# BIOGAS PRODUCTION FROM FOOD WASTE AT THERMOPHILIC CONDITIONS IN BATCH MODE

**By**

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**Islamabad, Pakistan**

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# DECLARATION

I hereby declare that this dissertation is the outcome of my own efforts and has not been published anywhere else before. The matter quoted in the text has been properly referred and acknowledged.

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# APPROVAL SHEET

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It is certified that the contents and form of this thesis entitled **"Biogas Production from Food Waste at Thermophilic Conditions in Batch Mode"**, submitted by Naila Azhar (2009-NUST-MS-PhD-Env-06) have been found satisfactory for the partial fulfillment of the degree of Masters in Environmental Science.

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# DEDICATION

I dedicate my work to my parents, without their moral support I would have not been able to complete my research work successfully.

# ACKNOWLEDGEMENTS

Many people helped me for completion of this research and it may not be possible to mention all those who were involved in one way or the other.

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# LIST OF ABBREVIATIONS

| Abbreviations | Description |
|---|---|
| ADB | Asian Development Bank |
| ASBR | Anaerobic Sequencing Batch Reactors |
| BMP | Biological Methane Potential |
| C/N ratio | Carbon Nitrogen Ratio |
| CDM | Clean Development Mechanism |
| COD | Chemical Oxygen Demand |
| DAP | Diammonium Phosphate |
| DGNRER | Directorate General of New and Renewable Energy Resources |
| FAO | Food and Agricultural Organization |
| FAS | Ferrous Ammonium Sulfate |
| FVW | Fruits and Vegetable Waste |
| $HNO_3$-$HClO_4$ | Nitric Acid-Perchloric Acid Mixture |
| HRT | Hydraulic Retention Time |
| ICARDA | International Center for Agricultural Research in the Dry Areas |
| IESE | Institute of Environmental Sciences and Engineering |
| Kg | Kilogram |
| KWh | Kilo Watt Hour |

| | |
|---|---|
| L $CH_4$/kg VS | Litre Methane per Kilogram of Volatile Solids |
| L/d | Litres per Day |
| L/hr | Litre per Hour |
| LCD | Liquid Crystal Display |
| $m^3$/kg | Meter Cube per Kilogram |
| MC | Moisture Content |
| mL/g | Milli Litre per Gram |
| MSW | Municipal Solid Waste |
| $Nm^3$/kg | Normal Cubic Metres per Kilogram |
| NCPC | National Cleaner Production Centre |
| OLR | Organic Loading Rate |
| PCAT | Pakistan Council of Appropriate Technology |
| PCRET | Pakistan Council of Renewable Energy Technologies |
| PFBR | Plug-Flow Biogas Reactor |
| Pa | Pascal |
| SNV | Stichting Nederlandse Vrijwilligers |
| TOC | Total Organic Carbon |
| TS | Total Solids |
| VFA | Volatile Fatty Acids |
| VS | Volatile Solids |

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# ABSTRACT

The present study was aimed on the minimization of solid waste disposal and effective reduction in green house gas emissions from the waste. The focus was on analyzing the potential of food waste being produced at NUST as a source for biogas production, for which a pilot biogas plant of 1.2 $m^3$ was installed at IESE. The process was optimized to maximum the biogas yield. The ideal feed size for food waste was found to be 2.5 cm, with a retention time of 17 days in batch mode. The codigestion of food waste with fresh cow dung as a starter gave significantly better results. The process was successfully demonstrated by using a temperature controlled system to maintain thermophilic conditions. It resulted in the biogas production of 0.04 $m^3$ per kg of food waste. The biogas with high methane content of 60% burned with a transparent flame. The process also resulted in the production of nutrient rich slurry with high NPK content and high C/N ratio. This slurry may be used as a natural fertilizer after drying. Thus the food waste proved to be a valuable alternate source of energy. The setup confirmed to be efficient and cost effective as it was not only a cheap source of energy but also a source of nutrient rich organic fertilizer. Therefore the application of biogas technology has economic, environmental, health and social benefits, thereby contributing towards sustainable development.

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND OF STUDY

In developing countries major environmental problems are associated with the lack of proper disposal of solid waste. This issue can be tackled by adopting sustainable methods for the treatment of organic waste as the waste can be used as a source of energy as well as nutrients. Infact, composting and anaerobic decomposition of organic waste are the best options to be considered. As in case of anaerobic decomposition energy in the form of biogas is produced.

Biogas is increasingly becoming an attractive source of energy all over the world. Historical evidence shows that it is one of the oldest technologies. Biogas was already used by the Assyrians during the 10$^{th}$ century BC and later in Persia during the 16$^{th}$ century. Its industrialization began in 1859 with the first plant in Bombay, India. As understanding of the process control and its benefits improved, more sophisticated equipment and operational techniques emerged. But it did not become popular due to low coal and petroleum prices and energy crisis in 1973 and 1979 gave a boost to this technology. It expanded in India, China and Southeast Asia, where human, animal and kitchen waste was used as source of energy (Muller and Dubendorf, 2007).

Europe, North America and the Soviet Union also became involved with research for methane production from animal manure. With the passage of time the process became more complex and was not limited to agriculture or animal waste treatment and the technology is now being applied for treatment of municipal and industrial waste (Shefali, 2002).

Energy has become an important prerequisite for the economic development of a country. Pakistan is presently facing a serious energy crisis, which is costly and multi-dimensional. This extreme shortage of energy resources in the country has lead to increase in fossil fuel prices. Therefore, research for developing alternative biomass for bioenergy has become increasingly important. Food waste is a very good source of biomass to be used in biogas plants for generating energy. This technology will not only produce energy but will achieve waste minimization as well.

In Pakistan, the estimated countrywide biogas potential is 12ï 16 million $m^3$/day (Akhter, 2004). The first biogas plant was installed in 1959 at Tando Jam Sindh (Ilyas, 2006). There are many government departments working on biogas. Directorate General of New and Renewable Resources (DGNRER) under the Ministry of Petroleum and Natural Resources started a comprehensive biogas scheme in 1974 (Sheikh, 2009). The Pakistan Council of Appropriate Technology (PCAT), now Pakistan Council of Renewable Energy Technologies (PCRET) is also working under the Ministry of Science and Technology for the promotion of biogas technology since 1976 (ADB, 2004). It has supported the installation of around 6000 plants till 2008 (SNV, 2007). In the year 2000 Pakistan's biogas support program was started, which has been considered as one of the most successful programs in the country (Ilyas, 2006).

Pakistan has great potential for the production of biogas. There are different types of biogas plants being used in the country for its production, but the most common are floating drum plants, fixed drum plants and concrete plants. The latest technology revealed that fibre plants and other fabricated plants are even more efficient. Therefore this study is based on a fabricated biogas plant, designed especially for food waste.

Minimization of waste has always been a serious problem. Food waste is mainly organic matter, which can be converted to useful energy by biochemical process (Angelidaki *et al.,* 2003). It results in two by-products: biogas and digested organic sludge (Hessami *et al.,* 1996). Biogas is a mixture of gases produced naturally from the decay of organic wastes (Igoni *et al.,* 2008). A variety of factors affect the rate of digestion and biogas production including temperature (Igonia *et al.,* 2007), pH, water/solids ratio, carbon/nitrogen ratio, mixing of the digesting material, the particle size of the material being digested, and retention time (Vindis *et al.*, 2009).

## 1.2 OBJECTIVES

The objectives of the study are:

- To set-up a compact fixed dome biogas plant at IESE.
- To analyze the potential of food waste of NUST for biogas production.
- To study the biogas generation in thermophilic range under batch conditions.

## 1.3 SIGNIFICANCE OF STUDY

Looking at Pakistan's energy demand and living standard of the people, biogas technology is one of the reliable clean renewable energy sources used for cooking and lighting purpose (Ilyas, 2006). It has many local and global environmental benefits.

- It has helped in reducing the use of fuelwood and hence conserves the forests.
- The slurry from the digester is also used as fertilizer, which has replaced the use of chemical fertiliser.
- This technology has health benefits from reduced indoor pollution and improvement of livelihood.
- Each biogas installation reduces $CO_2$ emissions, which helps to reduce the greenhouse effect.
- This technology has also indicated potentials for carbon trading under the Clean Development Mechanism (CDM) (Bajgain and Shakya, 2005).
- It has promoted the idea of waste to energy technology, which plays an important role in municipal solid waste management (Tchobanoglous and Kreith, 2002).

***CHAPTER 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 INTRODUCTION

The process for the production of biogas involves the decomposition of organic matter by micro-organisms in an oxygen-free environment (Hessami *et al.,* 1996). The overall biochemical reaction is simplified as (Vesilind *et al.,* 2002):

$$[Organic\ material] + heat \rightarrow CH_4 + CO_2 + H_2 + NH_3 + H_2S \qquad (2.1)$$

Biogas can be produced from municipal waste, animal dung, human sewage and crop residues (Igoni *et al.,* 2008). It is about 20 percent lighter than air and is an odourless and colourless gas that burns with a clear blue flame, with 60 percent efficiency in a conventional biogas stove. Biogas is mainly composed of 50 to 70 percent methane, 30 to 40 percent carbon dioxide ($CO_2$) and low amount of other gases as shown in table 2.1 (FAO, 1996).

In Pakistan, biogas produced in anaerobic digesters consists of methane ($CH_4$) 50ï 70%; carbon dioxide ($CO_2$) 30ï 35%; nitrogen ($N_2$) 1%; hydrogen ($H_2$) 0.1ï 0.5%; carbon monoxide (CO) 0.1%; hydrogen sulphide ($H_2S$) Traces. The relative percentage of these gases in biogas depends on the feed material and management of the process (Majid, 2006). It is considered as a renewable gas (Kossmann *et al.,* 2008).

| Table 2.1: Characteristics of biogas | |
|---|---|
| Density | 1 - 2 kg/ $m^3$ |
| Calorific value | 20 Mega Joules (MJ) per $m^3$ |
| Ignition temperature | 650 - 750°C |
| Ignition concentration gas content | 6 - 12 % |
| Smell | Odorless |

Source: http://www.energymanager.eu/getResource/10018/biogas.pdf

(Deublein, 2008)

## 2.2 THE CHEMISTRY AND PRODUCTION OF BIOGAS

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 (Vindis *et al.,* 2009). The four main stages of anaerobic digestion consist of:

**2.2.1 Hydrolysis:** In the first step large molecules of carbohydrates, proteins and lipids are broken down and liquefied into smaller components (sugars, fatty acids and amino acids) by the help of extra-cellular enzymes secreted by microorganisms (Rojas *et al.,* 2010). This stage is also known as polymer breakdown stage (FAO, 1996). The amount of methane produced is limited by the hydrolytic reactions (Rojas *et al.,* 2010). The rate of hydrolysis depends upon substrate availability, bacterial population density, temperature and pH (Evans, 2005).

**2.2.2 Acidogenesis:** This involves the production of acetic acid from monomers released in the preceding stage and volatile fatty acids (VFAs), which are derived from the protein, fat and carbohydrate components of feedstock (Evans, 2005). As a result of catabolism, $CO_2$ and $H_2$ are produced during the subsequent fermentative acidogenesis. The major short-chain fatty acids formed include acetate, propionate, butyrate, formate, lactate, isobutyrate and succinate, with acetate predominating (Rojas *et al.,* 2010). The pH falls as the level of these compounds increase. The optimum temperature for acid formation lies at around 30$^{o}$C and optimum pH lies around 6 (Evans, 2005).

**2.2.3 Acetogenesis:** The acids are used in the third step for the formation of mainly acetate ion by the actions of the acetogenic bacteria. Acetate is the major end product of the acetogenesis step in all anaerobic digesters (Rojas *et al.,* 2010). Carbon dioxide and hydrogen are also produced during this phase. An increased concentration of hydrogen has an inhibiting effect on the process (Evans, 2005).

**2.2.4 Methanogenesis:** The products of the acetogenesis are then converted to methane, carbon dioxide and water by the methane-forming bacteria in the final stage (Rojas *et al.,* 2010). This is brought about by obligate anaerobes, whose growth rate is slower than the bacteria responsible for the preceding stages (Vesilind *et al.,* 2002). Hydrogenotrophic methanogens produce around 30% of the $CH_4$ by the reduction of $CO_2$, $H_2$ and the conversion of other substrates (e.g. methanol and methylamines). Whereas acetoclastic methanogens convert acetate to $CH_4$, which account for around 60% of the total amount of methane (Rojas *et al.,* 2010). The optimum pH for this process is 7 (Evans, 2005).

