The government fully funded the first 100 installations and later on, withdrew the financial support. Since then, the growth rate of this technology dropped drastically and only 6,000 biogas plants were installed till the end of 2006. Pakistan Centre for Renewable Energy Technologies (PCRET) has already installed and supported 4,000 biogas plants with only 50 percent financial contribution from beneficiaries. (SNV, 2007)

There are significant social, economic and environmental benefits of biogas technology. The government of Pakistan through PCRET and Alternative Energy Development Board (AEDB) should take the initiative and announce more funds and support for this proven technology to be a part of our rural society. In parallel, the media should raise the level of awareness among the rural community by highlighting the benefits of this technology. NGOs and foreign investors should be encouraged to invest in this sector too. (Sheikh, 2009)

Nowadays biogas plants are easily available in the market, and biogas constructions have been installed all over Pakistan. The upgraded biogas is mainly used for heat and electricity production. However more and more research in using biogas as vehicle fuel is set up in different universities of Pakistan. Indeed, this vehicle fuel is the best way to upgrade waste. Nevertheless a governmental support is needed in order to make the biogas market attractive because of its high investment costs. (Technology times 2011)

1.4 Objective

The main objectives of study are following:

- Production of Biogas from organic food waste and to evaluate the optimum working parameters.
- Identify and locate the problems in biogas plants and eradicate them.
- Use of nutrient enriched slurry as a fertilizer, filters the CO_2 and traces of H_2S gas from biogas and burn pure methane.

2 LITERATURE REVIEW

This chapter provides a general overview of some of the main aspects of biogas production. The purpose is to give some background information to the interpretation of the results presented in the subsequent chapter.

2.1 History of Biogas

Anecdotal evidence indicates that biogas was used for heating bath water in Assyria during the 10th century BC and in Persia during the 16th century AD. (Philip D. Lusk)

Jan Baptista van Helmont first determined in 17th century that flammable gases could evolve from decaying organic matter. Count Alessandro Volta concluded in 1776 that there was a direct correlation between the amount of decaying organic matter and the amount of flammable gas produced. In 1808, Sir Humphrey Davy determined that methane was present in the gases produced during the AD of cattle manure. (Philip D. Lusk)

The first digestion plant was built at a leper colony in Bombay, India in 1859.In England, 1895 when biogas was recovered from a "carefully designed" sewage treatment facility and used to fuel street lamps in Exeter. The development of microbiology as a science led to research by Buswell and others in the 1930s to identify anaerobic bacteria and the conditions that promote methane production.

The history of biogas technology in Pakistan is about 35 years old. The Government of Pakistan started a comprehensive biogas scheme in 1974 and commissioned 4,137 biogas units by 1987 throughout the country. (Prakash C. Ghimire 2007)

2.2 Basics of biogas production

The biogas process is a closed biological process without oxygen where organic matter is converted to biogas (methane and carbon dioxide) by microorganisms. The biogas process is a natural process with bacteria from nature.(Igoni*et al.*, 2008).

Biogas originates from biogenic material and is a type of biofuel. Biogas is produced by anaerobic digestion or fermentation of biodegradable materials such as biomass, manures, sewage, municipal waste, green waste, and plant material and energy crops. (Harold House *et al.*, 2007)

Biogas fuel is a flammable substance that burns in a similar fashion to liquefied petroleum gas (LPG), and as such, biogas energy can be utilized as an alternative to fossil fuels. Biogas production is often achieved using a biogas plant, which is a system that "digests" organic matter to produce gas.

Natural gas is about 90-95% methane, but biogas is about 50-65% methane. So biogas is basically low grade natural gas. (Harold House, 2007)

2.3 Composition of Biogas

Table 1 - Composition of Biogas	
GASES	**% COMPOSITION**
Methane (CH_4)	40-75%
Carbon dioxide (CO_2)	25-55%
Hydrogen sulfide (H_2S)	50-5000ppm
Ammonia (NH_3)	0-1%
Water (H_2O)	0-10%
Nitrogen (N_2)	0-5%
Oxygen (O_2)	0-2%
Hydrogen (H_2)	0-1%

Composition depends upon the material feed and process nature. (Abdul Rauf, 2007)

Four ingredients are needed for biogas production:

1) Organic Matter
2) Bacteria
3) Anaerobic Conditions
4) Heat (Majid 2006)

2.4 What Kind of Substrates might be used?

Typical substrates for the biogas process:

- Food waste
- Sewage sludge
- Waste from food industry
- Manure from cows, pigs etc.
- Residues from agriculture
- ”Energy” herbs and plants like grass (Murmansk, April 2008)

2.5 Biogas Plant Slurry Characteristics

The biogas process produces a moist rest product (the bio rest), about 8% dry matter. The bio-rest contains the important nutrients (ammonia, potassium and phosphorus), stable organic matter and biomass.

In order to use the bio-rest in agriculture it is important:

- High quality with respect to nutrients and contaminants
- Using the bio-rest directly (without dewatering) all nutrients are used, but this represents large volumes for transport and storage.
- Dewatered bio-rest needs further processing, for example. Composting. How do you use the water phase (rich at N, and K)?

The biogas process produces no waste products because we are using the bio-rest as a fertilizer, it will replace the use of other fertilizers (Murmansk, April 2008)

2.6 The Facts about Biogas

Biogas is 55-65% methane, 30-35% carbon dioxide, with some hydrogen, nitrogen and other traces. Its heating value is around 600 B.T.U. per cubic foot. Natural gas consists of around 80 % methane, yielding a B.T.U. value of about 1000.

Biogas may be improved by filtering it through limewater to remove carbon dioxide, iron filings to absorb corrosive hydrogen sulphide and calcium chloride to extract water vapors after the other two processes.

About one cubic foot of gas may be generated from one pound of cow manure at around 28°C. This is enough gas to cook a day's meals for 4-6 people.

About 1.7 cubic meters of biogas equals one liter of gasoline. The manure produced by one cow in one year can be converted to methane which is the equivalent of over 200 liters of gasoline. (Kossmann*et al.,* 2008)

Gas engines require about 0.5 m^3 of methane per horsepower per hour. Some care must be taken with the lubrication of engines using solely biogas due to the "dry" nature of the fuel and some residual hydrogen sulphide; otherwise these are a simple conversion of a gasoline engine. (Habmigern, 2003)

2.7 Methods for Adding Feed

The central part of an anaerobic biogas plant is an enclosed tank known as the digester. This is an airtight tank filled with the organic waste, and which can be emptied of digested slurry with some means of catching the produced gas. Design differences mainly depend on the type of organic waste to be used as raw material, the temperatures to be used in digestion and the materials available for construction. (Habmigern, 2003)

It is divided into two types:

- Batch Feeding
- Continuous Feeding

2.7.1 Batch Feeding (Mostly Solids)

There is biogas systems designed to digest solid vegetable waste alone. Since plant solids will not flow through pipes, this type of digester is best used as a single batch digester. The tank is opened, old slurry is removed for use as fertilizer and the new charge is added. The tank is then resealed and ready for operation.

Dependent on the waste material and operating temperature, a batch digester will start producing biogas after two to four weeks, slowly increase in production then drop off after three or four months. Batch digesters are therefore best operated in groups, so that at least one is always producing useful quantities of gas (Yadvika*et al.,* 2004).

Most vegetable matter has a much higher carbon - nitrogen ratio than dung has, so some nitrogen producers (preferably organic) must generally be added to the vegetable matter, especially when batch digestion is used. Weight for weight, however, vegetable matter produces about eight times as much biogas as manure, so the quantity required is much smaller for the same biogas production. A mixture of dung and vegetable matter is hence ideal in most ways, with a majority of vegetable matter to provide the biogas and the valuable methane contained in it.(Igoni*et al.,* 2008).

2.7.2 Continuous Feeding (Mostly Liquids)

The complete anaerobic digestion of cow manure takes about 8 weeks at normally warm temperatures. One third of the total biogas will be produced in the first week, another quarter in the second week and the remainder of the biogas production will be spread over the remaining 6 weeks.

Gas production can be accelerated and made more consistent by continuously feeding the digester with small amounts of waste daily. This will also preserve the nitrogen level in the slurry for use as fertilizer.(Igoni*et al.,* 2008)

If such a continuous feeding system is used, then it is essential to ensure that the digester is large enough to contain all the material that will be fed through in a whole digestion cycle. One solution is to use a double digester, consuming the waste in two stages, with the main part of the biogas (methane) being produced in the first stage and the second stage finishing the digestion at a slower rate, but still producing another 20 % or so of the total biogas. (Habmigern*et al.,* 2003)

2.8 Biogas Production Rates

Food waste is almost largest category of municipal solid waste (MSW) sent to disposal in Pakistan, accounting for approximately 50% of the waste stream. Over 32 million tons of food waste is sent to dumping site each year. Very less amount of food waste currently being diverted from dumping site, most of it is being composted to produce a fertilizer. This food waste can generate approximately 12032 million m^3 of biogas.

Food waste has three times the methane production potential as bio-solids

- Cattle manure= 25m^3 gas/ton
- Bio-solids = 120 m^3 gas/ton
- Food waste = 376 m^3 gas/ton

As energy prices continue to climb and our nation looks towards renewable energy generation and energy independence, capturing the energy from food waste becomes more important.

When facilities start digesting food waste, the increased energy production allows them to offset the amount of energy they are using and potentially sell excess energy back to the grid.

2.9 Reactions in Biogas Production

2.9.1 Anaerobic digestion Steps for Biogas Production

Anaerobic digestion is the most widely used method of organic waste disposal due to its high performance in volume reduction and stabilization and the production of biogas that makes the process profitable.

2.9.1.1 Anaerobic Digestion

Anaerobic digestion treats waste by converting organic compound into methane gas and carbon dioxide. This methane is called biogas that can be used in power generation. During anaerobic digestion process, nitrogen is converted into ammonia and sulfur is converted into hydrogen sulfide, the reduction and oxidation reactions occur in the breakdown of organic materials are given below

Carbon, C → organic acids (R •COOH) → $CH_4 + CO_2$

Nitrogen, N→ amino acids [R • (NH_2) • COOH] →NH_3+ amines

Sulphur, S→ H_2S organic+ S compounds

Phosphorus, P→ PH_3 +organic P compounds (Vindiset al., 2009).

Anaerobic digestion takes place in four steps, which are given below.