The reactions that takes place in the process of methane production is called **Methanization,** is expressed by the following equations (FAO, 1996):

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (2.2)$$

Acetic acid Methane Carbon dioxide

$$2\,CH_3CH_2OH + CO_2 \rightarrow CH_4 + 2\,CH_3COOH \quad (2.3)$$

Ethanol Carbon dioxide Methane Acetic acid

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O \quad (2.4)$$

Carbon dioxide Hydrogen Methane Water

## 2.3 PROCESS VARIABLES AND OPERATIONAL CONSIDERATIONS

The performance of an anaerobic process is affected by many factors, ranging from process variables to operational considerations. The most important among these are discussed below:

**2.3.1 Input/ Substrate:** Any biodegradable organic material can be used as inputs for processing inside the biodigester. The term substrate refers to the degradable fraction of the input (Batstone *et al.*, 2002b; Moller *et al.*, 2004). Typical substrates for the biogas process are sewage sludge, food waste, waste from food industry, manure from cows and other animals, and residue from agriculture, herbs and plants like grass, etc (Bioforsk, 2008). Different organic materials have different origin and bio-chemical characteristics, so their potential for gas production also varies. Two or more of such materials can be used together for effective gas production and for growth of methanogens (FAO, 1996).

**2.3.2 Starter/ Seeding:** It is often necessary to introduce enriched seeding bacteria into the digester for starting up the anaerobic fermentation process. Generally digested sludge from a running biogas plant, municipal digester, well-rotted manure pit, or cow dung slurry is used as a seed. If, during the operation, volatile fatty acids are accumulated due to overloading, this can be corrected by reseeding and temporarily suspending the feeding of digester or by adding lime. Addition of inoculum tends to improve both the gas yield and methane content in biogas. It is possible to increase gas yield and reduce retention period by addition of inoculums (Yadvika *et al.,* 2004). Rojas *et al.* (2010) observed that the addition of manure slurry to the batch reactor as part of the starter improved the biogas production.

**2.3.3 Internal Mixing:** Stirring of digester contents needs to be done to ensure close contact between microorganisms and substrate resulting in improved digestion and more gas production. Agitation of digester contents can be carried out in a number of ways. For example daily feeding of slurry and recirculation of gas gives the desired mixing effect. Stirring can also be carried out mechanically by installing certain stirrer, piston or scraper in the plant (Yadvika *et al.,* 2004). Rojas *et al.* (2010) conducted experiments and found that absence of stirring yielded only about 50% of the expected biogas for the investigated substrates.

**2.3.4 Dilution and Consistency of Inputs:** The more diluted media in the reactor allowed a better contact between the bacteria and the substrates making stirring not necessary (Rojas *et al.,* 2010). Before feeding the digester, the waste, especially fresh cattle dung, has to be mixed with water in the ratio of 1:1, on a unit volume basis (i.e. same volume of water for a given volume of dung). If the dung is in dry form, the quantity of water has to be increased accordingly to arrive at the desired consistency of the inputs (e.g. 1:1.25 to 1:2). The dilution is made to maintain the total solids from 7 to 10 percent. If the slurry is too diluted, the solid particles will settle down into the digester, and if it is too thick, the particles would hinder the flow of gas formed at the lower part of digester. As a result the gas production will be less than optimum (FAO, 1996).

**2.3.5 Particle Size:** The size of the feedstock should not be too large otherwise it would result in clogging of the digester and also it would be difficult for microbes to carry out its digestion. Smaller particles provide large surface area for adsorbing the substrate that would result in increased microbial activity and hence increased gas production. Large particles can be used for succulent materials such as leaves. But for other materials such as straw, large particles could decrease the gas production. The shredding of waste can reduce the volume of digester required, without decreasing the biogas production (Yadvika *et al.,* 2004).

**2.3.6 pH:** Optimal growth of each of the microbial groups involved in anaerobic degradation is closely connected with pH since it effects the enzyme activity of microorganisms for their metabolism (Hwang *et al.,* 2004). The optimum biogas production is achieved when the pH value of the input mixture in the digester is between 6 and 7. The pH in a biogas digester is also a function of the retention time. In the initial period of fermentation, the pH inside the digester can decrease to below 5 because of the production of organic acids. This inhibits, or even stops, the digestion or the fermentation process. Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.5. Later, as the digestion process continues, concentration of $NH_4$ increases due to digestion of nitrogen which can increase the pH value to above 8. When the methane production level is stabilized, the pH range remains buffered between 7.2 to 8.2 (FAO, 1996; Evans, 2005)

**2.3.7** **Temperature:** There is a close relationship between the biogas fermentation and the temperature of the reactor. There are three effective temperature ranges for anaerobic digestion, each of which has its own favored group of bacteria. These ranges are psychrophilic (12-18°C), mesophilic (25-45°C) and thermophilic (50-65°C) (Metcalf and Eddy, 2003). However, anaerobes are most active in the mesophilic and thermophilic temperature range. The length of fermentation period is dependent on temperature (Yadvika *et al.,* 2004). Most important is the effect of temperature on the growth rate and activity of the methanogenic organisms. Within the temperature range of one species the growth rate increases exponentially until an optimum temperature is reached; the growth rate undergoes an exponential decline if the optimum temperature is exceeded (Van Lier *et al.,* 1997; Boe, 2006).

**2.3.8 Nutrient Content**: Efficient biodegradation requires that carbon source and nutrients are available in sufficient amounts in the substrate (Schon, 2009). Generally, in anaerobic digestion, microorganisms utilize carbon 25ï 30 times faster than nitrogen. Thus, to meet this requirement, microbes need a 20ï 30:1 ratio of C to N with the largest percentage of the carbon being in a readily degradable form. Waste material that is low in C can be combined with materials high in N to attain the desired C:N ratio of 30:1 (Yadvika *et al.,* 2004).

**2.3.9 Solid Concentration:** The amount of fermentable material of feed in a unit volume of slurry is defined as the solid concentration. The total solids concentration of the waste influences the pH, the temperature and the effectiveness of the microorganisms in the decomposition process. Usually solids concentration of 7ï 9% is best-suited. Results show that the amount of biogas produced as a power function of the %TS concentration, indicating that as the process continues, a time comes when any marginal increase in the %TS concentration would no longer contribute to the increasing volume of biogas produced (Igoni, 2008; Yadvika *et al.,* 2004).

**2.3.10 Hydraulic Retention Time:** HRT is the average time spent by the input slurry inside the digester before it comes out. In tropical countries like India, HRT varies from 30ï 50 days while in countries with colder climate it may go up to 100 days (Yadvika *et al.,* 2004). The retention time depends upon the temperature, higher the temperature smaller will be the retention time and vice versa. According to Eder and Schulz (2006) HRT also depends on the characteristics of the substrate: the easier a substrate can be degraded the shorter the required HRT. HRT can be estimated from the generation times of the microorganisms involved in anaerobic digestion. Generally, HRT controls the gas yield to a great extent (Dhanya *et al.,* 2009).

**2.3.11 Organic Loading Rate:** Loading rate is the amount of raw materials fed per unit volume of digester capacity per day. It is very important for the efficiency of anaerobic digestion as a means of material stabilization. The loading depends upon the input waste characteristic, wetness, plant design, digester volume and retention time. If the plant is overfed, acids will accumulate and methane production will be inhibited. Similarly, if the plant is underfed, the gas production will also be low (FAO, 1996; Evans, 2005).

**2.3.12 Toxicity:** Toxicity normally has irreversible effect on the biodigester. Inhibition, which is reversible, precedes toxicity as the concentration of a compound is increased. Inhibitory substances either affect the cell structure or the enzymes involved in metabolism (Eder and Schulz, 2006). A number of substances have toxic effects; even the required bacterial nutrients may become toxic at higher levels. Sometimes, heavy metals are produced during biodegradation in high concentration, which are toxic for the microbial population. Thus the input material is very important for determining the process stability (Evans, 2005).

## 2.4 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 (Igonia *et 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).

### 2.4.1 Types of Biogas Plant

Throughout the world, countless number of designs of biogas plants have been developed under specific climatic and socio-economic conditions. Many different shapes and styles of biogas plants have been experimented with: horizontal, vertical, cylindrical, cubic, and dome shaped. There are broadly three common types of biogas plants in Pakistan, namely fixed dome, floating drum and bag plant (PCRET, 2005).

**2.4.1.1 Fixed-dome plants:** Since it is underground plant, so steady temperature can be maintained inside the digester. Stirring and scum breaking is generally difficult. Gas pressure control is difficult. Exhaust slurry is to be taken out manually.

**2.4.1.2 Floating-drum plant:** It consists of a cylindrical or dome-shaped digester and a moving, floating gas-holder, or drum. Gas pressure is regulated by the weight of the gasholder. The gas-holder floats either directly in the fermenting slurry or in a separate water jacket. Gasholder helps in stirring/ scum breaking. If biogas is produced, the drum moves up, if gas is consumed, the gas-holder sinks back.

**2.4.1.3 Bag/ balloon type plant**: It consist of a heat sealed plastic or rubber bag (balloon), the top and bottom parts of which serve as the gasholder and digester, respectively. The requisite gas pressure is achieved by weighting down the bag. Since the material has to be weather-resistant, specially stabilized, reinforced plastic or synthetic material is preferred (PCRET, 2005).

**2.4.1.4 Horizontal plant:** Horizontal biogas plants are used in case of shallow installation due to groundwater or rocks. They are made of masonry or concrete plants.

**2.4.1.5 Earth-pit plant:** It is sufficient to line the pit with a thin layer of cement (wire-mesh fixed to the pit wall and plastered) in order to prevent seepage. The edge of the pit is reinforced with a ring of masonry that also serves as anchorage for the gas-holder. The gas-holder can be made of metal or plastic sheeting. The requisite gas pressure is achieved by placing weights on the gas-holder. An overflow point in the peripheral wall serves as the slurry outlet.

**2.4.1.6 Ferro-cement plants**: This type of construction can be applied either as a self-supporting shell or an earth-pit lining. The vessel is usually cylindrical. Very small plants (volume under 6 $m^3$) can be prefabricated. As in the case of a fixed-dome plant, the ferrocement gasholder requires special sealing measures (proven reliability with cemented-on aluminium foil).

### 2.4.2 Specifications of Biogas Plant

The specifications of biogas plant are given in the table below:

**Table 2.2: Specifications of biogas plant**

| Criteria | System | Characteristics |
|---|---|---|
| Dry matter content | Wet fermentation | Upto ca. 15 % DM content |
| | Dry fermentation | From 25-35 % DM content |
| Staging | Single stage | All decomposition stages at the same time alongside each other. |
| | Two stage | Separation of hydrolysis and methane formation. |
| | Multi stage | Separation of hydrolysis, acid formation and methane formation. |
| Charging | Continuous | The same quantity of substrate added and removed daily. |
| | Batch operation | Complete filling and complete emptying. Change-out receptacle necessary. |

| | | |
|---|---|---|
| Fermenter form | Fermentation channel | Long, rectangular, concrete. |
| | Horizontal tank | Steel receptacle e.g. used oil storage tank |
| | Vertical circular receptacle | Silo made of concrete or steel |
| Mixing | Mechanical | Slow moving central agitator, rapid moving side located agitator, paddle agitator (for horizontal fermenters) |
| | Hydraulic | External pump |
| | Pneumatic | Injection of biogas, utilization of the gas pressure for production of a hydraulic gradient. |
| Substrates | Agricultural plants | Liquid manure, manure, cut green material. |
| | Co-fermentation plants | Liquid manure, manure, cut green material + certain waste material (e.g. fat) |
| | Industrial plants | Only certain waste materials (e.g. green waste) |

Source: http://www.energymanager.eu/getResource/10018/biogas.pdf

## 2.5 BIOGAS PRODUCTION FROM FOOD WASTE

The main focus of the biological treatment of waste is the stabilization of biodegradable material present in the waste. Organic waste is biodegradable, and the ease with which it breaks down depends upon the nature and the amount of a particular material in the feedstock. The materials which cannot be digested interfere with the homogenization and mixing of the digester contents. Therefore, the feedstock is generally optimized before putting it in the digester (Evans, 2005).

Fruit wastes have a large amount of pectin which decomposes easily to organic acids and becomes pulpy. This eventually slows down anaerobic and aerobic decomposition processes. It was found that fruit wastes also produce large amount of leachate, therefore it need to be mixed with leachate absorbing materials (dry wastes) for good composting. Such a feedstock has good biological methane potential (BMP) and biogas production under a mixed feed operation. It leads to the production of 0.18 $m^3$ biogas/kg VS and had BMP of 0.55 $m^3$/kg (Chanakya *et al.,* 2007).

Zhang *et al.* (2007) characterized food waste collected in San Francisco for anaerobic digestion processes under batch conditions at 50°C. The daily average moisture content (MC) and the ratio of volatile solids to total solids (VS/TS), determined from a week-long sampling, were 70% and 83%, respectively. The nutrient content analysis showed that the food waste contained well balanced nutrients for anaerobic microorganisms. The methane yield was determined to be 348 and 435 mL/gVS, respectively, after 10 and 28 days of digestion. The average methane content of biogas was 73%. The average VS destruction was 81% at the end of the 28 day digestion test. The results of this study indicate that the food waste is a highly desirable substrate for anaerobic digesters with regards to its high biodegradability and methane yield.

Dearman and Bentham (2007) studied anaerobic digestion of food waste due to its high methane potential. To maximise methane yield, a sequential batch anaerobic system was chosen as the most appropriate system. Two sets of sequential batch systems, consisting of mature and start-up reactors in triplicate exchanged leachate.

Results showed that by increasing the leachate volume between mature and start-up reactors, the time to degrade feedstock decreases, but total methane generation yields did not markedly differ, being 229 $LCH_4$ kg($^{-1}$) VS added and 214 $LCH_4$ kg($^{-1}$) VS added.

Chanakya *et al.* (2009) studied the decomposition patterns and changes in chemical composition of waste streams used as feedstocks. Components like cabbage waste, banana peels, and orange peels degraded rapidly both in a plug-flow biogas reactor (PFBR) as well as under a biological methane potential (BMP) assay, while other components like leaf litter from bamboo and teak leaves and newsprint degraded very slowly. In fruit and vegetable wastes, a rapid and efficient removal of pectins is the main cause of quick biodegradation of these feedstocks. And it left behind only 2-5 % of compost forming residues.

Guangqing *et al.* (2009) determined biogas and methane yields of food and green wastes and their mixture using batch anaerobic digesters at mesophilic (35 ± 2 °C) and thermophilic (50 ± 2 °C) temperatures. The mixture was composed of 50% food waste and 50% green waste, based on the volatile solids (VS) initially added to the reactors. About 80% of the biogas production was produced in the first 10 days of digestion process. The biogas and methane yields from mesophilic digestion of food waste, green waste and their mixture were lower than the yields obtained at thermophilic temperature. The biogas yields were 430, 372 and 358 mL/g VS, respectively, and the methane yields were 245, 206, and 185 mL/g VS, respectively.

Mandachittibabu *et al.* (2009) carried out a study for determination of the treatability of vegetable solid wastes by co-digestion with municipal sewage and cattle slurry in different ratios. The laboratory batch scale analysis was carried out to determine the effects of various process parameters on startup and digestion. The pretreatment of vegetable solid waste has resulted in effective co-digestion and increased biogas yield. For this the optimum ratio of vegetable wastes to inoculum (cow dung and anaerobic sewage sludge in the ratio of 1:1) was found to be 1:2.

Bouallagui *et al.* (2009) analyzed the effect of the addition of co-substrates on the fruit and vegetable waste (FVW) anaerobic digestion performance under mesophilic conditions using four anaerobic sequencing batch reactors (ASBR). The reactors were operated at an organic loading rate of 2.46-2.51 g volatile solids (VS)L/d, of which 10% were co-substrates and 90% were FVW. The hydraulic retention time of the process was 10 days. It enhanced biogas yield by 51.5-43.8% and total volatile solids removal by 10-11.7%. There was low VFAs/Alkalinity ratio of 0.28, and a decrease in the C/N ratio from 34.2 to 27.6. A C/N ratio between 22 and 25 seemed to be better for anaerobic co-digestion of FVW with its co-substrates. There was improvement in the organic nitrogen content provided by the additional wastes.

Voegeli *et al.* (2009) evaluated the suitability of a small-scale biogas system as a decentralised treatment option for the organic fraction of market and household solid waste in Dar es Salaam, Tanzania. The system proved to be effective in terms of the reduction of waste volume and organic loading. Laboratory analyses were conducted for determining various parameters of the feedstock (TS, VS, COD total, COD dissolved, N total, $NH_4$-N, and P total) and effluent (TS, VS, COD total, COD dissolved, N total, $NH_4$-N, P total, $PO_4$, Pb, Cu, Cd). The result showed that one ton of food waste can produce 160-200 $m^3$ of biogas. The HRT of 42.5 days was designed to compensate for incomplete mixing.

El Mashad *et al.* (2010) evaluated the effect of manure-screening on the biogas yield of dairy manure in batch digesters under mesophilic conditions (35°C). The study determined the biogas production potential of different mixtures of unscreened dairy manure and food waste and compared these with the yield from manure or food waste alone. Methane yield of the food waste was 353 L/kg VS after 30 days of digestion. The results showed that adding the food waste into a manure digester at levels up to 60% of the initial volatile solids significantly increased the methane yield for 20 days of digestion.

Velmurugan *et al.* (2010) examined the anaerobic co-digestion of fruit and vegetable wastes (FVW) and primary sewage sludge, which was carried out in a batch reactor under ambient temperature conditions. Three different proportions (25:75, 50:50 and 75:25 in terms of VS) of fruit and vegetable wastes and primary sewage sludge were studied for an organic loading rate (OLR) of 1.0 g VS/d and with HRT of 25 days. The reactor with 75% FVW and 25% sewage sludge showed better performance in terms of VS reduction and biogas yield when compared to other two proportions.

Satoto *et al.* (2010) examined co-digestion of water from organic municipal wastes and of homogenized food residues with defibered kitchen waste as the main substrate to improve biogas production. The digester was operated at a high organic loading (OLR) of 12.3 kg COD $m^{-3}$ $d^{-1}$. The addition of co-substrates increased the biogas production rates and total biogas production. By feeding the two co-substrates up to 20 kg COD $m^{-3}$ $d^{-1}$ gas production followed the increasing OLR linearly. Addition of water or food waste to biowaste co-digestion resulted in a higher buffer capacity, allowing very high loadings without pH control.

Elango *et al.* (2007) conducted experiments to investigate the production of biogas from municipal solid waste (MSW) and domestic sewage by using anaerobic digestion process. The batch type of reactor was operated with a HRT of 25 days. The maximum biogas production of 0.36 $m^3$/kg of VS added per day occurred at the optimum organic feeding rate of 2.9 kg of VS/$m^3$/day. The maximum reduction of TS (87.6%), VS (88.1%) and COD (89.3%) also occurred at the same organic loading rate. The quality of biogas produced during anaerobic digestion process was 68–72%.

Banks *et al.* (2011) monitored an anaerobic digestion of food waste collected from domestic kitchens. Over 90% of the material entering the plant was converted into gaseous or digestate products. The energy balance showed that for each tonne of input material the potential recoverable energy was 405kWh. Biogas production in the digester was stable at 642$m^3$/tonne VS added with a methane content of around 62%. The nitrogen in the food waste input was on average 8.9kg/tonne.

*CHAPTER 3*

# METHODOLOGY

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This chapter describes the materials and method for:

- the experimental set-up for biogas production
- operational parameters
- physical and chemical analysis of biogas and slurry

## 3.1 INSTALLATION OF BIOGAS PLANT

The significance of biogas all over the world shows that we can implement this technology in NUST, Sector H-12 Campus. The study area for the research was the biogas plant being installed in IESE, for converting the organic waste into a source of renewable energy. NUST is located at a distance of about 10 km from zero point towards Golra toll tax on Kashmir Highway. It is about 1 kilometer off the Kashmir Highway.

A specially designed fixed dome fabricated biogas plant of 1.2 $m^3$ was installed at IESE. For this about 3 meters deep well was dug in the ground, with 2 meter diameter. The plant was designed in such a way to keep the temperature of waste inside at a suitable temperature, which is necessary for its decomposition.

The main part of biogas plant was the digester, its specifications were: volume 1.2 $m^3$, diameter 0.9 m and height 1.8 m. It was a specially designed multilayered structure, consisting of a fibre glass layer, between two layers of steel. The digester has an inlet from where the waste was introduced, and an outlet from where the slurry comes out. A pretreatment tank was constructed near the plant to treat the food waste. An effluent tank was also constructed along the outlet to collect the effluent slurry, displaced from the digester due to gas pressure. The effluent slurry goes back to the digesteras the biogas accumulated in the gas storage portion is consumed. Thus the effluent slurry regulates the gas pressure in gas storage part of the digester.

The cost of a fixed-dome biogas plant is relatively low. It is simple as no moving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected. The plant was fixed underground, protecting it from physical damage. While the underground digester was protected from low temperatures at night and during cold seasons, sunshine and warm seasons take longer to heat up the digester. No day/night fluctuations of temperature in the digester positively influence the bacteriological processes.

Figure 3.1: Components of biogas plant setup

## 3.2 RESEARCH PHASES

The study includes three phases described below:

**3.2.1 Acclimatization phase:** The first batch was processed just to acclimatize the newly installed biogas plant. Therefore it is called as Acclimatization phase. The duration of this batch was of 30 days. No production of biogas was observed during this phase.

**3.2.2 Batch I:** The actual study started from this phase as the biogas production started in this batch. The results of this batch were analyzed and compared with the next batch.

**3.2.3 Batch II:** The last batch was the most successful batch, as maximum production was observed in this batch. The ideal conditions were maintained successfully during this batch.

## 3.3 SART-UP OF BIOGAS PLANT AND OPERATIONAL PARAMETERS

The following operational parameters were significant in starting up the biogas plant under study:

**3.3.1 Collection of Waste:** The average generation of food waste in NUST H-12 campus is around 860 kg per day. The food waste including leftover of vegetables and fruits was collected from cafeteria, hostels, institutes and residential area for making biogas. The waste was analyzed and segregated and then it was weighed at the plant site using a weighing balance. The composition of food waste by weight (kg) is given in the table below.

**Table 3.1: Composition of waste by weight (kg)**

| Sr No | Food item | Batch I (kg) | Batch II (kg) |
|---|---|---|---|
| 1 | Cabbage | 55 | 50 |
| 2 | Cauliflower | 70 | 50 |
| 3 | Cucumber | 50 | 60 |
| 4 | Eggplant | 60 | 50 |
| 5 | Potato | 40 | 70 |
| 6 | Capsicum | 20 | 45 |

| | | | |
|---|---|---|---|
| 7 | Water melon | 65 | 50 |
| 8 | Spinach | 30 | NIL |
| 9 | Bottle guard | 60 | 70 |
| 10 | Beans | 10 | NIL |
| 11 | Mango | 20 | 45 |
| 12 | Banana | 20 | NIL |
| 13 | Tomato | 50 | 60 |
| **Total food waste** | | **550** | **550** |

**3.3.2 Preparation of Waste:** In batch I food waste was shredded by using a shredder, installed near the plant along with a 1.5 HP motor. The feed size was about 3.5 cm. In batch II the waste was cut manually by using a knife to reduce the feed size to 2.5 cm. Each piece of waste was further cut into small pieces to reduce the feed size and to make the process of degradation more effective. After shredding, the waste was added in the pretreatment tank for preparation. Water was also added in the tank equal to the quantity of waste, so that the waste was dipped properly. Then the waste was left for 3 to 4 days (from the date of receiving it) before putting it into the digester.

**3.3.3 Batch Condition:** The batch conditions were applied to all the phases, in which the organic material was loaded for certain fixed period. The plant was filled 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.

**3.3.4 Temperature Controller:** An electronic sensor circuit was installed to monitor the temperature inside the digester and water tank, combining a thermocouple and a temperature regulator. It had an LCD on which the temperature was displayed. A 4 m long heating coil made up of 1 inch diameter copper pipe was fixed inside the digester, to allow the hot water to flow through the pipe, making the digester content warm. The temperature of circulating water was maintained at 60 to 65$^{o}$C for thermophilic conditions. In addition, pieces of styrofoam were also placed around the digester for controlling temperature in extreme winter conditions. They were then covered with mud, to fix them properly and not let the rain water to get in. Voegeli *et al.* (2009) conducted a similar study and used 20-m long heating coil made of 19-mm diameter copper pipe located within the digester. In order to keep the contents of the digester at the optimum temperature of 35°C at all times, for the worst condition during winter, hot water at 60°C and a maximum flow rate of 8L/min is required.

Figure 3.2: Cross sectional area of biogas plant showing copper coils for hot water circulation

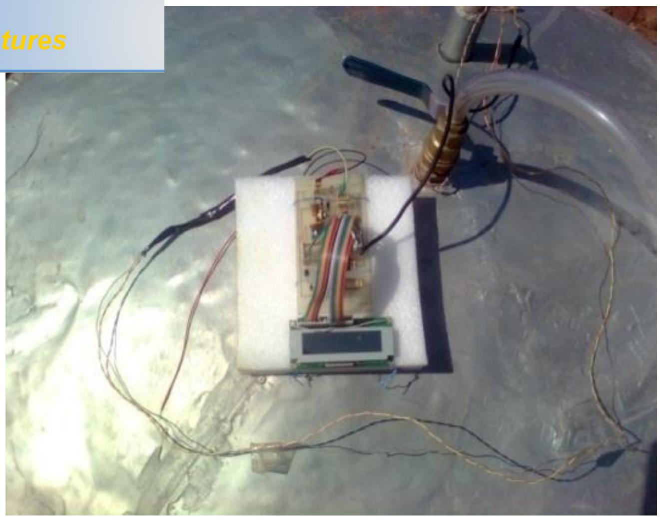

Figure 3.3: Thermocouple circuit for maintaining hot water circulation

**3.3.5 Water Recirculation System:** A water tank was placed near the plant, in which water was heated using an electric rod. A recirculation pump was also installed inside the water tank, to help recirculate the water. This helped hot water to flow through a pipe and enter into the coils of the digester. The water flows out of the digester from another opening, to which pipe is attached, allowing the same water to recirculate. The thermocouple keeps the temperature of water at the required temperature to maintain the digester conditions.