1. **Hydrolysis:** In first step the organic materials are depolymerized, in which the complex polymers e.g.; proteins, carbohydrates and lipids are break down into monomers e.g.; cellulose, protease, lipase and amylase, by extracellular enzymes. Polysaccharides are converted into sugar. Lipids are converted into small or long chain fatty acids. (Gunaseelam, V.N.1997)
2. **Acidogenesis:** In this process, microorganisms use fatty acids, amino acid and sugars as substrates to produce organic acids like acetic, propionic, butyric and small chain fatty acids, alcohols, H_2 and CO_2.(Vindis*et al.,* 2009).
3. **Acetogenesis:** There is no clear distinction between Acetogenesis and Acidogenesis reaction. In this step, the Acetogenesis bacteria degrade the hydrogen sinks acids like propionic, butyric and valeric acids into formate, acetate, CO_2 and hydrogen. (Rojas *et al.*, 2010).This step is very important for

the production of biogas because electron sinks are not utilized by methanogens. Acetogenic bacteria are very slow growing and sensitive to environmental changes.(Gunaseelam, V.N 1997)

4. **Methanogenesis:** H_2/CO_2 and acetic acid are mainly utilized by methanogens to form methane and carbon dioxide. Methanogens utilize limited amount of other substrate like methanol, alcohols and formate to produce methane..

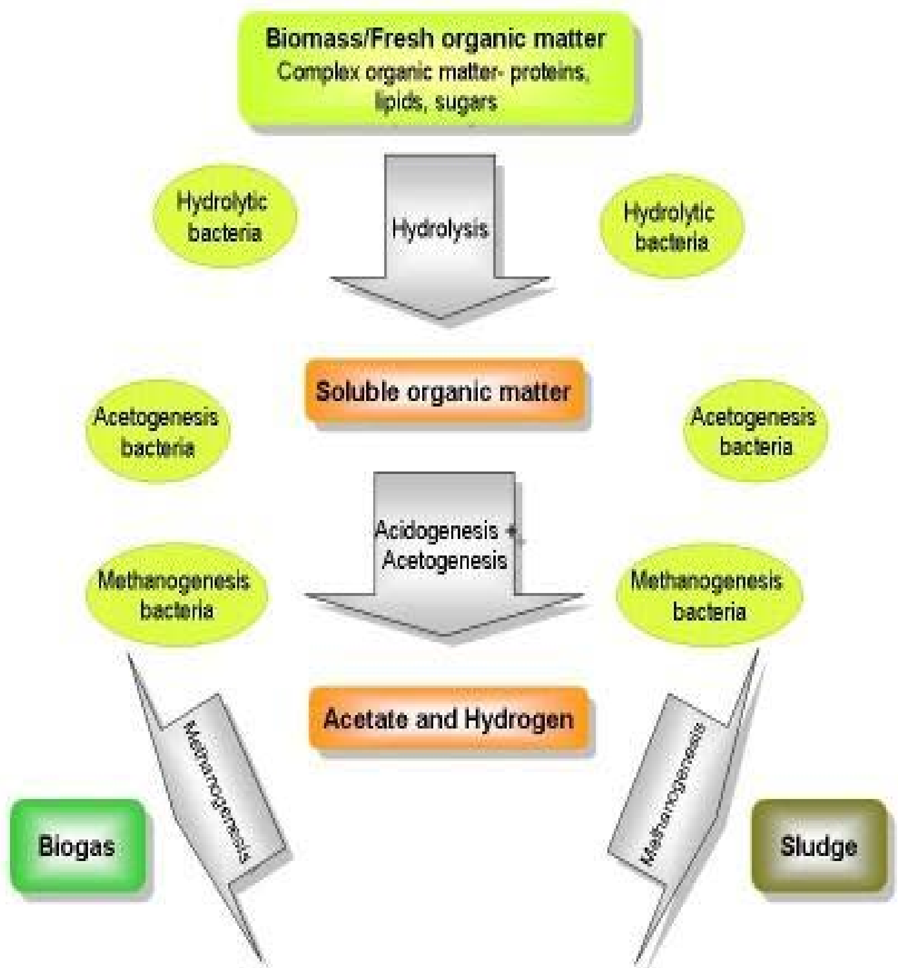


Figure 1 - Anaerobic Digestion Process (Gunaseelam, V.N 1997)

2.10 Types of Biogas Plant

A biogas plant refers to any structure that is used to ferment organic waste anaerobically (Bensah et al., 2010). The main parts of a biogas plant are: influent collecting tank, inlet and outlet, digester, gasholders, gas pipe, valves and stirring facilities (Vassiliou, 1997). Anaerobic digestion takes place in the digester (Igoniaet al., 2007). It is a cube-shaped or cylindrical waterproof container with an inlet into which the fermentable mixture is introduced in the form of liquid slurry. When the gas valve is closed, the biogas produced in the digester is collected in the dome, called the gasholder. The gas holder is normally an airtight steel container. The accumulated gas displaces the digested slurry through the outlet opening, to the drainage pit where it is collected and composted. The gas is supplied to the point of application through a pipeline. The gas pressure depends on the prevailing difference of the slurry levels and the size of the plant depends on the substrate available (Bajgain, 1994; Sasse et al., 1991).

2.10.1 Biogas - Digester types

1) Fixed-dome plants
2) Floating-drum plants
3) Balloon plants
4) Horizontal plants
5) Earth-pit plants
6) Ferro cement plants

Fixed-Dome Plants: This is a low cost Biogas plant consisting of steel parts and with no moving parts in it. This type plants are protected from low temperature during nights and cold weathers. Nicarao design is the basic element of fixed dome plant (Hoerz et al, 1998).

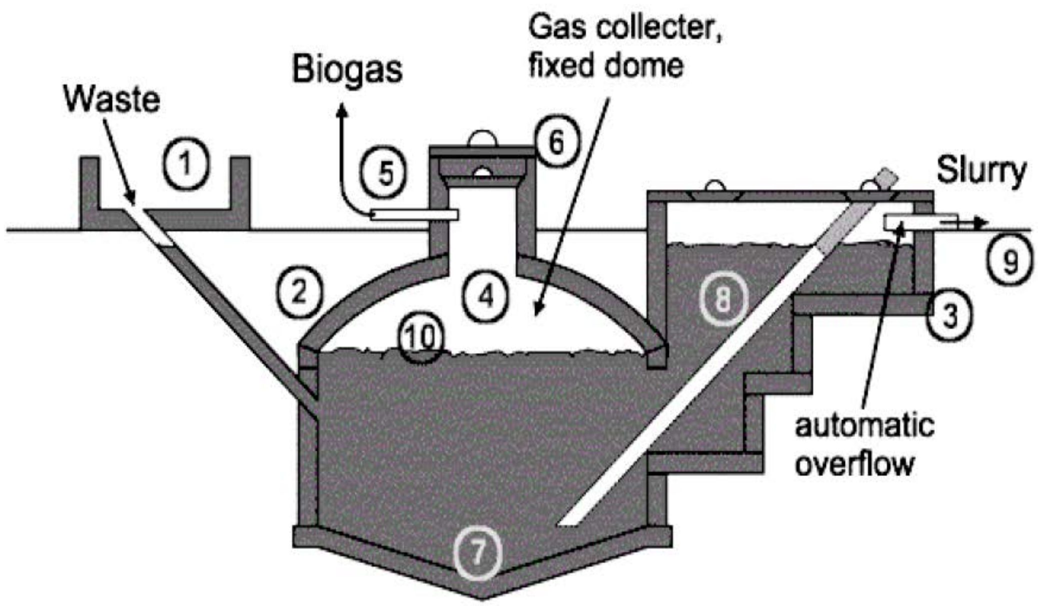


Figure 2 - Fixed Dome Plant (Hoerz, et al, 1998)

Floating-Drum Plants: These are usually built in India which consists of cylindrical or dome-shaped digester and a moving gas holder or drum. The drum holds the gas and lift up wards and if gas consumed the gasholder sinks (Aziza Kenya Empowerment, 2010)

Figure 3 - Floating Drum Plants

Balloon Plants: These consist of plastic or rubber bag which is heat sealed. In whole balloon the digester and gasholder are combined and gas is stored in the upper part. In case of gas pressure balloon can be damaged so it should be protected from the sides. (PCRET, 2005)

Horizontal Plants: Horizontal Biogas plants are usually chosen when shallow installation is called for (groundwater, rock). They are made of masonry or concrete.

Earth-pit plants: This is also called masonry digester and walls are plastered with cement. Enforced masonry is used on the edge of the pit which also used as gas holder. (F. V., & Euler, H. 1998)

Ferro Cement Plants: It can be self-supporting shell or an earth-pit lining. Usually cylindrical and is very small in size.

2.11 Types of Anaerobic Digestion Processes

There are three major processes in anaerobic digestion, which are given below;

2.11.1 Psychrophilic Anaerobic Digestion:

This type of anaerobic digestion is mainly carried out in that region where temperature is low. Temperature ranges between 10-20 °C. Under this temperature range, digestion is very slow and time consuming. About 40-50 days are required for biogas generation.

2.11.2 Mesophilic Anaerobic Digestion:

Temperature ranges for mesophilic digestion are between 25-40 °C. This type of digestion takes 25-30 days for bio degradation. Mesophilic digestion tends to be more sturdy and tolerant than thermophilic anaerobic digestion but biogas generation is less.

2.11.3 Thermophilic Anaerobic digestion:

Thermophilic digestion occurs between 50-65 °C. Digestion process is very fast in the thermophilic process. Biogas generation starts in 8 to 10 days. High biogas production is achieved in this process but it is very costly because high degree of energy input is required. During this process, about 30-60% of the digestible solids are converted into biogas.

2.12 Operating Parameters in Biogas Production

Many factors affect the anaerobic digestion process, controlling these factors can enhance the anaerobic process. These factors include:

- Type of Organic waste
- Waste particle size
- Temperature
- pH
- Presence of toxic material
- Hydraulic retention time
- Solid retention time
- Carbon to nitrogen ratio
- Digester loading rate
- Mixing

2.12.1 Type of Organic Waste:

Not all types of waste can be converted to biogas. Anaerobic bacteria cannot degrade lignin, Waste that contain huge amount of sulfur or nitrogen result in large amount of unwanted ammonia and hydrogen sulfide that is not our requirement. The waste that is not completely soluble in water can degrade very slowly.

2.12.2 Size Reduction:

Size reduction is very important parameter in anaerobic digestion. Pumping of waste after size reduction is much easier as compared to raw waste. We can avoid blockage of pipes after shredding. Shredding is not only help in pumping but also increase the surface area for bacteria in reaction. Through shredding biodegrading can easily accomplish. It also helps in getting the consistent feed.

2.12.3 Temperature:

Temperature plays very important role in anaerobic digestion. Biogas production depends on temperature variation. With increase in temperature, biogas production increase.

2.12.4 pH:

pH plays a vital role in anaerobic digestion. Methane producing bacteria are directly affected with the hydrogen ion concentration. Digestion is completely prohibited by excess of acidity. Bacteria produce methane in the pH range of 6-8.At the start acid forming bacteria begin to produce acids which break down into methane by methanogens. If acids formation still increasing and exceed the consumption level of methanogens then these acids decrease the pH. When pH decreases, the carbon dioxide contents start to increase while methane production decreases. Normally to keep the anaerobic digestion balance, lime is added. However, a level of lime should maintain carefully because excess lime result in precipitation of sodium carbonate. Sodium bicarbonate can also be used to maintain the pH.

2.12.5 Toxic Material:

The toxic material level should be maintained at optimum. Anaerobic digestion process can handle small quantity of toxic material. These toxic materials are avoided because these materials can inhibit the process.

2.12.6 Hydraulic Retention Time:

Hydraulic retention time means how many days the material remains in the digester. This retention time play important role in anaerobic digestion because it tells us the time factor for bacteria growth which other hand tells the conversion of biodegradation of organic material into methane.

2.12.7 Solid Retention Time:

The solid retention time is one of the important factors in digestion process. It is equal to the amount of solids maintained in the digester divided by the amount of solid drained. Conversion of volatile solids into methane depends on solid retention time. If solid retention time is very low then it shows that there is no sufficient time for bacteria to grow. Bacteria loss in effluent increases. If bacteria loss rate exceeded than bacteria growth rate, wash out occurs.

2.12.8 Carbon to Nitrogen Ratio:

Carbon to nitrogen ratio is also a main factor that affects the anaerobic digestion process. Carbon provides energy to microbes while nitrogen enhances the microbial growth. If we do not maintain the quantity of nitrogen then microbial growth is inhibited which have adverse effect on methane production. If carbon contents increases and nitrogen contents decreases this will result in increase in energy level which inhibits microbial growth. Carbon is utilized 30 times more than the nitrogen. Therefore, carbon to nitrogen ratio should be maintained at 30:1

2.12.9 Digester Loading Rate:

Volatile components are those, which can be digested. It depends on the type of feed or waste, which is fed into the digester because it will dictate the biochemical activity in the digester. Loading rate keeps the balance between the acid formation and methanogensis. If the acid formation increases then the pH level decrease this has adverse affect on methanogensis and also effect the carbon to nitrogen ratio.

2.12.10 Mixing:

Mixing plays an important role in achieving the optimum anaerobic process. Mixing keeps uniformity in substrate concentration and in temperature. Mixing helps avoid solid deposition in anaerobic reactor.

2.13 Feed Stocks and Their Characteristics

In general, all organic matters can be utilized in anaerobic digestion. Anaerobic digestion can degrade less structured material like food waste, easily as compare to more structured material like wood. Lipids; carbohydrates and protein are main constituents for digestion. Lipids produces 1250 l/kg of gas, carbohydrates produces 790 l/kg while proteins produce 700 l/kg. However, there are certain characteristics, which are desired for feedstock for anaerobic digestion. (Jilani et al, 2007)

These characteristics are;

- It should be easily digestible
- Nutrients contents should be balanced
- The pH must be near neutral
- Volatile contents should be in large quantity as compare to solid contents
- Constant composition of feed is required

The important parameters are given as:

Table 2 - Design Parameters of Biogas plant (Jilani et al, 2007)

Parameter	Range
Temperature	50-60 °C (thermophilic condition)
pH	6.8-7.4
Total Solid	8-10%
C / N ratio	25-30:1
VolatileSolids	≥ 80%
MoistureContent	≥70%
Particle Size	10-12mm

2.14 Positive Reasons for Producing Biogas

Not only is biogas a fuel for producing green energy, but it has many other advantages both for the producer, and for society as a whole. Biogas production offers an alternate use for food by-products. Instead of food by-products taking up costly space at land fill sites, they can be used to further boost the biogas production from manure.

The fermentation of manure in biogas production greatly reduces the pathogen content of the manure. It also greatly reduces the odor of the manure, as in the end, all the volatile gases have been removed. The process also serves in homogenizing the manure, so that it is easier to agitate, pump, and spread.

The other major spin-off advantage is rural economic development. The expansion of biogas production in Europe has resulted in expansion in all the related industries leading to the increase in jobs, and millions being poured into the rural economy. (Harold House 2007)

3 METHODOLOGY

Adopted methodology is shown in the form of simplified figure:

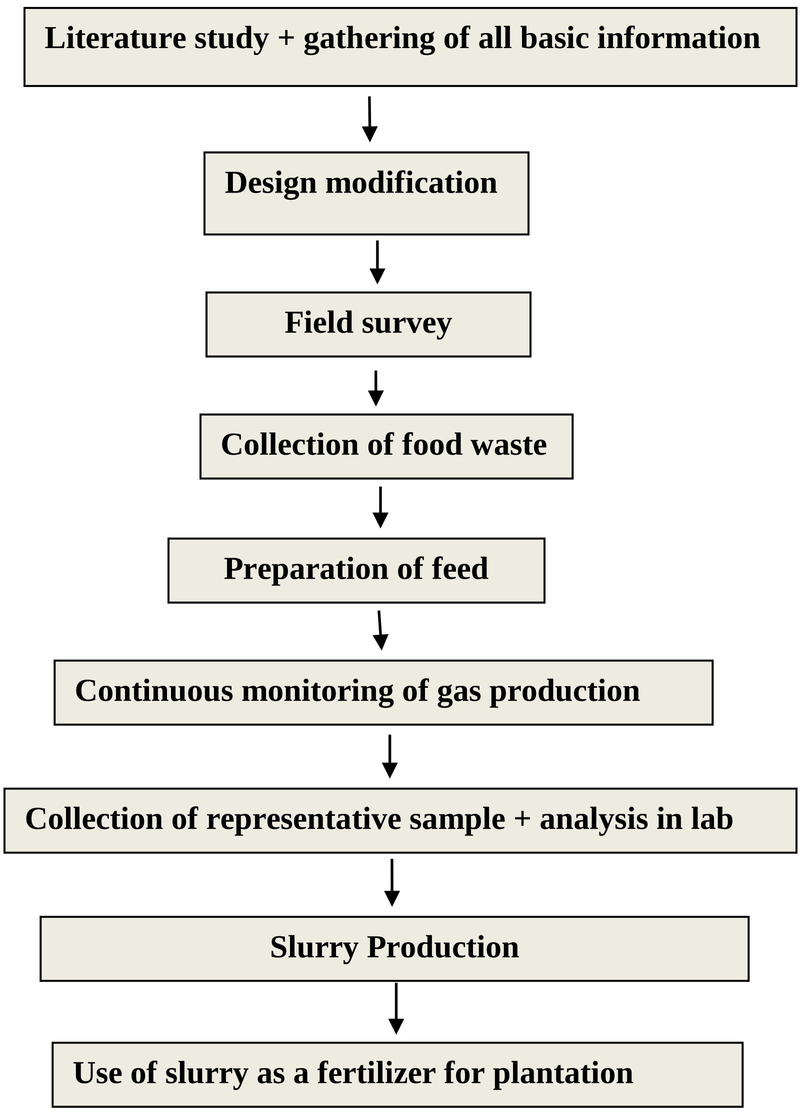
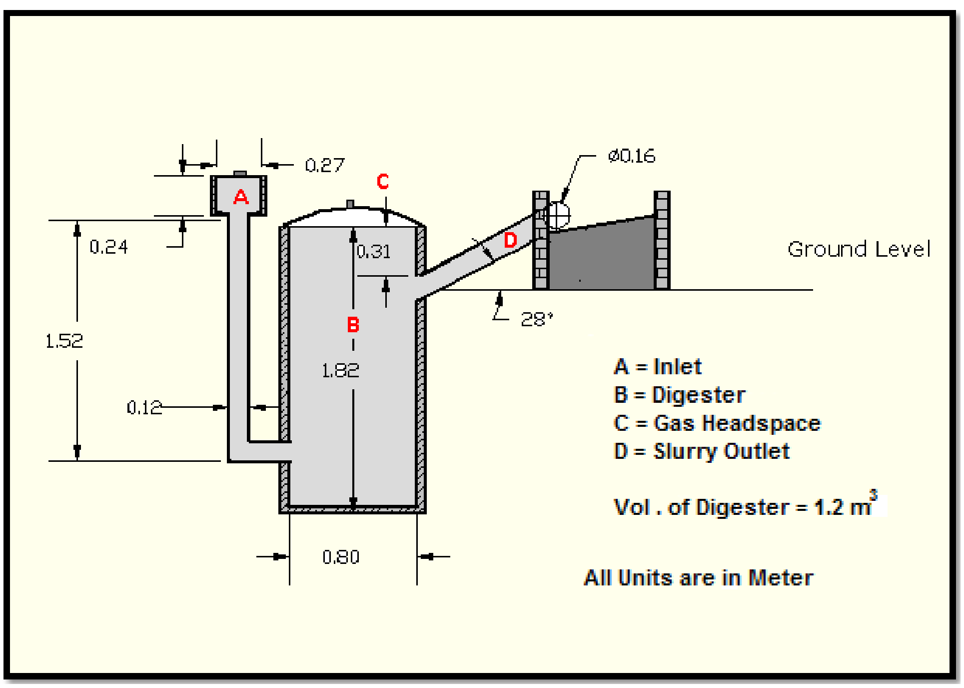


Figure 4- Flow Diagram of Research Methodology Adopted

3.1 Biogas Production under Thermophilic Condition

3.1.1 Layout of Biogas Plant

Biogas plant used for this research has a slightly different layout than conventional biogas plants. It will run in batches of feed stock, for this reason, the slope of the outlet pipe is given a positive angle. For biogas plants, that run on continuous feed, have their outlets negatively sloped. When biogas produced inside the digester creates pressure and as a result it raises the slurry which comes out of the outlet. And when this biogas moves out through the gas nozzle, this escaped slurry flows back into the digester. The amount of slurry replaced, equals the volume of biogas produced. The inlet pipe was connected to the base of the digester as anaerobic conditions at the bottom are best developed due to which digestion process is very fast here.