**3.3.6 Organic Loading Rate:** The total capacity of our plant was 1200 litres (1.2 $m^3$), 50 % of which should be waste and 50 % should be water, for proper mixing of the digestate. All the prepared food waste was added in the digester in one day for all the batches.

**Table 3.2 Organic loading rate for Batch I and II**

| Parameter | Batch I | Batch II |
|---|---|---|
| Total amount of food waste | 550 kg | 550 kg |
| Amount of fresh cow dung | NIL | 100 kg |
| Amount of seeding from existing biogas plant | 100 L | NIL |
| Amount of water | 500 L | 500 L |
| Total feed material | 1150 L | 1150 L |
| Total capacity of digester | 1200 L | 1200 L |

**3.3.7 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 litres of processed slurry was added in the plant as starter in batch I. 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. Cow dung was not added in this batch. In batch II only 100 kg of fresh cow dung was added in the disgester. The fresh cow dung was brought from a cattle farm in G-12 on Kashmir Highway, Islamabad. It was mixed with equal amount of water to make slurry, before putting into the digester, as according to many studies cow dung and effluent slurry both speeds up the biological degradation of waste for biogas production.

**3.3.8 Hydraulic Retention Time:** As discussed earlier, HRT depends upon the size of the digester and the amount of waste being digested. The 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. The HRT of all the batches is given in table 3.3.

**Table 3.3 Comparison of HRT of Batches**

| Sr No | HRT |
|---|---|
| Acclimatization phase | 30 days |
| Batch I | 21 days |
| Batch II | 17 days |

**3.3.9 Gas storage chamber:** The headspace to be left for biogas collection in the digester should be 10 to 15% 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.

## 3.4 SAMPLING

**3.4.1 Sampling of Feed Material:** A representative sample of the feed material was taken from the raw waste, as received from the generation source.

**3.4.2 Sampling of Digestate:** The digestate samples were taken from the outlet channel 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 100 ml plastic bottles which were sealed properly before taking for lab analysis.

**3.4.3 Sampling of Biogas:** There are two openings on the top of the dome of digester; one of which was used for the analysis of biogas, its production and composition. For this, a gas collection fixture was installed along with a nozzle and a valve. A gas pipe was connected to the fixture for taking samples of biogas. The samples were collected in football bladders to analyze the biogas composition.

**3.4.4 Sampling of Effluent Slurry:** The samples were taken from the slurry collected in the effluent tank. The slurry samples were also taken in plastic bottles.

## 3.5 DATA COLLECTION SCHEME

The following table is showing the scheme of data collection for this study.

**Table 3.4: Data collection scheme**

| Sr No | Parameter | Material to be analyzed | Interval for sampling |
|---|---|---|---|
| 1 | Feed size | feed | Once at the start of batch |
| 2 | Moisture content | | Once at the start of batch |
| 3 | Ash content | | Once at the start of batch |

| | | | |
|---|---|---|---|
| 4 | pH | | daily |
| 5 | Temperature inside digester | | 3 times a day |
| 6 | Ambient temperature | digestate | 3 times a day |
| 7 | TS & VS | | daily |
| 8 | COD | | daily |
| 9 | Volume of gas | | 3 times a day |
| 10 | Pressure of gas | | 3 times a day |
| 11 | Flame of gas | Biogas | When production becomes maximum |
| 12 | Composition of gas | | Once in a week |
| 13 | NPK analysis | Effluent slurry | Once at the end of batch |
| 14 | C/N ratio | | Once at the end of batch |

## 3.6 ANALYTICAL PROCEDURE

All the parameters tested during the study for the performance evaluation of biogas plant were analyzed using standard methods.

### 3.6.1 Analysis of Feed Material

The proximate analysis was done to analyze the potential of food waste to produce biogas.

**3.6.1.1 Feed size:** The initial analysis of feed material includes the analysis of feed size. It was measured by using a measuring scale. The feed size needs to be maintained according to the standard limits. According to EPA report by Hedman (2009), the appropriate feed size for a biogas plant is between 0.6 to 5 cm.

**3.6.1.2 Moisture content:** For the proximate analysis of waste a representative sample was taken from the raw waste, as received from the generation source. Half of the sample was used to measure the pH of the waste, by mixing it in 20 ml of distilled water. 20 g of the sample was dried in the oven Model WTC Blender for about 24 hours at 103°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 (APHA, 2005).

$$\square\ \square\square\square\square\square\square\,\%\ \square\,/\,\square = \frac{\square\ \square\square\ \square\square\ \square\square\square}{\square\ \square\square\square\square\square\ \square\square\ \square\square\ \square\square} \times 100 \qquad (2.5)$$

$$= \frac{\square^{\square}\square\ \square^{\square}}{\square^{\square}\square\ \square^{\square}} \times 100$$

$m^1$ = Weight of empty dish

$m^2$ = Weight of empty dish + sample before drying

$m^3$ = Weight of empty dish + sample after drying

**3.6.1.3 Ash content:** The sample was placed in muffle furnace Model NEY M 525 Series III at 550°C for 5 hours, to measure the ash content. Water and other volatile materials were vaporized and organic substances were burned. After taking it out from furnace, it was stored in desiccator for half an hour before analysis. The sample was then weighed again (APHA, 2005).

$$\%\ \square\square\square\ \square\square\square\ \square\square\square\square\square = \frac{\square\ \square\square\square\square\ \square\square\ \square\square}{\square\ \square\square\ \square\square\ \square\square\ \square\square\ \square\square\ \square\square\square\square\ \square\square\square\ \square\square\square\square} \times 100 \qquad (2.6)$$

### 3.6.2 Analysis of Digestate

The digestate is the material inside the digester of plant. The analysis of digestate was carried out to check the trend of reduction in the organic content of food waste. The following parameters were analyzed in the lab:

**3.6.2.1 pH:** Electrometric method was used to measure the pH of the digestate samples. The basic principle of this method is the determination of the activity of the hydrogen ions by potentiometric measurement using a standard hydrogen electrode and a reference electrode (APHA, 1998). A glass electrode pH meter Model Cyberscan $500^{pH}$ was used to measure sample pH soon after taking into the laboratory.

**3.6.2.2 Temperature:** A second opening on the dome of digester was used for fixing the temperature sensor, which was placed inside a 1 meter long and 1.25 cm wide copper pipe. As copper is a good conductor therefore it is best suited for our project to check the temperature inside the digester. This pipe was inserted inside the digester from the opening on the dome. The wire of the temperature sensor was connected to an electronic circuit, combining a thermocouple and a temperature regulator. The circuit was placed on the dome. The temperature was recorded from the LCD of the circuit.

**3.6.2.3 Total solids:** Gravimetric method was used to determine solids in the sample. For TS an evaporation dish was weighed to the nearest 0.1 mg. An accurately measured volume of sample in the evaporation dish was placed in the oven at $105^{o}C$. After all the water had evaporated, the dish was cooled in a dessicator, and the dish plus the remaining solids was weighed. Total Solids is the term applied to the material residue left in the vessel (APHA, 2005).

□□□ □/□ = (□□ −□□× □□□□ □ □/□) / (□□□ □□□ □□□□□ □ □ □) □ □/□ (2.7)

$A$ = weight of dried residue + dish after 24 hrs at 105°C (g)

$B$ = weight of dish (g)

$C$ = sample volume (ml)

**3.6.2.4 Volatile solids:** VS are solids that are removed by igniting a sample in a 550°C muffle furnace for 1 hour. The remaining solids represent the fixed total, dissolved, or suspended solids while the weight lost on ignition is the volatile solids. The determination offers a rough approximation of the amount of organic matter present in the solid fraction of wastewater, activated sludge, and industrial wastes (APHA, 2005).

□□□ □ □/□ = (□□ −□□× □□□□ □ □/□) / (□□□ □□□ □□□□□ □ □ □) □ □/□ (2.8)

$A$ = weight of crucible + filter + residue after 24 hrs at 105°C

$B$ = weight of crucible + filter + residue after 1 hr at 550°C

**3.6.2.5 COD:** The closed reflux titrimetric method was used to determine COD in the samples. The digestate sample was first centrifuged and then diluted upto 10 % in 100 ml distilled water before COD analysis. 10 ml of it was oxidized by 3.5 ml of sulfuric acid in COD vial. The sample was then refluxed in strongly acidic solution with a known excess of potassium dichromate ($K_2Cr_2O_7$). After digestion, the remaining unreduced $K_2Cr_2O_7$ was titrated with ferrous ammonium sulfate to determine the amount of $K_2Cr_2O_7$ consumed and the oxidizable matter was calculated in terms of oxygen equivalent. The standard reflux time was 2 hours. The samples were analyzed in duplicate and their average value was taken (APHA, 2005).

$$\text{[illegible]} = \frac{\text{[illegible]}_2\text{[illegible]}_2\text{[illegible]}_7\text{[illegible]}(\text{[illegible]})}{\text{[illegible]}} = 0.8\ \text{[illegible]} \qquad (2.10)$$

$$\text{[illegible]}_2\text{[illegible]} = \frac{(\text{[illegible]} - \text{[illegible]}) \times \text{[illegible]} \times \text{[illegible]}}{\text{[illegible]}} \qquad (2.11)$$

*A* = mL FAS used for blank,

*B* = mL FAS used for sample,

*N* = normality of FAS, and

8000 = milliequivalent weight of oxygen X 1000 mL/L

**3.6.2.6 Percentage removal of organic matter:** It gives an indication of the efficiency of a biological treatment process in a biogas plant. The efficiency of the treatment process is normally expressed as COD removal, TS removal and VS removal. It tells the strength of the effluent slurry. To analyze the % removal of organic material following formula was used (Qureshi, 2005).

$$\%\ \text{[illegible]} = \frac{(\text{[illegible]} - \text{[illegible]})}{\text{[illegible]}} \times 100 \qquad (2.12)$$

### 3.6.3 Analysis of Biogas

The volume and pressure of biogas were observed at plant site, while the gas composition analysis was done in the analytical lab.

**3.6.3.1 Volume of biogas:** The volume of gas was measured three times a day. For this liquid displacement setup was installed near the plant. This setup included a 20 litre bucket filled with water. An empty 11 litre calibrated plastic transparent jar was inverted inside the bucket. A hole was made on the flat end of the jar, through which a gas pipe was passed. The other end of this pipe was attached to the t-joint, near the gas valve, of the plant. The volume of biogas was measured by the displacement of the jar, due to collection of gas inside it. Ayu and Aryati (2010) conducted a study in which the total biogas production was measured daily by the water displacement technique.

Figure 3.4: Water displacement setup for measuring volume of biogas

**3.6.3.2 Pressure of biogas:** A manometer measures the pressure difference by balancing the weight of a fluid column between two pressures of interest. A manometer was made by using a vertical wooden rod, on which a U-shaped tube was attached. The wooden rod was calibrated upto 100 cm. About 5-10 drops of blue ink were dissolved in 100 ml of distilled water. 40 ml of the colored water was filled in the U-shaped tube with the help of a pipette. One end of the U-shaped tube was attached to the gas vent of the plant and the other end was left open. The difference in the liquid column gave the reading of pressure in cm, which was converted into pascal (SI Unit). Itodo *et al.* (2007) used a manometer for determining the operating pressure of biogas.

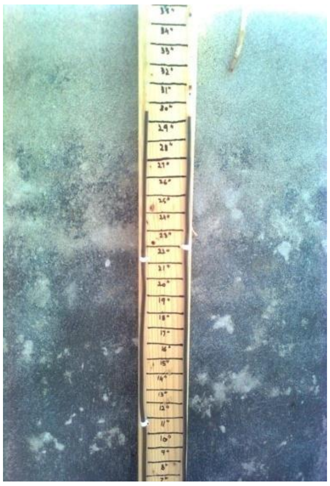

Figure 3.5: Manometer for measuring pressure of biogas

**3.6.3.3 Flame of biogas:** Following Itodo *et al.* (2007) a pipe was attached to the gas opening of the digester. This pipe was connected to a bunsen burner. A petri dish was placed on a tripod stand, over the burner. The gas was ignited to observe the flame of biogas. If combustion is perfect, the flame is dark blue and almost invisible in daylight.

**3.6.3.4 Gas Composition:** Ghani and Idris (2009) analyzed biogas contents using gas chromatography, therefore the composition was determined for biogas samples in triplicate by gas chromatography. The gases to be measured by this method were $CO_2$, $CH_4$, $H_2$ and $O_2$. They were determined using a Perkin Elmer Sigma 2000 Capillary chromatograph with a PE Nelson 1020 Personal Integrator

(Perkin Elmer, Norwalk, Connecticut, USA). The instrumental details and the analysis conditions are given in table 3.5.