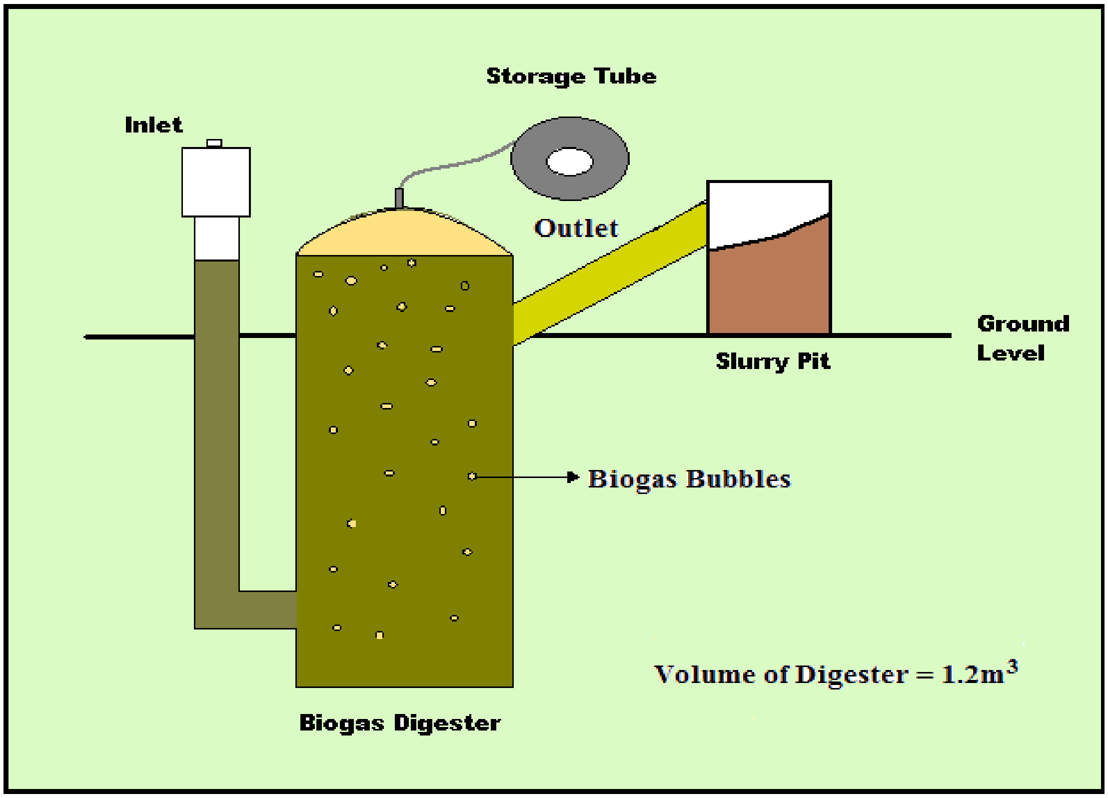


Figure 5 – (a) Layout of biogas plant **(b)** Design of Experiment

Table 3 - Specification of Biogas Plant	
Plant type	Fixed dome
Batch type	Batch feeding
Type of waste	Vegetable waste
Temperature	Thermophilic conditions (55 ^{o}C-70^{O}C)
pH	6.5-7.9
Length of inlet	1.76 m
Angle of inclination of outlet	28^{o}
Volume of digester	1.2 m^3

3.1.2 Modifications

3.1.2.1 Temperature Control System

Methanogenic bacteria are most active in thermophillic a condition that ranges between 55^{o}C-60^{o}C. to provide heat inside the digester, a hollow copper coil was installed that worked as heat exchanger. Hot water heated by heating rod ran through this hollow tube by a pump, was controlled through a programmed circuit coupled by a temperature sensor. This circuit automatically turns of the heating rod and the pump when temperature sensor shows a reading above 60^{O}C on the LCD and turns on when it cools down to 50^{O}C.

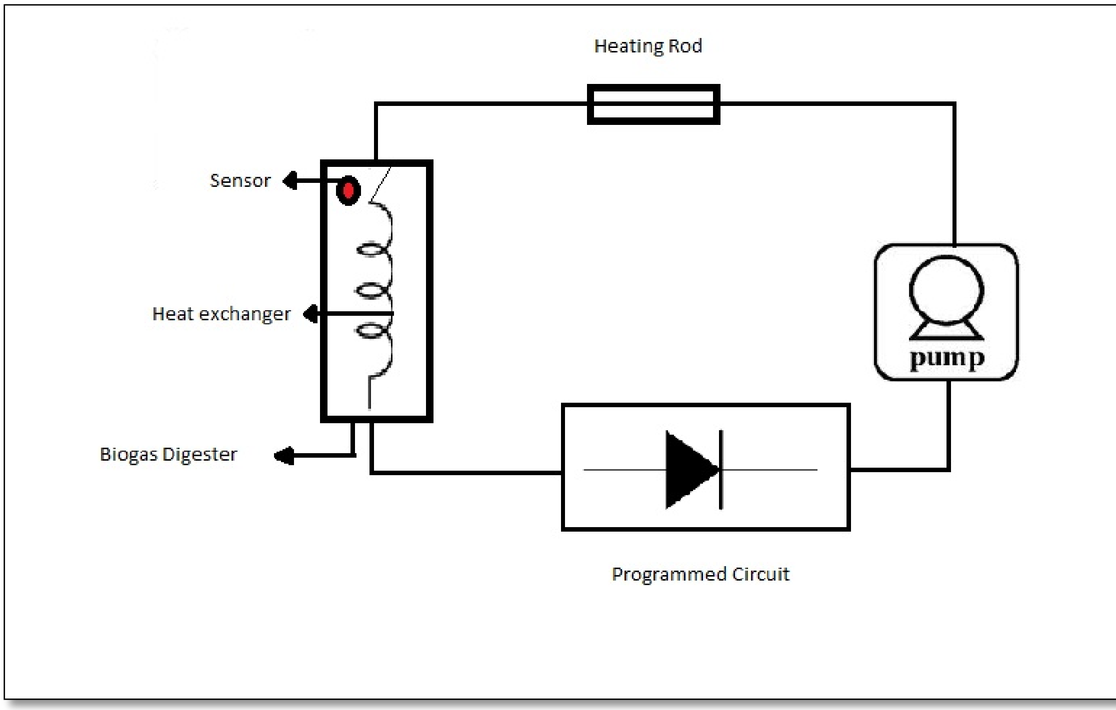


Figure 6 - Flow Diagram of Temp Control System

Figure 7 - Heating System for maintaining temp inside the tank

Figure 8 - Temperature Controlling System with LCD Screen that shows temperature inside digester

3.1.2.2 Resizing of the Slurry Pit

Slurry pit of the biogas plant was re-sized from 1.6 x 1.6 m^2 to 0.5x0.5 sq.m^2; height was kept the same of 0.5 m. This modification was required to maintain pressure at the outlet so that the gas doesn't escapes from the outlet. As the raw feed is provided in a batch, the amount of slurry replaced from the outlet equals the volume of gas produced in the digester. After the gas has been collected, this replaced slurry moves back into the digester.

3.1.2.3 Adjusting and Sharpening the Blades of the Shredder

Feed size places a crucial role in taking the process to maturation at a relatively quicker rate. This enhances the surface area for microbial activity. The blades were spaced in such a configuration so that an optimum feed size of - 2.5 cm. The shredder was operated manually by hand.

3.1.2.4 Glass Box

LCD along with Temperature control circuit was placed in a plastic glass box so that adverse climatic condition is not able to damage the device.

Figure 9 - Glass Box to Protect Temp Controlling Sensors Circuit

3.1.2.5 Gas kit

The existing gas kit was required to be replaced by a more durable gas kit which was used in closing the digester so that loses due to gas leakage can be avoided.

3.1.3 Field Survey and waste collection

Different areas in Islamabad were visited to collect the vegetable waste for the feeding of Biogas plant. For example, H-9 bazaar, G-6 Bazaar (Sunday market), I-11 SabziMandi and NUST cafeteria. I-11 Mandi is one of the biggest markets in Islamabad, and is one of the major sources of food waste therefore I-11 Mandi was selected for the sampling. The food waste was collected in 3 trips on different days to meet the experimental requirement.

Table 4 - Total Weight of Vegetables added in Tank

Vegetables	**wt. (kg)**
Spinach	360
Potato	280
Cabbage leaves	220
Turnip leaves	40
Carrot	20
Dried potatoes	90
Dried spinach (one day old)	75
Total	1085

This waste was segregated on site and was then transported to H-12 at NUST campus, where the biogas plant has been installed.

Figure 10- Segregation of Vegetable Waste

3.1.4 Preparation of Digester Feed

3.1.4.1 Shredding of Waste

The segregated waste was shredded by using a manly operated shredder, installed near the plant. For potatoes and carrots was cut manually by knife and choppers. The feed size was about 0.5 to 1 inch (1.2 – 2.5 cm). After shredding and cutting the feed was added in pretreatment tank for preparation. Water was also added in a pretreatment tank in equal quantity to dip the food waste properly. Then waste was left for a week (from the date of receiving it) before putting it into the digester.

Figure 11 - Shredding of Vegetable Waste

3.1.4.2 Seeding

For seeding, effluent slurry was brought to the plant site, from an already working biogas plant installed in Chak Shehzad Town, Islamabad. To make up 50% of the organic matter, effluent slurry and cow dung were also added in addition to food waste. Almost 100 liters of processed slurry was added in the plant as starter. It was added immediately after bringing from the collection site. Otherwise the active decomposing microbes in the slurry would become inactive, due to temperature variation. The fresh cow dung was brought from a cattle farm in Kirpa. Slurry /cow dung contains suitable bacteria which help in biodegradation of food waste for the production of biogas.

Figure 13 - Slurry from Working Biogas Plant to be used for seeding purpose

Figure 12 - Cow Dung for Seeding

3.2 Total Feed Added in the Tank

All the prepared food waste was added in the digester in one day

Table 5 - Total Feed Added in Tank	
Total amount of food waste	1085 kg
Amount of fresh cow dung	30 kg
Amount of Slurry from existing biogas plant	100 L
Amount of water	150L
Total feed material	1180 L
Total capacity of digester	$1.2m^3$

3.2.1 C: N Ratio

C:N ratio of feed material calculated theoretically to know the optimum value of carbon and nitrogen.

The C:N ratio is the relative percentage of carbon to that of nitrogen in various organic materials. C:N ratio was estimated by multiplying the percent carbon of each ingredient by the number of parts by weight of that ingredient and then adding the carbon total for ingredients, dividing it by total added material. It gives us total carbon content in feed. Then divided the total amount of C by N which gave the C:N ratio where N = 1.

Table 6 - Calculation of C/N ratio			
Feed material	**C/N ratio**	**Vegetables wt. (kg)**	**carbon content**

Potato	25:1	370	25*370 =9250
Spinach	30:1	435	30*435=13050
Carrot	27:1	20	=540
Cabbage leaves	12:1	220	=2640
Turnip leaves	19:1	40	=760
Cow dung	25:1	30	=750
Total		1115	26990/1115 = 24.21

C/ N ratio = 24:1

3.2.2 Mixing of Feed Inside Digester

Different options for mixing the feed inside the digester were considered:-

- Manual Mixing by propeller
- Mixing by auger

Later one thought to be more viable and effective due to the viscous nature of the feed. Auger rod was used to mix the feed by turning it upside down a number of times. Moisture was not enough so we had a lot of difficulty in mixing the feed, more water was added and top hard dry scum was removed.

3.3

Figure 14 - Manual Mixing of Feed Material to Remove the Scum Layer

3.3.1 Hydraulic Retention Time

HRT depends upon the size of the digester and the amount of waste being digested. Thermophilic conditions, when maintained properly, reduce the HRT of the feed material. In the present study all batches were processed in summer, as anaerobic decomposition speeds up in warm conditions. HRT for this batch was 6 weeks after the feedstock was added to the digester. In the first two week, little or no production was observed. But eventually, the production should a continuous increment.

3.3.2 Gas Storage chamber

In this fixed dome biogas plant, the headspace left for biogas collection in the digester was 10 to 12% of the total volume of digester. As the volume of digester is 1.2 m^3, so its fermentation chamber is about 1.05 m^3. The volume of the dome is about 0.15 m^3 that acts as a gas storage chamber. This was also ensured that no gas gets released through the outlet, for this, the digester was filled up to the outlet. This allowed the gas to maintain pressure inside the digester. The lid of the tank was tightly closed and sealed properly using a gas kit and silicones to avoid any lose due to leakage.

Figure 15 - Headspace Left in Tank for Gas Collection

3.4 Sampling

3.4.1 Sampling of feed material

The samples were taken from the digester of the plant. In order to take a representative sample, the inner material was thoroughly mixed manually by using a metal rod before taking the sample. The samples were taken in 500 ml plastic bottles which were sealed properly before taking for lab analysis.

3.4.2 Moisture Content

3.4.2.1 Theoretically Calculated Moisture Content

Table 7 - Calculated Moisture Content

Vegetables	**wt. (Kg)**	**moisture content %**
Spinach	360	92
Potato	280	79
cabbage leaves	220	93
turnip leaves	40	90
Carrot	20	87
dried potatoes	90	61
dried spinach	75	49
Total	1085	

Water added =150 litters

Volume of slurry = 100 litters

Total moisture content of vegetables =

(360x0.92)+(280x0.79)+(220x0.93)+(40x0.90)+(20x0.87)+(90x.61)+(75x0.49)

=903.1

Total digestate added in tank = 150+100+1085

= **1335 kg**

Total dry content = 1085-903.91 = **181.09 kg**

Moisture Content = $((W_w\text{-}W_d)/W_w)$ x 100

in which:

M_n = moisture content (%) of material

W_W = wet weight of the sample, and

W_d = weight of the sample after drying.

Moisture content in tank % =[(1335-181.09)/1335]x100 **86.4%**

3.4.2.2 Moisture Content Calculated Practically In Lab

850 g of the sample was dried in the oven Model WTC Blender for about 24 hours at 105^{o}C till a constant weight was obtained. The sample was weighed before putting into oven and also after taking out of the oven. This gave the measure of moisture content.

Table 8 - Moisture Content of Sample calculated after 25 days

Initial weight	1.25 kg
Pan weight	0.4 kg
Weight of sample	1.25-0.4 = 0.85 kg
Dry weight of sample	0.55-0.4 =0.15 kg
Moisture content	(0.85-0.15)/0.85x100 = 82.35 %

3.4.3 Volume of Gas (Using Displacement Method)

By using liquid displacement method we measured volume of gas once a day. This apparatus was designed in the lab which includes 40 liters_plastic bucket. An empty 20 liter calibrated plastic bottle was inverted inside the bucket .Each reading on bottle represents one liter. A hole was made on the flat end of the bottle through which gas pipe was passed. The other end of pipe was attached to t- joint near the gas valve of the plant. The volume of gas is measured by displacement of bottle, due the collection of gas inside it. As the gas produced replaces the water inside the bottle and amount of water displaced gives the volume of biogas produced.

Figure 16 - Displacement Method to Measure Volume of Gas

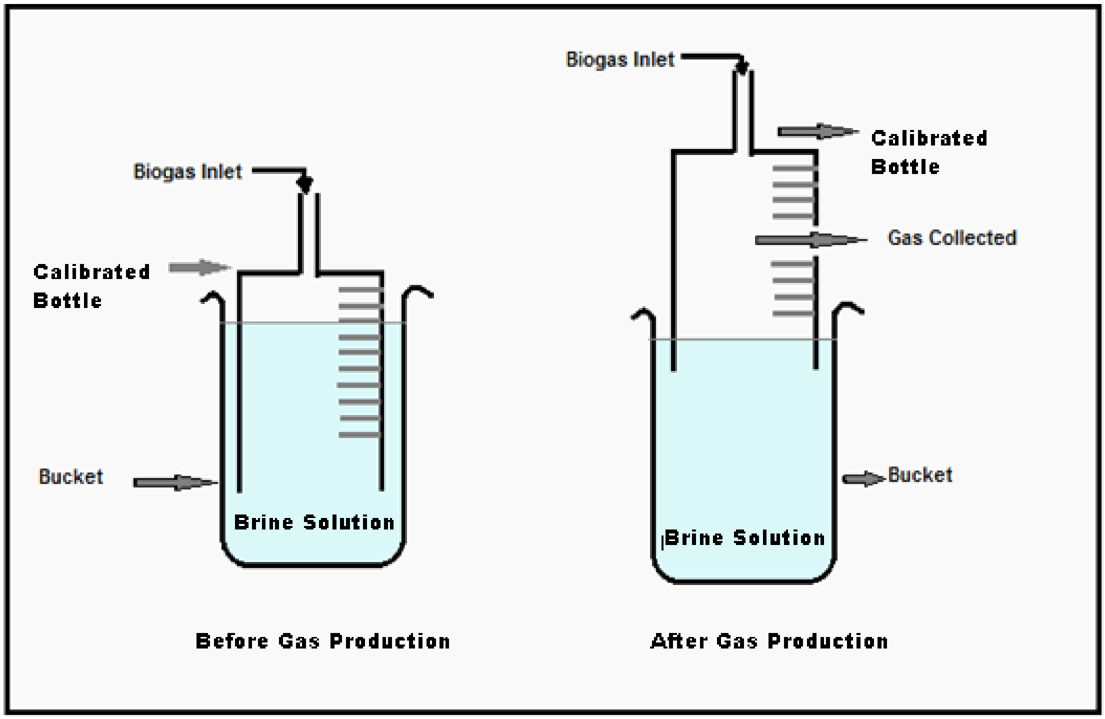


Figure 17 - Displacement Method Before and After the Volume of Gas Collected

3.5 3.4 Filtration of Biogas to Remove Carbon Dioxide

The biogas produced contains 50-60 % methane, 40-50 % carbon dioxide and traces of hydrogen disulphide gas and water vapors. To remove this proportion of CO_2 and extract relatively pure methane, biogas filter was designed. Solution of lime was used as the filter media. When this impure biogas plant was bubbled through this lime solution, relatively pure biogas with greater proportion of methane was then collected for burning. The concentration of lime for this filter was taken to be 200g/l. By increasing the concentration of lime solution, efficiency of filter will be increased.

Figure 18 - Filtration of Biogas by Using Lime Water

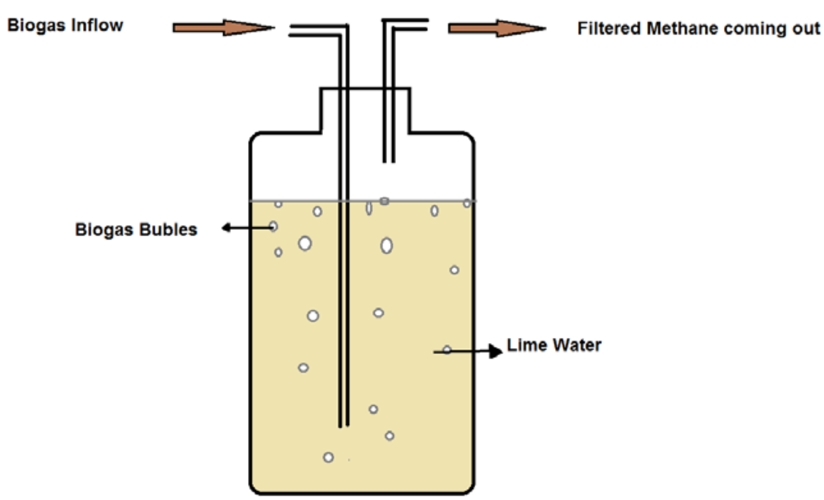


Figure 19 - Mechanism of Biogas Filtration

3.6 On Site Measurement of Critical Operational Parameters

3.6.1 Temperature

Temperature is measured once a day throughout the process of biogas production. A programmed electronic circuit coupled with a thermostat was installed. An LED was also installed which showed the temperature reading. The purpose of this electronic circuit was to digitize the temperature reading and control the operation of hot water circulating pump. This hot water circulation system helped to maintain the temperature inside the digester to thermophilic condition

3.6.2 pH

pH inside the digester is measured by using pH paper.