**Table 3.5: Instrumentation details for gas composition analysis**

| Parameters | Value |
|---|---|
| Gas chromatograph | Perkin Elmer Sigma 2000 |
| Data handling | PE Nelson 1020 Personal Integrator |
| Column | PorapakQ Mesh 60/80 (1.8m x 3mm) |
| Detector type | Thermal conductivity |
| Column temperature | Ambient |
| Detector temperature | 100°C |
| Carrier gas | Helium |
| Sample size | 0.25 ml (gas) |
| Injector syringe | Hamilton 1001SL sample lock syringe |
| Gas flow rate | 60 ml/min |
| Total analysis time | 1.5 min |

### 3.6.4 Analysis of Effluent Slurry

**3.6.4.1 NPK analysis:** The NPK analysis was done by following the standard methods. The total nitrogen present in the effluent slurry was examined by Kjeldahl method. Total N includes organic N, ammonium N and nitrate N. The sample was digested in sulfuric acid, using $CuSO_4/TiO_2$ as catalysts, to raise the boiling temperature and to promote the conversion from organic-N to ammonium-N. Ammonium-N from the digest was obtained by steam distillation, using excess NaOH to raise the pH. The distillate was collected in saturated $H_3BO_3$ and then titrated with dilute $H_2SO_4$ to pH 5. Phosphorus was determined by wet digestion method through spectrophotometer at 410 nm wavelength. Total P measurement involves digestion of a slurry sample with a strong acid i.e $HNO_3$-$HClO_4$ (2:1 ratio) and the dissolution of all insoluble inorganic minerals and organic P forms. Potassium was measured by wet digestion using a flame photometer (Jenway) at 767 nm wavelength (APHA 2005; ICARDA 1996).

**3.6.4.2 C/N ratio:** The organic carbon content in the slurry was determined by the rapid titration procedure of Walkley-Black method involving chromic acid wet oxidation. Oxidisable matter in the sample was oxidised by 1 N $K_2Cr_2O_7$ solution. The reaction was assisted by the heat generated when two volumes of $H_2SO_4$ were mixed with one volume of the dichromate. The remaining dichromate was titrated with ferrous sulphate. The titre was inversely related to the amount of C present in the sample. 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. Then divided the amount of N into the amount of C, which gave the C:N ratio where N = 1. The analysis was done by following standard methods in ICARDA manual (1996).

***CHAPTER 4***

# RESULTS & DISCUSSION

This chapter gives a detailed analysis of the results achieved during the present study, and their comparison with other similar studies. The main focus of this study was to estimate the efficiency of the plant under thermophilic conditions. The comparison of results of batch I and II is explained below.

## 4.1 QUALITY OF FEED MATERIAL

**4.1.1 Moisture Content:** The results of the proximate analysis of feed material showed that the moisture content of food waste in the batch I and II was 88.4 and 90.1% respectively. The findings of a previous study conducted on solid waste of sector H-12 Islamabad showed that the food waste in the area has 82% of moisture content (Khan, 2010). Zhang *et al.* (2007) carried out the characterization of food waste as feedstock for anaerobic digestion and found that the optimum moisture content for food waste is 74 to 90%.

**4.1.2 Ash Content:** The food sample was weighed before and after ashing to determine the concentration of ash present. The ash content of batch I was found to be 17.6%. In batch II the ash content was measured to be 13.6%. An almost similar finding was achieved by Khan (2010), when the ash content of waste was 15%.

## 4.2 QUALITY OF DIGESTATE

The analysis of digestate showed that it was thick slurry, blackish in color. It was very smelly in the start, but the smell reduced with the passage of time as the degradation proceeded.

**4.2.1** **pH:** The trend of variation in pH during the process showed that the pH of digestate increases as the process proceeds. The value of pH for batch I ranged from 6.1 to 8.1. The optimum pH on which biogas production was observed in batch I was ranging from 6.6 to 7.6. The biogas production started reducing at pH above 7.6. The pH for batch II ranged from 6.3 to 8.2, shown in figure 4.1. In this batch the biogas production started when pH of the digestate was 6.6 and the maximum production was seen at 7.0. The gas production started reducing at pH above 7.7 and almost stopped at pH 8.2 after 17 days of retention time. According to Williams (1998) the ideal conditions for the methanogenic microorganisms are a pH range from 6.8 to 7.5. According to Metcalf and Eddy (2003), generally the optimum pH for bacterial growth lies between 6.5 and 7.5. Ayu and Aryati (2010) conducted a study on biogas production from cassava starch effluent using anaerobic biodigester. The ruminant bacteria were used as biocatalyst and the pH was maintained between 6.8 to 7.2 to get maximum yield.

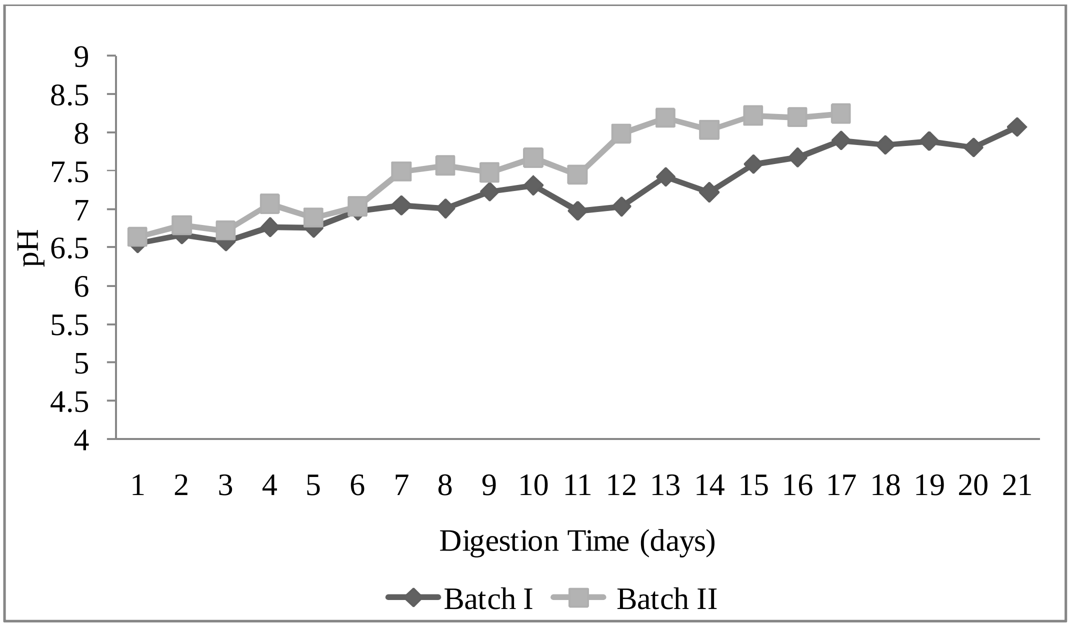


Figure 4.1: Variation of pH for batch I and II

**4.2.2 Total Solids:** Solid analysis was important in the control of biological treatment process. The initial and final TS for batch I was 12% and 6% and for batch II was 10% and 3% respectively. The TS reduction for batch I was 50.2% and for batch II was 77.5%, shown in figure 4.2. According to NRCS Report (2005) the TS of feed material can be upto 14%. Igoni *et al.* (2008) conducted a research on anaerobic digestion of municipal solid waste for biogas production and found that the TS reduced from 10% to 4%. Zhu *et al.* (2009) conducted a similar study and established that TS reductions ranged from 50.2% to 65.0%.

**4.2.3 Volatile Solids:** The methane producing potential depends on the amount and nature of the accessible organic material, which is sometimes referred to as the volatile solids (Mistry *et al.,* 2005). The breakdown of organic solids depends upon the temperature (Metcalf and Eddy 2003). In the present study the initial and final value of VS for batch I was 82.4% and 38.5%, and for batch II was 86.3% and 17.8% respectively. The VS reduction was 53.3% for batch I and 79.4% for batch II, shown in figure 4.2. Xu *et al.* (2003) examined that significant enhancement in methane production was confirmed by the removal of 60% of VS in 12 days of HRT, with 71% of methane content in the biogas. Chen *et al.* (2009) explored that in thermophilic condition the VS reduction for cafeteria waste was 87% due to continuous feeding rate.

**4.2.4** **COD:** Chemical oxygen demand is a measure of the oxygen consumed when organic matter is broken down chemically (Metcalf and Eddy 2003). The initial and final COD for batch I was 17287 mg/l and 6416.9 mg/l, and for batch II was 19340 mg/l to 4254.8 mg/l respectively. The percentage removal of COD for batch I was 62.9% and for batch II was 84.2%. Sakar *et al.* (2009) carried out anaerobic digestion of livestock waste treatment, where the chemical oxygen demand (COD) removals ranged from 57 and 78%. Dawood *et al.* (2011) found that the percentage COD reduction has been observed to be 50.0% at the retention time of 72 days. The percentage COD reduction decreases with increase in organic loading rates but not monotonically for different time periods. The comparison of percentage removal between both the batches is given in the figure 4.2.

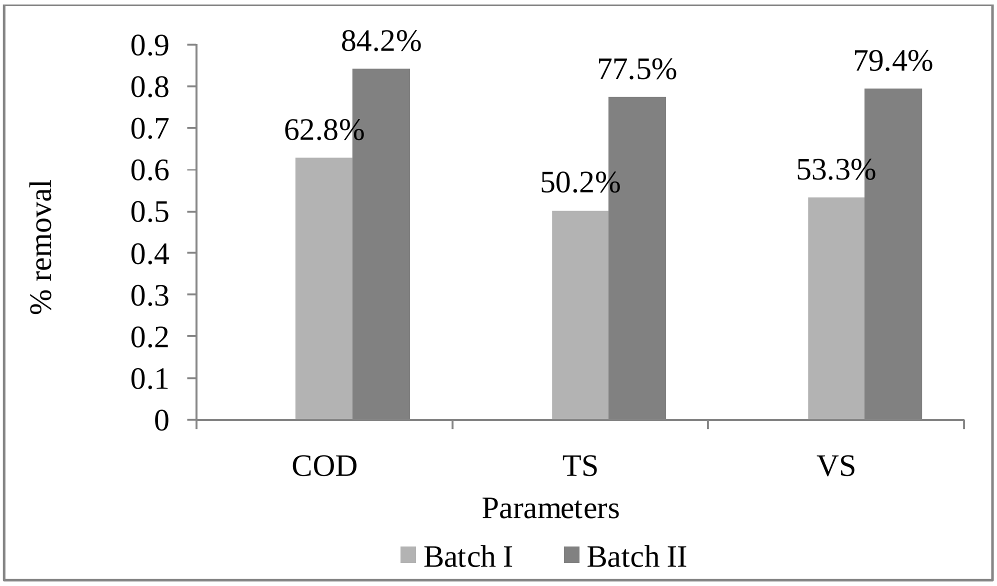


Figure 4.2: Comparison of percentage removal of organic matter

## 4.3 BIOGAS PRODUCTION

**4.3.1 Production in Batch I:** In this phase 550 kg of pretreated food waste was added along with 100 L of effluent slurry from a biogas plant as seeding. This batch was started on 23$^{rd}$ June and production started after 7 days on 29$^{th}$ June. The gas production remained steady for almost 5 days and then started declining. The production ended on 19$^{th}$ July 2011, after 21 days of HRT. The average production for this batch was 1.7 L/hr. The average temperature of digester was 57.9$^{o}$C and the ambient temperature was 32.8$^{o}$C given in appendix A-1.

The main reason for lower production was the large feed size of 3.5 cm, due to use of electric shredder for cutting the food waste. The high TS of 12% also lead to low production. The scum layer was formed on the top of the digestate due to lack of any mixing system. The percentage removal of organic matter was also low. All these factors decreased the potential of biogas production, even in the presence of slurry from an already working plant. Thus the biogas was not enough to burn a flame. Therefore it was considered as trial phase for the biogas plant under study. Pound *et al.* (1981) had observed that the very low gas production is due to lack of methanogenesis, with alcohol fermentation taking place instead. The gas produced consisted mainly of $CO_2$.