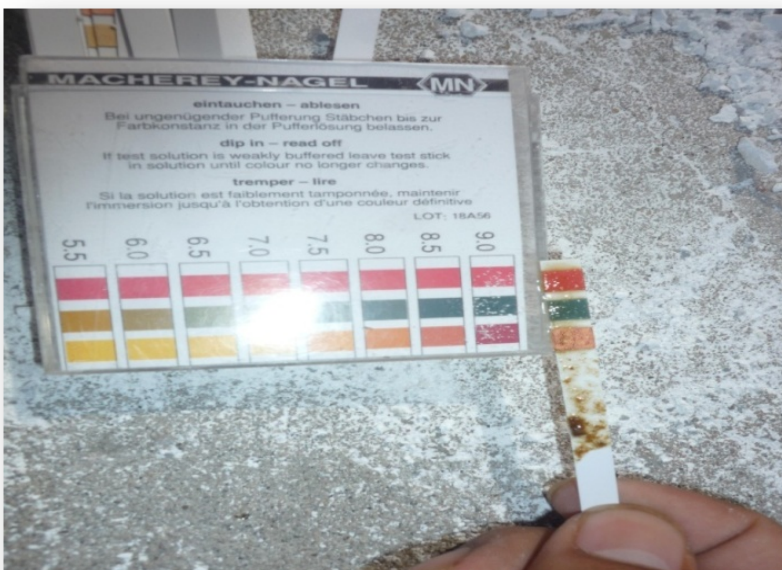


Figure 20 - pH measurement using pH Paper

4 OBSERVATION AND RESULTS

4.1 Monitoring of the Biogas Unit

The bio gas unit was monitored for 30 days and during the study three variables recorded were at regular intervals:

1) Temperature (Internal temperature of Biogas plant digester and ambient temperature)
2) pH
3) Biogas production

4.1.1 Temperature

This graph shows the changing trend of ambient temperature and the temperature inside the tank throughout the process of biogas production. The internal temperature of bio-gas plant was almost constant by the temperature controlling circuit. Variation in ambient temperature were observed and the trend was asymmetrical, but this didn’t affect much the inside temperature of the tank. Methane production is high and rapid under thermophilic condition so that is why high production rates are observed when temperature was between 55^{o}C-60^{o}C. Under thermophilic condition, the activity of methanogen gets enhance

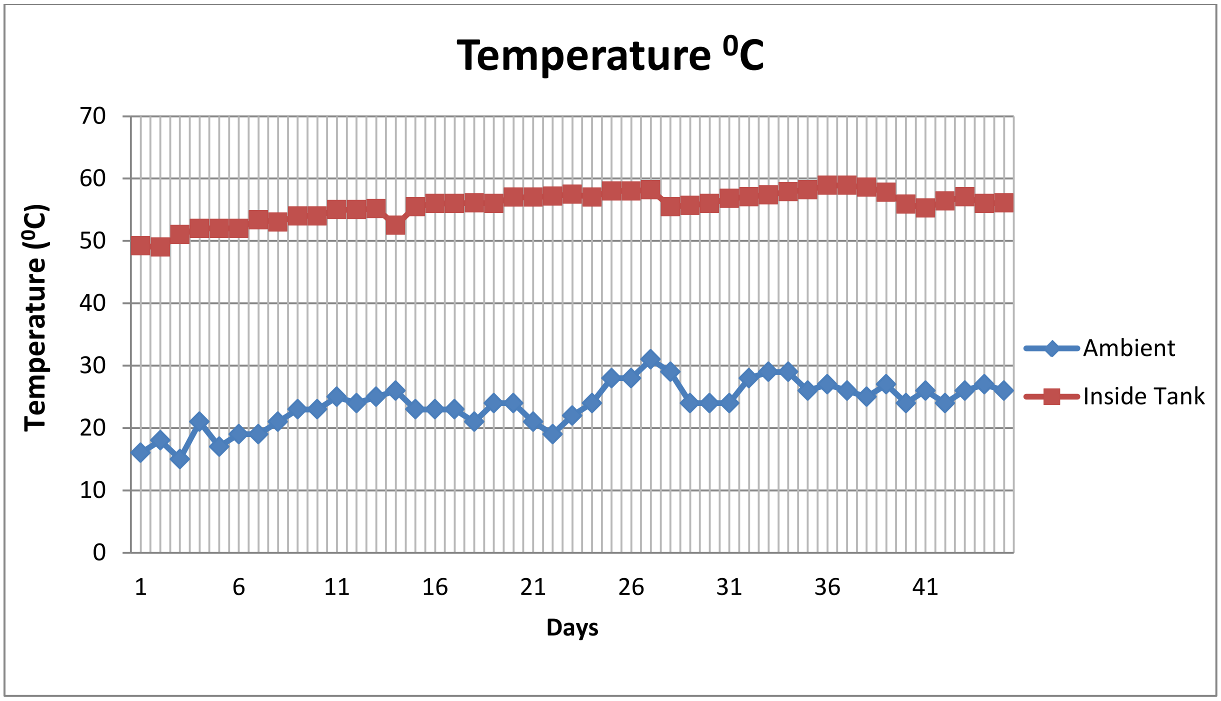


Figure 21 - Correlation of Ambient temperature with inside tank temperature over a period (days)

4.1.2 pH inside Digester

There was a gradual increase in the pH (from 5.5 to 7.9) of the biomass over a period of approximately 4 weeks. This indicates the decrease in the acidity of the sample which can be attributed to the growth of methane generating bacteria. pH holds a critical importance in this experiment. Initially the pH got stable at 5.5 and there was low methane production. Under these conditions, the biogas produced a greater CO2 content. To counter this problem, lime solution was added at regular intervals after pH became from less acidic to neutral. pH was checked at regular intervals from inlet and outlet to check for pH, if it remains in the neutral zone.

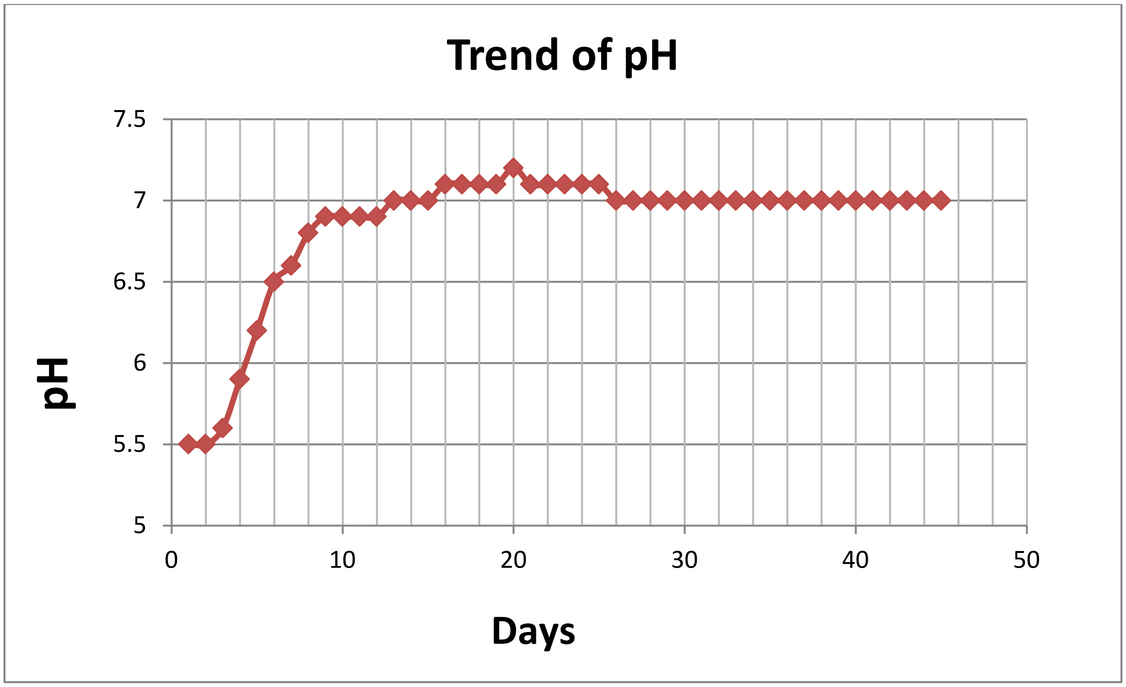


Figure 22 - pH Value Variation of Organic Waste during Fermentation Process

4.1.3 Biogas Production

Initially, during the 1st week, the gas production was very low. However its production gradually increased from zero liters to maximum of 83 liters on the 20th day. From then onwards, a decrease in the trend of gas production was seen because of no further batch feeding and consumption of substrate by methane generating bacteria declined. The total amount of gas produced was 52,104 liters during these 5 weeks from 1,085 Kg of batch feed. The gas was measured by making scale on floating drum of the unit and was utilized daily as it was produced. The gas production trend is explained in the graph in which it shows that gas production.

The resulting production of biogas was 48.02 liters/kg

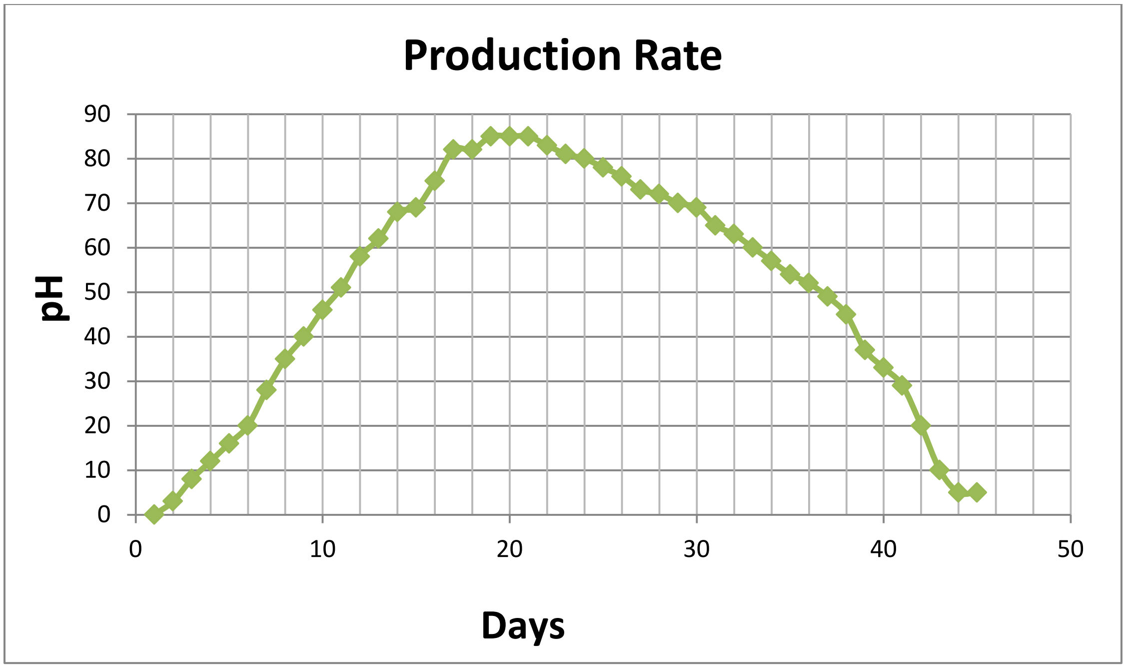


Figure 23 - Biogas production measured against Time (days)

4.1.4 Biogas Flame

Biogas burned with a blue flame on. The flame was obtained due to increased production of biogas. The experiment showed that this process of biogas production from food waste was successful and that the biogas can be used for heating and cooking purpose.

Figure 24- Ignited biogas to observe the Flame

5 BIOGAS PRODUCTION UNDER MESOPHILIC CONDITION

A separate experiment was done on small scale in a small tank having a volume of 180 liters. In order to observe the gas production pattern in mesophilic condition.