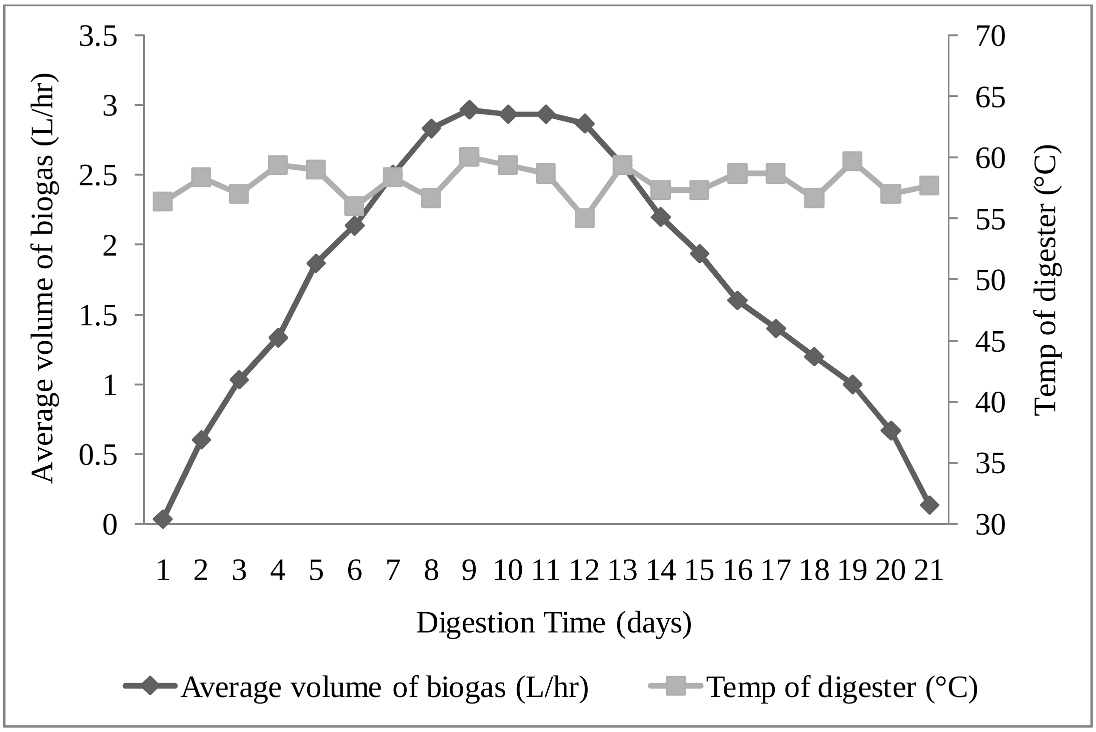


Figure 4.3: Trend of biogas production for batch I

**4.3.2 Production in Batch II:** In this phase food waste was added along with fresh cow dung as starter. The batch was processed in August 2011. About 550 kg of pretreated food waste along with water, was added in the digester on 3rd August. The production of biogas started after 5 days on 8th August with 15 L/hr. The maximum production of 80 L/hr was seen on 14th August with 57.5°C of digester temperature. The biogas production remained high for 4 days. It started decreasing on 17th August and it ceased after 22nd August with 7 L/hr. The average biogas yield was 52.3 L/hr. The average digester temperature was 56.3°C, whereas the average ambient temperature was 30.2°C given in appendix A-2.

This was the most effective batch as it showed maximum biogas production and proved the efficiency of the plant. It also showed maximum percentage removal of organic matter due to efficient working of the digester. The HRT was also reduced to 17 days. The maximum production was also due to relatively small feed size of 2.5 cm and each piece of food waste was further cut into pieces. TS of 10% proved to be ideal for this batch. An important factor was the addition of 100 kg of cow dung in the digester. The manual mixing of digestate from the outlet of plant, using an iron rod, also reduced the risk of the formation of scum. All these factors lead to maximum production of biogas.

Islam *et al.* (2009) carried out a study in thermophilic range to analyze the production of biogas from 200 to 300g of vegetable waste along with a mixture of 0 to 300g of cow dung at different ratios. The result showed maximum gas production of 1200 mL/kg of total waste. Pound *et al.* (1981) pointed out that the improved gas production is due to reduction of ammonia production which is otherwise toxic to bacteria, and to the ready availability of carbon for $CO_2$ and $CH_4$ synthesis. The quantity and quality of biogas was increased by the addition of fresh cow dung, which raised the percentage of methane in the biogas up to

70%. The following graph shows the trend of biogas production during the batch II under thermophilic conditions.

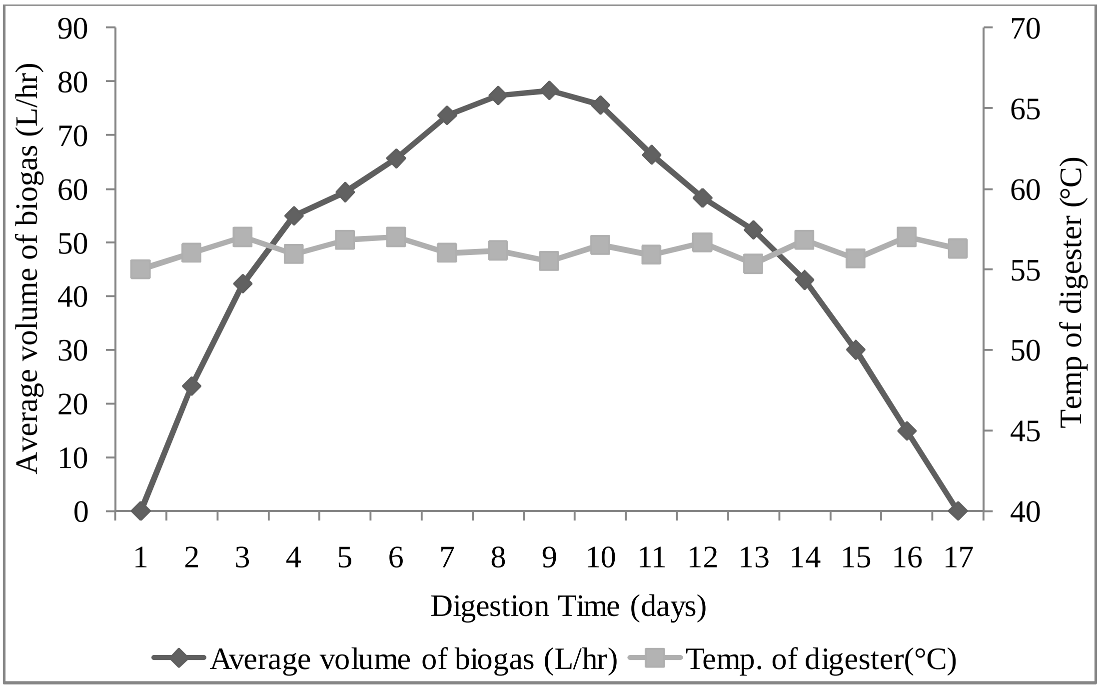


Figure 4.4: Trend of biogas production for batch II

### 4.3.3 Biogas Pressure

In batch I the average biogas production of 1.7 L/hr was observed with very low pressure, which was not measurable with manometer. Therefore the gas did not burn a flame on ignition. But in batch II a sudden increase in pressure was seen on the manometer with high production of biogas. The pressure increased with increase in volume of biogas produced. The initial value of pressure was 388 Pa on 8$^{th}$ August and it started increasing steadily. The increase in pressure lead to burning of the flame of biogas on 10$^{th}$ August. The maximum pressure reading was observed as 1785 Pa on 14$^{th}$ August. The pressure remained high for 4 days, when the biogas production was also high. The pressure started decreasing on 17th August with the value of 1408 Pa. The minimum value of 165 Pa was observed on 22nd August. The last value on same day was 0 Pa, with this the production of biogas also diminished. The average value of pressure was 1166 Pa. According to Vivekanandan and Kamaraj (2011) the pressure of biogas was achieved as 1600 Pa.

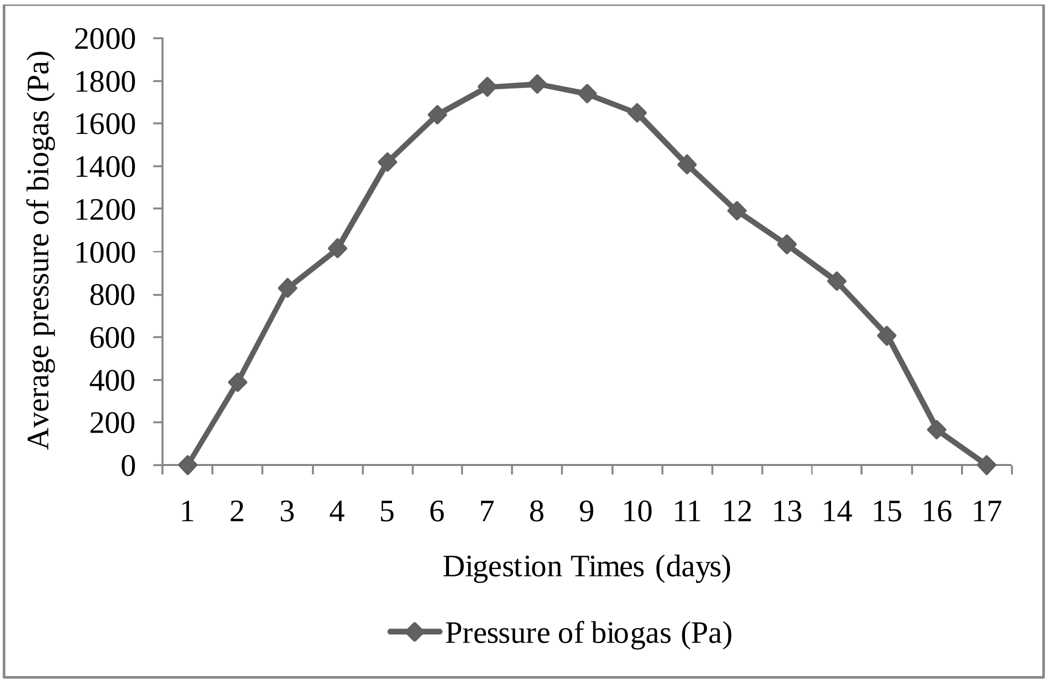


Figure 4.5: Pressure of biogas for batch II (Pa)

### 4.3.4 Biogas Flame

No flame was obtained for batch I due to low pressure of biogas. According to Mandal *et al.* (1999) the burning of flame depends on the change in the methane content of biogas. In batch II the biogas burned with a transparent flame on 10th August. The flame was obtained due to increased production of biogas. Water was placed in a petri dish over the burner. It started boiling within a few minutes. On 14th of August 2 eggs were also boiled on the flame. The flame did not burn after 19th August, with the decline in the 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. The figure 4.6 is showing the flame being burnt to analyze the biogas.

Figure 4.6: Successful experiment of biogas utilization

### 4.3.5 Biogas Composition

The composition of the biogas was analyzed on the basis of % by weight. The resulting biogas for batch I was composed up of 30.2% of $CH_4$, 65.9% of $CO_2$, 0.9% of $O_2$ and 3.1% of $N_2$. The biogas composition for batch II consisted of 60.8% of $CH_4$, 33.6% of $CO_2$, 1.5% of $O_2$ and 4.1% of $N_2$. The bladder took only 5 to 10 minutes to fill as production rate was relatively high. Comparing the results of both the batches depicted that biogas produced from the temperature controlled digester has high methane content in batch II.

Figure 4.7: Football bladder filled with biogas

Voegeli *et al.* (2009) conducted a study on biogas production and found that the average composition of methane in biogas produced from food waste was 56.8%.

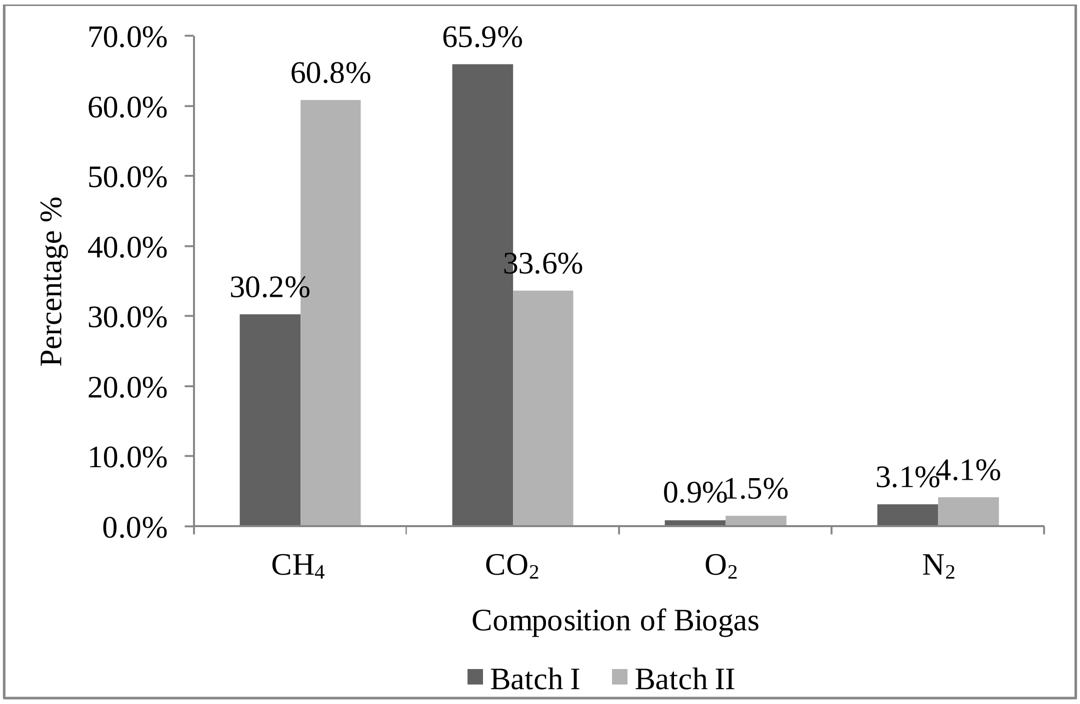


Figure 4.8: Comparison of biogas composition for batch I and II

### 4.3.6 Cumulative Biogas Production

The cumulative production for batch I was 693.6 L and for batch II was 21338.4 L. The methane yield calculated for batch I and II was 0.5 L $CH_4$/kg VS and 27.3 L $CH_4$/kg VS respectively. This difference in the production of biogas between both the batches is due to changes in composition of feeding material and other conditions. The composition of feeding material is given in table 3.2. The difference in the production of biogas in both the batches is given in table 4.4. The resulting production of biogas in batch I was 0.001 $m^3$ per kg of food waste and for batch II was 0.04 $m^3$ per kg of food waste.