5.1 Biogas Digester

The experiment under mesophilic condition was carried out in a 180 litres container having two opening at the top. One opening has a gas nozzle installed in and through the other opening raw feed was added. This experiment was also carried out for batch.

5.2 Total Feed Added in Tank

Figure 25- Biogas Digester used under Mesophilic Condition

Table 9 - Composition of Feed in Tank	
Feed in tank	**weight (kg)**
Potatoes	10
Spinach	10
cow dung	5

In this batch food was first shredded manually using knife and the feed size was about 0.5 to 1 inch. After shredding, food was left in an open container for pretreatment. Water was also added in a tank in an equal to waste so that waste was dipped properly. The waste left in an open container for one day before putting in a digester.

The tank was filled with waste and it was closed to allow the process of anaerobic digestion to proceed. It was emptied after a fixed retention time, when the production of biogas had completely stopped.

5.3 Temperature

The temperature inside the tank was monitored by temperature sensor and was displayed on LCD.

Figure 26- Temperature Measuring Device

5.4 Organic Loading Rate

The total capacity of our mesophilic tank was 180 Liter (0.18 m^3), 50 % of which should be waste and 50 % should be water, after proper mixing of the digestate. All the prepared food waste was added in the digester in one day.

5.5 Hydraulic Retention Time

The mesophilic conditions, when maintained properly, reduce the HRT of the feed material. The HRT for this batch was 25-30 days because of low feed. But, generally it is 50-60 days.

5.6 Biogas collection system for Mesophilic Process

The headspace left for biogas collection in digester was 20% of the total volume of digester. The gas produced was collected in a rubber tube.

Figure 27 - Biogas Collected in a rubber tube produced under Mesophilic Condition

5.6.1 Parameters

All the parameters were controlled like in pervious batch of thermophilic condition

Table 10 - Parameters for the Production of Biogas	
C:N ratio	25:1
Moisture content	90 %
pH	6.5-8
Temperature	25-40°C
HRT	25-30 days
Feeding type	Batch feeding

5.6.2 Temperature inside Digester

The average temperature of the inside tank in correlation with average temperature of days are shown in the below graph.

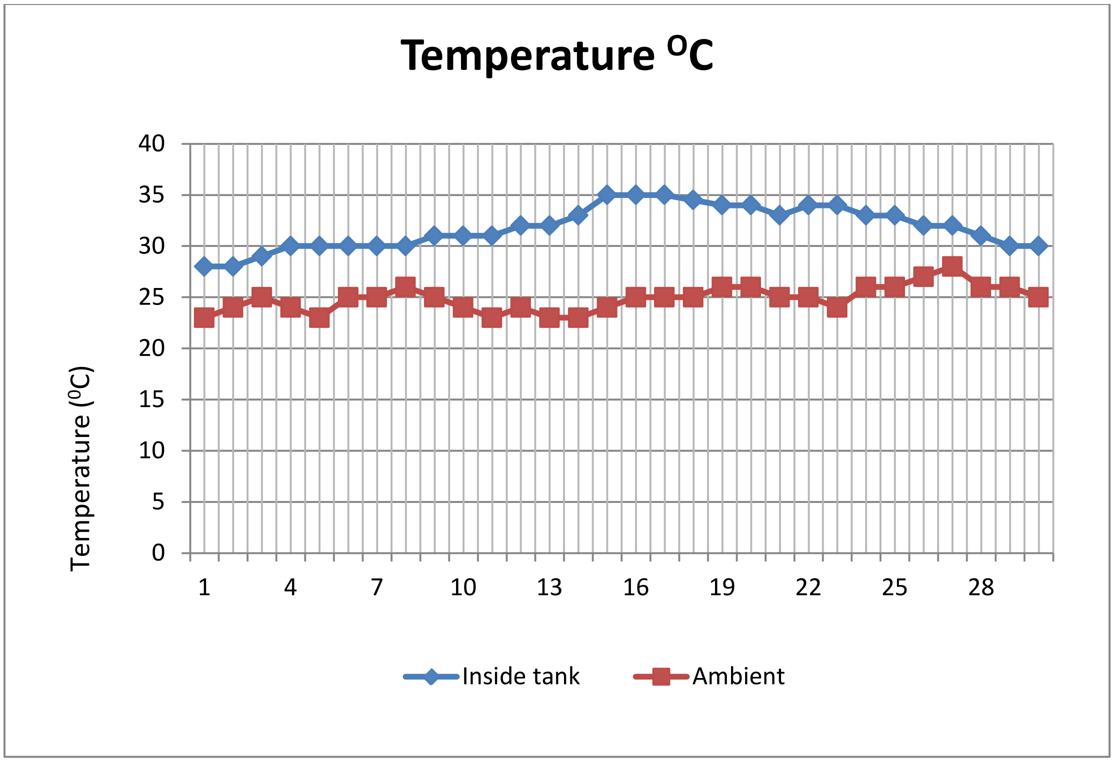


Figure 28 - Correlation between the variations in inside temperature of tank and ambient temperature

5.6.3 pH inside Digester

There was a gradual increase in the pH (from 5.8 to 6.9) of the biomass over a period of approximately 4 weeks. This indicates the decrease in the acidity of the sample which can be attributed to the growth of methane generating bacteria.

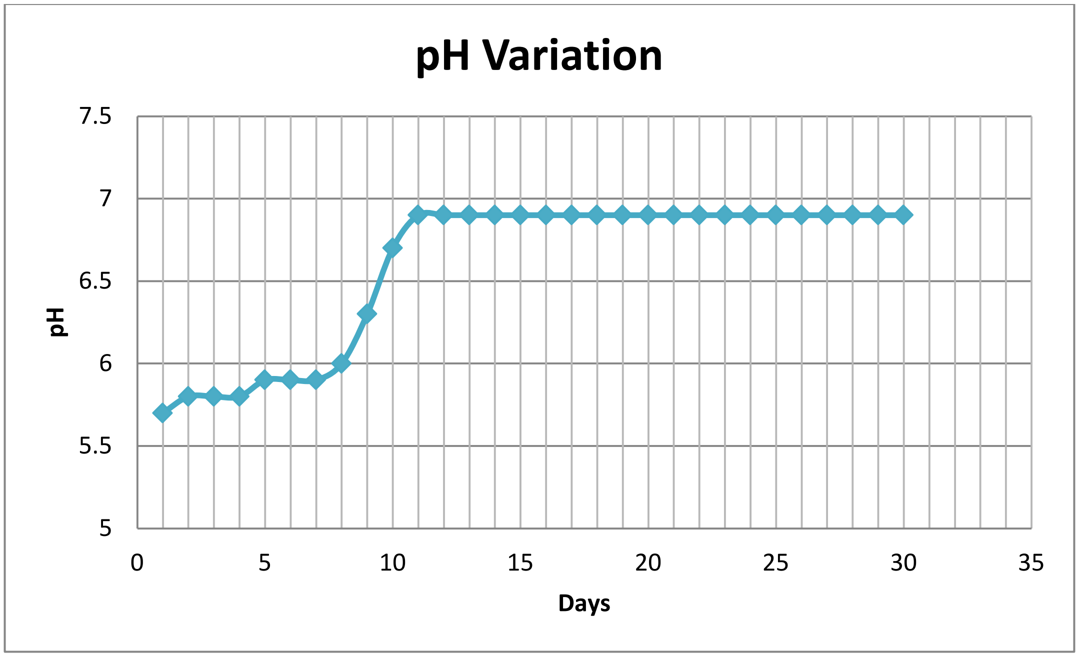


Figure 29 - Variation in pH

5.6.4 Biogas Production

The biogas production trend is explained in the graph measured over a period of time.

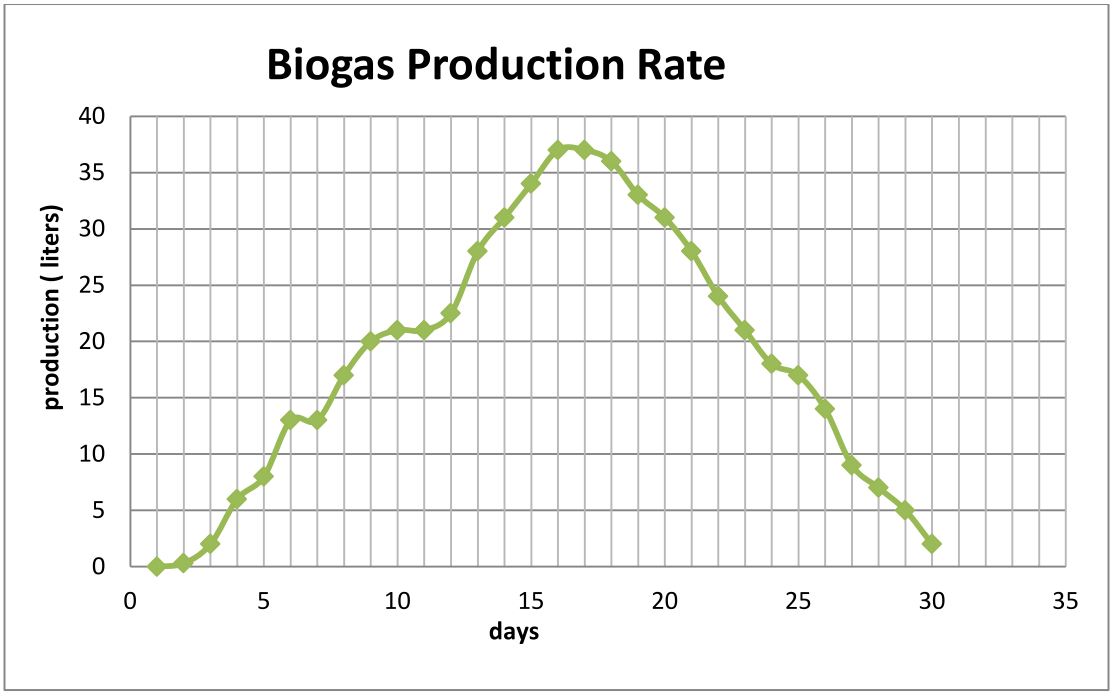


Figure 30 - Biogas production measured against Time (days)

Initially, during the 8 days period the gas production was nil. However its production gradually increased from zero liters to maximum of 37 liters on the 24th day. From then onwards, a decrease in the trend of gas production was seen because of no further batch feeding and consumption of substrate by methane generating bacteria. The total amount of gas produced was 555.8 liters during these 30 days from 12 Kg of batch feed.