**Table 4.1: Calculations for cumulative biogas production**

| Parameter | Batch I | Batch II |
|---|---|---|
| Total amount of food waste | 550 kg | 550 kg |
| Average biogas per hour | 1.7 L/hr | 52.3 L/hr |
| Average biogas per day | 40.8 L/d | 1255.2 L/d |
| Total practical biogas production in L | 693.6 L | 21338.4 L |
| Total practical biogas production in $m^3$ | 0.7 $m^3$ | 21.3 $m^3$ |
| Methane yield per kg VS | 0.5 L $CH_4$/kg VS | 27.3 L $CH_4$/kg VS |
| Biogas produced per kg of food waste | 1.3 L/kg | 38.7 L/kg |
| Biogas produced in $m^3$ per kg of food waste | 0.001 $m^3$/kg | 0.04 $m^3$/kg |
| Biogas produced from dry content of food waste | 7.0 L/kg | 387.9 L/kg |
| Biogas produced from total amount of digestate | 0.6 L/kg | 18.6 L/kg |
| Biogas produced in $m^3$ per kg of VS | 0.002 $m^3$/kg VS | 0.04 $m^3$/kg VS |
| Calorific heat value | 14 MJ | 426.7 MJ |
| Burning time | ------ | 122 hours |

Li *et al.* (2009) found that the codigestion of kitchen waste and cow manure can be used as feedstock to produce biogas through an anaerobic digestion process. It enhanced kitchen waste buffering capacity and improved cow manure solubilization. It resulted in efficient biogas production, with 44% more methane production and waste treatment. Mshandete *et al.* (2004) reported that codigestion of sisal pulp and fish wastes at a volatile solids (VS) ratio of 2:1 gave an increase of 59ī 94% in methane yield as compared to that obtained from the digestion of pure fractions.

Ghani and Idris (2009) conducted a research in which the methane yield was calculated as 220 to 350 ml $CH_4$/g VS from swine manure and 620 ml $CH_4$/g VS from municipal solid waste. Another study was conducted by Dearman and Bentham (2007) on food waste in which the total methane generation was 229 L $CH_4$/kg VS and 214 L $CH_4$/kg VS. Kameswari *et al.* (2007) conducted a study on a plant of capacity of 30 tonnes per day for biogas production from vegetable market waste. It resulted in the organic rate of 2.5 kg of VS/day/$m^3$ with biogas generation of 2500 $m^3$ of biogas per day.

As already stated in literature, food waste turned out to have considerable potentials for its efficient utilization to energy. El-Mashad *et al.* (2010) found methane yield of approximately 350 L/kg VS in single-stage batch test. Also higher ranges of up to 440 L CH4/kg VS were documented by Zhang *et al.* (2007). Moreover, laboratory scale experiments with yields about 350 L methane/kg VS as well as 640 l methane/kg VS achieved in pilot scale were determined by Beck *et al.* (2010). Whereas Grasmug and Braun (2002) reported yields of 1100 L biogas/kg VS with methane contents of 72 %.

## 4.4 EFFLUENT SLURRY PRODUCTION

The average slurry produced during batch I was analyzed to be 1.5 litres per day. The total slurry produced for this batch was 31.5 litres for 21 days. The average amount of slurry produced during batch II was 10 litres per day. This accounted for total production of 170 litres for a batch of 17 days. This slurry can be used as organic fertilizer after drying in sunlight, after which the weight of manure becomes half of that of slurry.

Figure 4.9: Effluent slurry from biogas plant collected in the effluent tank

### 4.4.1 Nutrient Content in Effluent Slurry

The effluent slurry produced as byproduct during the batch I and II has variation in their nutrient contents. The NPK analysis of slurry from batch I showed that the N was 56.4 mg/L, P was 22.6 mg/L and K was 26.6 mg/L. The slurry from batch II consisted of 84.9 mg/L of N, 33.4 mg/L of P and 34.8 mg/L of K. The comparison of results showed that the slurry from batch II has more concentration of nutrients as compared to slurry from batch I. The high nutrient content in batch II was due to the composition of feed material, which consisted of food waste and cow dung. Another reason was the maximum reduction in the organic material at the end of batch II as compared to that in batch I. The feed material in batch I was composed of food waste and seeding from an already existing plant.

Voegeli *et al.* (2009) evaluated that the effluent had a concentration of 225 mg/L $PO_4$-P and 74.1 mg/L of $NH_4$-N for food waste. The concentration of K, Fe, Ca, Mg and Zn was also analyzed. Elango *et al.* (2007) carried out a research on production of biogas from municipal solid waste with domestic sewage. The effluent slurry had high nutrient contents of N, P, K of 60%, 73% and 70% respectively. This slurry was used as natural fertilizer in the agriculture. Namasivayam and Yamuna (1992) confirmed that NPK is higher in the digested biogas slurry. The average nutrient content for N, P and K is in the range of 1.6 to 1.9, 0.4 to 0.7 and 1.4 to 1.9 % and fairly large amount of essential micronutrient elements are present.

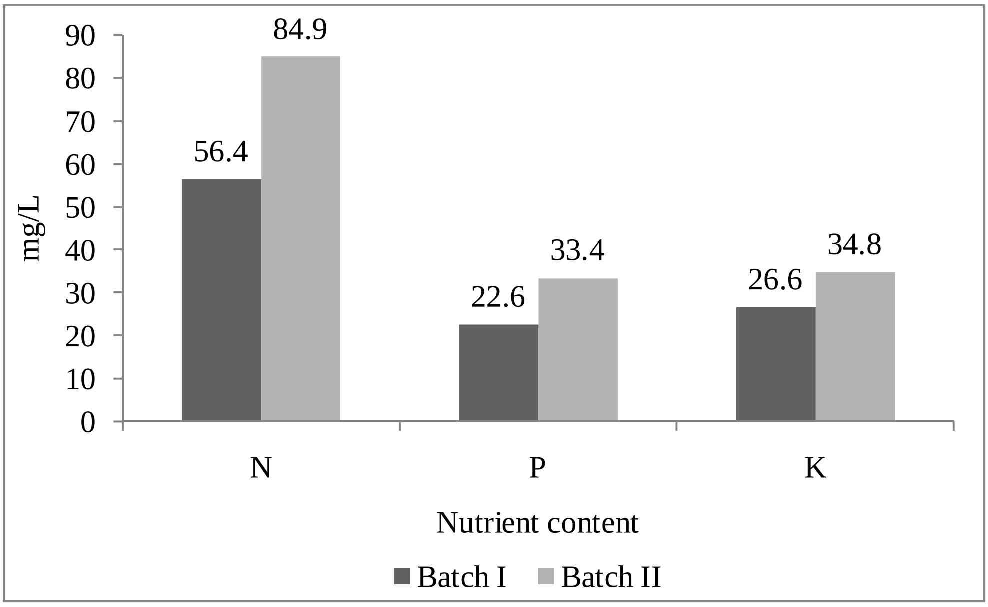


Figure 4.10: NPK analysis of effluent slurry from batch I and II

**4.4.2 C/N Ratio of Effluent Slurry**

The C/N ratio tells the nutrient content present in the effluent slurry. Total carbon content in effluent slurry of batch I was 959.1 mg/l and in batch II was 2123.5 mg/l. The result of C/N ratio for batch I was 17:1, because the feeding material consists of food waste and the C/N ratio of seeding was 23:1. The ratio for effluent slurry of batch II was 25:1, which was relatively high due to addition of cow dung in the food waste. The C/N ratio of cow dung was calculated to be 30:1. This depicts that the addition of cow dung was productive for the slurry.

According to Verma (2002) the optimum C/N ratio in anaerobic digestion is between 20 to 30. A high C/N ratio is an indication of rapid consumption of nitrogen by methanogens and results in lower gas production. On the other hand lower C/N ratio causes ammonia accumulation and pH values exceeding 8.5, which is toxic to methanogenic bacteria. The optimum C/N ratio of the digester material can be achieved by mixing materials of high and low C/N ratios, such as organic solid wastes with sewage and animal manure.

**Table 4.2: Comparison of C/N ratio for batch I and II**

| Sample # | Sample description | C/N ratio |
|---|---|---|
| 1 | Effluent slurry | 23:1 |
| 2 | Batch I (food waste + effluent slurry) | 17:1 |
| 3 | Cow dung | 30:1 |
| 4 | Batch II (food waste + cow dung) | 25:1 |

## 4.5 ORGANIC LOADING RATE

Annual organic loading rate for 1.2 $m^3$ biogas plant is explained below:

### 4.5.1 For Batch Conditions = 550 [illegible] [illegible] 17 [illegible]

= 970 [illegible]/[illegible] [illegible]

= 11647 [illegible]/[illegible]

### 4.5.2 For Continuous Conditions

[illegible] [illegible] [illegible] = [illegible] / [illegible]

= [illegible] / [illegible]

= 70.5 [illegible]/[illegible]

= 35 [illegible] [illegible] [illegible] [illegible] + 35 [illegible] [illegible] [illegible]

As waste and water are added in 1:1, so for 35 kg of food waste, an equal amount of water needs to be added along with waste.

= 1058 □/□ □□□□

= 12705 □/□□□□

Thus the annual organic loading of 12705 L would be required to maintain the controlled conditions inside the digester, for continuous high production of biogas. The dotted line in the figure below shows the expected continuous production of biogas with daily organic loading rate of 35 kg of food waste along with water.

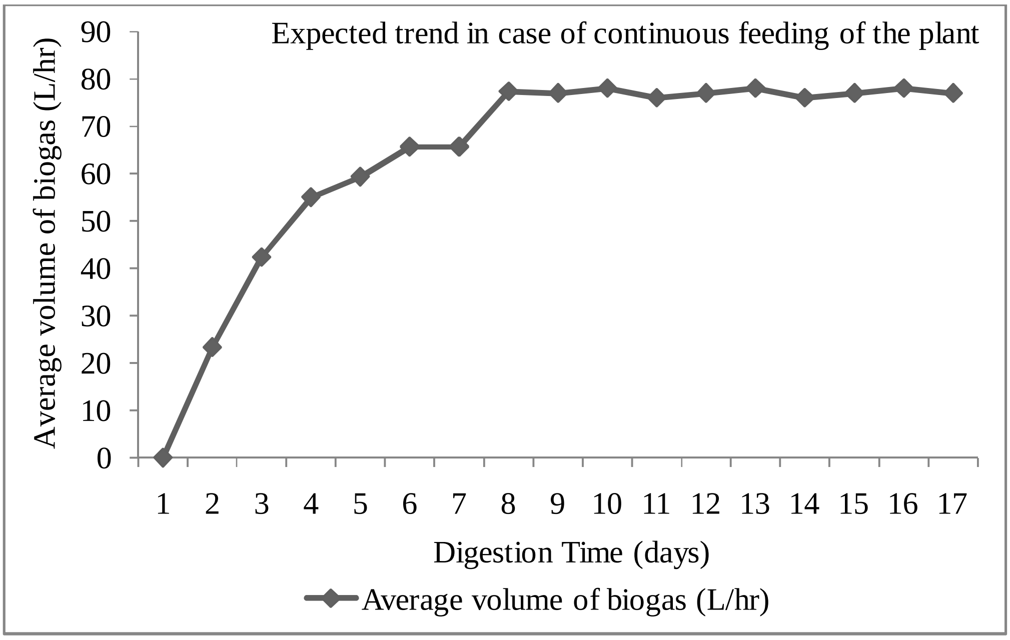


Figure 4.11: Expected trend of biogas production in case of continuous feeding of the plant

## 4.6 COST BENEFIT ANALYSIS

### 4.6.1 For Biogas

As biogas production per day = 1255.2 □/□□□

Biogas production per month = 37656 □/□ □□□□

Biogas production per year = 451872 □/□□□□

= 451 □ □/□□□□

1 $BTU$ = 1.05 □□

Calorific heat value of biogas, depending upon the methane content

= 20 □ □/□ □

= 20 □ □/□ □ × 451 □ □/□□□□

= 9020 □ □/□□□□

As 1 $MJ$ = 947.8 □□□

= 9020 □ □/□□□□ × 947.8 □□□

= 8.6 □ □ □□□

Cost of 1 $m^3$ of sui northern gas supplied in Islamabad = □□ 1302.5/□ □ □□□

This can lead to Annual saving = □□ 1302.5 × 8.6 □ □ □□□

= □□ 11201.5/□□□□

**For Slurry**

As the total amount of slurry produced = 170 L for 17 days

After drying its weight can be reduced to = 85 kg for 17 days

The production of natural fertilizer per month = 150 kg/month

The production of natural fertilizer per year = 1800 kg/year

Cost of 1 bag of 20 kg of chemical fertilizer (DAP) = Rs 4336

Cost per kg of chemical fertilizer = Rs 216.8 per kg

The saving of 1800 kg/year of natural fertilizer will be = 1800 kg x Rs 216.8

= Rs 390240/ year

Cost of 1 bag of 20 kg of Urea = Rs 1800

Cost per kg of Urea = Rs 90

The saving of 1800 kg/year of natural fertilizer will be = 1800 kg x Rs 90

= Rs 162000/ year

The cost benefit analysis of the biogas and slurry illustrated that the implementation of such a setup is beneficial, as it will produce low cost gas along with cheaper natural fertilizer. Talukder (2010) confirmed that the bio slurry is considered as a byproduct of a biogas plant, but it has great economic benefit as shown in the financial analysis.

*CHAPTER 5*

# CONCLUSION & RECOMMENDATIONS

## 5.1 CONCLUSION

The conclusions drawn from the results are as follows:

- In the present study, 1.2 $m^3$ of fixed dome biogas plant at IESE demonstrated to be an efficient setup.
- The codigestion of food waste and fresh cow dung proved to be suitable with feed size of 2.5 cm.
- The process was successfully demonstrated by using temperature controlled system to maintain thermophilic conditions in batch mode.
- The resulting successful production of biogas was 0.04 $m^3$ per kg of food waste.
- The nutrient content of the effluent slurry indicated its potential use as a fertilizer.

## 5.2 PROBLEMS FACED

The problems faced during the study are enlisted below:

- There was blockage of food waste in the inlet, while adding it in the plant.
- Difficulty in mixing of waste manually, through outlet of plant.
- Scum was formed in batch I which reduced the production of biogas.

- Rain used to enter the plant through outlet, therefore it was covered with a thick plastic sheet during the experiment.

## 5.3 RECOMMENDATIONS

To improve the efficiency of biogas plant, following recommendations should be followed in any further study.

- A mechanical mixer/mixing shaft should be installed for proper mixing of material, and it will also serve as a scum breaker to help the gas to release easily from the waste material.
- There should be installation of gas collector to use the biogas produced for different purposes such as heating.
- A permanent fibre glass shed needs to be installed to cover the setup and protect it from rain.
- The dimensions of inlet and outlet of the plant need to changed for any new installation, to avoid any blockage of food waste.
- The insulation of the biogas plant need to be improved, to avoid loss of biogas produced in the plant.
- In future research can be conducted on continuous conditions to the 1.2 $m^3$ biogas plant at IESE.

## 5.4 FUTURE PROSPECTS

The future expectations for the study are as follows:

- Production of useful gas for heating purpose such as cooking at IESE.
- Success with the activity would ultimately lead us to implement a programme for the minimization of solid waste produced within the NUST campus at H-12, which shall be processed in an environmental friendly and sustainable manner.
- Making of compost to be used as natural fertilizer in the botanical garden of campus.
- This would certainly contribute to the projection of NUST as a truly Green Campus and a Zero Waste University.

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# APPENDICES

## *APPENDIX 1*

| A-1: Biogas production for batch I | | | | | |
|---|---|---|---|---|---|
| **Sr No.** | **Date** | **Time** | **Ambient temp** | **Temp of plant** | **Volume of biogas (L/hr)** |
| 1 | 29/6/2011 | 9:00 AM | 25 | 54 | 0 |
| | | 1:00 PM | 34 | 58 | 0.1 |
| | | 5:00 PM | 29 | 57 | 0 |
| 2 | 30/6/2011 | 9:00 AM | 25 | 58 | 0.1 |
| | | 1:00 PM | 35 | 60 | 0.5 |
| | | 5:00 PM | 28 | 57 | 0.2 |
| 3 | 01/07/2011 | 9:00 AM | 23 | 62 | 0.6 |
| | | 1:00 PM | 36 | 54 | 1.2 |
| | | 5:00 PM | 30 | 55 | 1.4 |
| 4 | 02/07/2011 | 9:00 AM | 30 | 56 | 1.5 |
| | | 1:00 PM | 38 | 65 | 1.3 |
| | | 5:00 PM | 30 | 57 | 1.3 |
| 5 | 03/07/2011 | 9:00 AM | 26 | 54 | 1.4 |
| | | 1:00 PM | 37 | 66 | 1.5 |
| | | 5:00 PM | 29 | 57 | 1.6 |
| 6 | 04/07/2011 | 9:00 AM | 26 | 56 | 1.4 |
| | | 1:00 PM | 39 | 55 | 1.5 |
| | | 5:00 PM | 30 | 57 | 2.1 |
| 7 | 05/07/2011 | 9:00 AM | 27 | 56 | 1.8 |
| | | 1:00 PM | 38 | 61 | 2.2 |

| | | | | | |
|---|---|---|---|---|---|
| | | 5:00 PM | 29 | 58 | 1.5 |
| 8 | 06/07/2011 | 9:00 AM | 28 | 59 | 2.1 |
| | | 1:00 PM | 41 | 57 | 3 |
| | | 5:00 PM | 31 | 54 | 3.4 |
| 9 | 07/07/2011 | 9:00 AM | 28 | 58 | 3 |
| | | 1:00 PM | 40 | 57 | 2.5 |
| | | 5:00 PM | 32 | 65 | 3.4 |
| 10 | 08/07/2011 | 9:00 AM | 28 | 56 | 3 |
| | | 1:00 PM | 41 | 65 | 3.1 |
| | | 5:00 PM | 33 | 57 | 2.5 |
| 11 | 09/07/2011 | 9:00 AM | 28 | 58 | 2.9 |
| | | 1:00 PM | 42 | 59 | 2.9 |
| | | 5:00 PM | 30 | 59 | 2.6 |
| 12 | 10/07/2011 | 9:00 AM | 29 | 54 | 2.3 |
| | | 1:00 PM | 42 | 55 | 3 |
| | | 5:00 PM | 31 | 56 | 3.1 |
| 13 | 11/07/2011 | 9:00 AM | 30 | 57 | 2.4 |
| | | 1:00 PM | 42 | 63 | 2.1 |
| | | 5:00 PM | 33 | 58 | 2.5 |
| 14 | 12/07/2011 | 9:00 AM | 29 | 55 | 2 |
| | | 1:00 PM | 42 | 56 | 1.9 |
| | | 5:00 PM | 34 | 61 | 1.2 |
| 15 | 13/07/2011 | 9:00 AM | 30 | 56 | 1.6 |
| | | 1:00 PM | 43 | 59 | 1.5 |

| | | | | | |
|---|---|---|---|---|---|
| | | 5:00 PM | 34 | 57 | 1.3 |
| 16 | 14/07/2011 | 9:00 AM | 29 | 58 | 1.2 |
| | | 1:00 PM | 43 | 65 | 1.2 |
| | | 5:00 PM | 33 | 53 | 1.4 |
| 17 | 15/07/2011 | 9:00 AM | 29 | 55 | 1.7 |
| | | 1:00 PM | 42 | 64 | 1.1 |
| | | 5:00 PM | 32 | 57 | 1.4 |
| 18 | 16/07/2011 | 9:00 AM | 29 | 56 | 1.3 |
| | | 1:00 PM | 41 | 59 | 1.1 |
| | | 5:00 PM | 31 | 55 | 1.2 |
| 19 | 17/07/2011 | 9:00 AM | 27 | 55 | 1.1 |
| | | 1:00 PM | 37 | 67 | 0.9 |
| | | 5:00 PM | 30 | 57 | 1.3 |
| 20 | 18/07/2011 | 9:00 AM | 29 | 56 | 0.8 |
| | | 1:00 PM | 40 | 57 | 0.7 |
| | | 5:00 PM | 29 | 58 | 0.5 |
| 21 | 19/07/2011 | 9:00 AM | 28 | 57 | 0.3 |
| | | 1:00 PM | 39 | 59 | 0.1 |
| | | 5:00 PM | 30 | 57 | 0.1 |

## *APPENDIX 2*

| A-2: Biogas production for batch II | | | | | | |
|---|---|---|---|---|---|---|
| **Sr No.** | **Date** | **Time** | **Ambient temp** | **Temp of plant** | **Volume of biogas (L/hr)** | **Pressure of biogas (Pa)** |
| 1 | 07/08/2011 | 9:00 AM | 26 | 49 | 0 | 0 |
| | | 1:00 PM | 32 | 55 | 0 | 0 |
| | | 5:00 PM | 30 | 54 | 0 | 0 |
| 2 | 08/08/2011 | 9:00 AM | 27 | 55 | 15 | 227 |
| | | 1:00 PM | 34 | 57 | 31 | 565 |
| | | 5:00 PM | 30 | 56 | 24 | 372 |
| 3 | 09/08/2011 | 9:00 AM | 26 | 56 | 36 | 648 |
| | | 1:00 PM | 36 | 58 | 47 | 923 |
| | | 5:00 PM | 31 | 57 | 44 | 917 |
| 4 | 10/08/2011 | 9:00 AM | 25 | 55 | 50 | 937 |
| | | 1:00 PM | 36.5 | 56.8 | 56 | 999 |
| | | 5:00 PM | 31 | 56 | 59 | 1110 |
| 5 | 11/08/2011 | 9:00 AM | 25.5 | 56 | 60 | 1937 |
| | | 1:00 PM | 35.5 | 57.5 | 60 | 1247 |
| | | 5:00 PM | 30 | 57 | 58 | 1075 |
| 6 | 12/08/2011 | 9:00 AM | 21 | 57 | 64 | 1303 |
| | | 1:00 PM | 32 | 57 | 67 | 2069 |
| | | 5:00 PM | 25 | 57 | 66 | 1551 |
| 7 | 13/08/2011 | 9:00 AM | 26 | 56 | 65 | 1992 |
| | | 1:00 PM | 33 | 56 | 80 | 1316 |
| | | 5:00 PM | 29 | 56 | 76 | 2006 |
| 8 | 14/08/2011 | 9:00 AM | 26 | 55.5 | 76 | 1744 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 1:00 PM | 35.5 | 57.5 | 80 | 1868 |
| | | 5:00 PM | 30 | 55.5 | 76 | 1744 |
| 9 | 15/08/2011 | 9:00 AM | 26 | 55 | 79 | 1703 |
| | | 1:00 PM | 35 | 56 | 80 | 1896 |
| | | 5:00 PM | 30 | 55.5 | 76 | 1620 |
| 10 | 16/08/2011 | 9:00 AM | 25 | 56 | 67 | 1896 |
| | | 1:00 PM | 36 | 57 | 71 | 1620 |
| | | 5:00 PM | 31 | 56.5 | 67 | 1551 |
| 11 | 17/08/2011 | 9:00 AM | 26 | 55 | 85 | 1709 |
| | | 1:00 PM | 36.5 | 56.7 | 75 | 1689 |
| | | 5:00 PM | 30.5 | 56 | 55 | 999 |
| 12 | 18/08/2011 | 9:00 AM | 26.5 | 56 | 77 | 1716 |
| | | 1:00 PM | 37.8 | 57 | 67 | 1509 |
| | | 5:00 PM | 31.5 | 57 | 52 | 979 |
| 13 | 19/08/2011 | 9:00 AM | 24.5 | 55 | 67 | 1551 |
| | | 1:00 PM | 36 | 56 | 56 | 1041 |
| | | 5:00 PM | 30 | 55 | 49 | 951 |
| 14 | 20/08/2011 | 9:00 AM | 25 | 55.5 | 58 | 1075 |
| | | 1:00 PM | 35 | 58 | 50 | 1075 |
| | | 5:00 PM | 29 | 57 | 43 | 923 |
| 15 | 21/08/2011 | 9:00 AM | 26 | 55 | 47 | 744 |
| | | 1:00 PM | 34 | 56 | 39 | 948 |
| | | 5:00 PM | 29 | 56 | 24 | 372 |
| 16 | 22/08/2011 | 9:00 AM | 27 | 56 | 18 | 248 |
| | | 1:00 PM | 35 | 57 | 20 | 248 |
| | | 5:00 PM | 30 | 58 | 7 | 0 |
| 17 | 23/08/2011 | 9:00 AM | 28 | 55 | 3 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 1:00 PM | 34 | 56 | 0 | 0 |
| | | 5:00 PM | 31 | 56 | 0 | 0 |