5.7 Cumulative Biogas Production for Thermophilic conditions

The cumulative gas production for the batch of thermophilic condition was calculated to be 38,592 liters with production rate of 61.6 L biogas /kg VS. Biogas produced was passed through lime water to remove carbon dioxide and then collected in rubber tube of 50 liters on daily basis from 18th of Feb to 26th of Mar 2012.

Biogas Contents	**Thermophillic**
Methane (CH_4)	62.07
Carbon Dioxide (CO_2)	23.65
Nitrogen (N_2)	14.23

5.8 Cumulative Biogas Production for Mesophilic Conditions

The cumulative gas production for the batch of mesophilic condition was calculated to be 555.8 liters with production rate of 46.3 L biogas/kg VS. Biogas produced was collected on daily basis from 7th April 2012 to 8th May 2012. Initially no gas was produced, but after a week biogas production started that was collected in a rubber tube with a capacity of 20 liters.

5.9 Biogas Plant Effluent Slurry Used as Fertilizer

Biogas effluent slurry or manure is a by-product obtained from the biogas plant after the digestion of biomass or cow dung for the generation of methane rich gas. The effluent slurry provides essential nutrients to plants, enhances water holding capacity and soil aeration, accelerates root growth and inhibits weed seed germination. The liquid slurry is the best form for usage. Apart from its advantages over chemical fertilizers, biogas slurry has proven superiority in its nutrient content with respect to other manures also. The fermentation process is reduced by C/N ratio by removing some of the carbon thus increasing the fertilizing effect. . It is important, that the slurry is covered to prevent the mineralised nitrogen to escape into the air, or to make sure that the slurry is brought to the plants as soon as possible, in this way the mineralised nitrogen is made useful when it still is fully present.

We planted some flowers nearby our bio gas plant and used liquid effluent slurry as fertilizer. Slurry was used directly by irrigating into feet of plants; however it can be mixed with other chemical fertilizers when applying to plants. The growth of plants was noticeable.

Table 11 - Slurry Analysis

Components	**Concentration (mg/L)**	
	Thermophillic	**Mesophillic**
N	84.9	56.4
P	33.4	22.6
K	34.8	26.6

Figure 31- Biogas Plant Effluent Slurry Used as Fertilizer to nourish plants

6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

1) Biogas plant at IESE can produce 0.047m3/kg at production rate of 0.059m3/hr.
2) The experiment showed that this process of biogas production from food waste was successful and that the biogas can be used for heating and cooking purpose.
3) This gas can be stored in cylinders and can be used an alternate fuel .e.g. from one kg of food waste can provide enough energy to cook 15 cups of tea or boil 3.75 liter of water.
4) Pakistan currently suffering from natural gas short fall which is likely to get even worse in future; can take benefit from this renewable energy source.
5) It will not only help to bridge the gap between the supply and demand of natural gas, but, also help to improve the solid waste management system because 50% of our solid wastes include organic content.
6) Land filling and municipal solid waste transportation cost will also decrease.
7) With this Pakistan can register more projects in CDM and earn carbon credits which they can later sell in the international market and generate revenue.
8) This will also ensure that Pakistan is playing its role to encounter global warming.

6.2 Cost and Benefit Analysis

6.2.1 Unit Cost Saving Estimation

- Waste added for one batch = 1.085 ton
- Biogas produced per batch = 54.6 m3
- One m3 of biogas = 0.45 kg LPG
- 54.6 m3 of biogas = 24.6kg LPG
- Cost for one 12kg LPG Cylinder = 1700 PKR

6.2.2 Annual Cost Saving Estimation

- Waste Added Annually = 9.76 ton
- Biogas produced annually = 491.4 m3
- 12 kg LPG Cylinder replaced annually = 18 cylinders

6.2.3 Benefits

- Annually Fuel Saving = 30,600 PKR
- Annual Methane Offset = 3 ton
- Annually Land filing Saving = 300 US$

The above illustration shows that if we put waste in a biogas plant that has no operation cost, but only installation cost, large revenues can be generated along with offsetting large volume of methane gas that could contribute to global warming.

We can also register these biogas plants for CDM projects and sell the offset carbon saving in the form of carbon credits.

6.3 Problems Faced

1) Problems were faced during opening of tank top because the bolts were jammed due to rusting caused by the gas leaking through the lid. This gas contained H_2S.
2) Power failure, due to use of high voltages.
3) It was difficult to work in the field during rain and hot climatic conditions.
4) Size of feed was not uniform, and potatoes passed through the shredder uncut.
5) Formation of scum that trapped the gas inside.
6) Difficulty in mixing the waste manually as no automatic mixer was installed.
7) Maintaining the temperature of digester to 55^0C to have thermophilic conditions.
8) Maintaining the pH from 6.5 to 8 for methanogenesis to start, it was between 5 and 6 in the initial stages which was obtained by adding lime.
9) Difficulty in storing gas due to lack of gas collectors.

6.3.1 Scum Formation

Scum formation is one of the major cause that interrupted the operations of biogas plant. The reason behind scum formation is dry matter. This dry matter has low density as compared to the digestate so it moves up to the top and forms a layer. As the digestion continues more dry matter reaches the top, and eventually this layer gets so thick that it prohibits the passage of flow of biogas outside the digester in the gas holder.

This particular problem was faced by us during our experiment, run for thermophilic batch. A thick 7 inch (18 cm) scum layer was formed inside the digester which didn't allow the biogas to come out of the gas nozzle. We removed it after opening the digester to restore our operations.

The solution to this problem is that you prepare the raw feed well during hydrolysis so that no matter gets dry and forms the scum. With it, a mechanical mixer needs to be installed to homogenize the digestate and remove the scum when formed.

6.4 Recommendations

1) A mechanical mixer should be installed to provide uniform mixing and to avoid formation of scum, so that gas can rise up easily and can be collected.
2) Dry feedstock should not be used as input gas production, because in the later stages this dry material raise to the top and form scum.
3) Insulation system needs to be improved to avoid heat losses and to maintain the temperature in thermophilic conditions to the required value during winter season as well.
4) Fiber shed is essential to avoid any damages done by rain.
5) Proper electricity connection is required, which can support high voltages.
6) Gas collector should be installed for storing biogas and using it for different purposes.
7) Biogas filter should be installed to remove carbon dioxide and hence to get pure methane gas for use.

8) More research and further studies may be conducted to enhance the efficiency of plant.

6.5 Future Prospects

1) Waste from NUST hostels and cafeterias can be used for production of biogas, which will convert NUST to a truly green and zero waste campus.
2) The slurry can be used as fertilizer throughout the campus for better productivity of plants, as it is a better fertilizer.
3) Biogas can be useful for IESE labs as well as for cooking purposes.
4) With the support of Government of Pakistan, new plants can be installed to meet out the demand.
5) Electricity production can be practiced, as it is highly economical

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8 APPENDIX 1

A-1: Biogas production under Thermophilic condition						
S/N	**Date**	**Temperature ◦C**		**pH**	**Biogas Production (Liters/ hr)**	**Biogas production (Liters/day)**
		Inside tank	**Ambient**			
1	18-02-2012	49.2	16	5.5	0	0
2	19-02-2012	49	18	5.5	3	72
3	20-02-2012	51	15	5.6	8	192
4	21-02-2012	51	21	5.9	12	288
5	22-02-2012	52	17	6.2	25	600
6	23-02-2012	52	19	6.5	31	744
7	24-02-2012	53.4	19	6.6	36	864
9	26-02-2012	53	21	6.8	50	1200
10	27-02-2012	54	23	6.9	54	1296
11	28-02-2012	54	23	6.9	56	1344
12	1-03-2012	55	25	6.9	59	1416
13	2-03-2012	55	24	6.9	62	1488

14	3-03-2012	55.2	25	7.0	65	1560
15	4-03-2012	52.5	26	7.0	68	1632
16	5-03-2012	55.5	23	7.0	69	1656
17	6-03-2012	56	23	7.1	77	1848
18	7-03-2012	56	23	7.2	82	1968
19	8-03-2012	56.1	21	7.3	82	1968
20	9-03-2012	56	24	7.4	85	2040
21	10-03-2012	57	24	7.5	85	2040
22	11-03-2012	57	21	7.5	85	2040
23	12-03-2012	57.2	19	7.6	83	1992
24	13-03-2012	57.5	22	7.7	81	1944
25	14-03-2012	57	24	7.7	80	1920
26	15-03-2012	58	28	7.7	78	1872
27	16-03-2012	58	28	7.7	75	1800
28	17-03-2012	58.2	31	7.8	75	1800
29	18-03-2012	55.5	29	7.8	72	1728
30	19-03-2012	55.7	24	7.8	70	1680
31	20-03-2012	56	19	7.8	69	1656
32	21-03-2012	56.8.	20	7.8	65	1560
33	22-03-2012	57.1	28	7.8	63	1512
34	23-03-2012	57.4	29	7.8	60	1440
34	24-03-2012	57.9	29	7.8	57	1368

35	25-03-2012	58.2	26	7.8	54	1296
36	26-03-2012	58.9	27	7.8	52	1248

9 APPENDIX 2

A-1: Biogas Production Under Mesophilic Condition					
S/N	**Date**	**Temperature ◦C**		**pH**	**Biogas Production (Liters/ day)**
		Inside tank	**Ambient**		
1	7-04-2012	27	28	5.7	0
2	8-04-2012	27	34	5.8	0.3
3	9-04-2012	29	32	5.8	2
4	10-04-2012	29	29	5.8	6
5	11-04-2012	29	26	5.9	8
6	12-04-2012	29	29	5.9	13
7	13-04-2012	30	29	5.9	13
8	14-04-2012	30	31	6.0	17
9	15-04-2012	31	33	6.3	20
10	16-04-2012	31	29	6.7	21
11	17-04-2012	31	29	6.9	21
12	18-04-2012	32	28	6.9	22.5
13	19-04-2012	32	32	7.1	28
14	20-04-2012	33	29	7.3	31
15	21-04-2012	35	31	7.3	34

16	22-04-2012	35	28	7.3	37
17	23-04-2012	35	29	7.3	37
18	24-04-2012	34.5	30	7.3	36
19	25-04-2012	34	31	7.3	33
20	26-04-2012	34	34	7.3	31
21	27-04-2012	33	34	7.3	28
22	28-04-2012	34	36	7.3	24
23	29-04-2012	31	29	7.3	21
24	30-04-2012	31	30	7.4	18
25	1-05-2012	31	31	7.4	17
26	2-05-2012	31	31	7.4	14
27	3-05-2012	33	34	7.4	9
28	4-05-2012	34	35	7.4	7
29	5-05-2012	34	36	7.4	5
30	6-05-2012	34	34	7.4	2