KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KUMASI

COLLEGE OF ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING

PROJECT REPORT

PRODUCTION OF BIOGAS FROM FRUIT AND VEGETABLE WASTES

A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF

AGRICULTURAL ENINEERING IN PARTIAL FULFILLMENT

OF THE REQUIREMENT FOR THE BACHELOR OF SCIENCE (HONS) DEGREE

BY: YEBOAH, PATRICIA OHENEWA

, **MAY, 2016**

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BY: YEBOAH, PATRICIA OHENEWA

SUPERVISOR: PROFESSOR EBENEZER MENSAH

CO-SUPERVISOR: DR. GEORGE YAW OBENG

MAY, 2016

DECLARATION

I Yeboah Patricia Ohenewa, declare that I personally undertook this project and it has not been produced anywhere for award of a degree except other people's works cited which have been dully acknowledged.

……………………………..   ………………………..

YEBOAH PATRICIA OHENEWA   DATE

(STUDENT)

……………….................   ………………………..

PROF. EBENEZER MENSAH   DATE

(SUPERVISOR)

…………………………….   …………………………

DR. GEORGE YAW OBENG   DATE

(CO-SUPERVISOR)

ABSTRACT

Organic waste was recognized as a source of energy for the first time when Davy in 1808 recognized that methane was produced from decomposition of cattle manure. Biogas is a flammable gas composed mainly of a mixture of methane and carbon dioxide. Biogas-generating technology is a favourable dual-purpose technology, at present; Biogas that is generated can be used to meet energy requirements and also the secondary product of the process is a sludge residue (digestate) that can be directly used as soil amendment or as starting material for high quality compost preparation. In principle, many types of biomass can be used for biogas production. In Ghana, the commonest and most important commodities to find in abundance on the market are fruits and vegetables. Its production and consumption rate has been increasing yearly, consequently generating high volumes of waste. Fruit and vegetable wastes are highly perishable and this makes their landfill disposal quite challenging, thus, this generates high environmental complications even for short-term disposal. Conversion of these fruits and vegetable wastes to produce biogas provides some energy that can have a beneficial effect on the environment. This study presents results on biogas production from fruits and vegetables waste materials and a mixture of fruit and vegetable waste materials. It was observed that the highest biogas yield of 996 ml was recorded for vegetable waste followed by the mixture of fruit and vegetable waste which had 668 ml of biogas. The results obtained shows that difference in the production of biogas to a large extent depends on the nature of the substrate and factors such as pH and C: N ratio. Throughout the entire anaerobic digestion process, the ambient temperature for digestion ranged from 26°C to 32°C and there was little temperature variation effect on biogas production once biogas production began.

DEDICATION

Ebenezer! This is how far the Lord has brought me. I dedicate this thesis work to the Lord Almighty for His guidance and protection, to my father; Mr. Seth Yeboah, my mother; Mrs. Gladys Yeboah, my siblings; Mrs. Naomi Fuseini and Ms. Priscilla Yeboah for their love, support, unselfish sacrifices, prayers and encouragement that urged me on through my academic journey.

I also dedicate this work to Technology Consultancy Centre (TCC) KNUST, MIT D-Lab International Development Innovation Network (IDIN) Project for the financial support to see me through my project work.

ACKNOWLEDGEMENTS

I acknowledge God almighty for His unfailing love, guidance, mercies and immense favour, bestowed upon me, that has brought me to a successful completion of my project work.

I also take this opportunity to express my profound gratitude and deep regards to my supervisor, Prof. Ebenezer Mensah for his exemplary guidance, monitoring and providing valuable insights leading to the successful completion of this project study. The blessing, help and guidance given by him time to time shall carry me a long way in the journey of life on which I am about to embark. I also take this opportunity to express a deep sense of gratitude to Dr. George Yaw Obeng for his cordial support, valuable information and guidance, and also for teaming up with my supervisor to link me up with the organisation that funded my research work; Technology Consultancy Centre (TCC) KNUST, MIT D-Lab International Development Innovation Network (IDIN) Project without which this project would not have been possible.

I am grateful to lecturers of the Department of Agricultural Engineering, for the valuable information provided by them in their respective fields. I sincerely appreciate the inspiration and support of all those people who have been instrumental in making this project a success most especially my teaching assistant, Mr. Bright Mensah, Ms. Nomo Ernestina and Mr. Samuel Acquah and all the technicians at the Soil Science laboratory. Lastly, I place a deep sense of gratitude to my family and my friends who have been constant source of inspiration during the preparation of this project work.

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CHAPTER ONE

INTRODUCTION

1.1 Background

The general technology of anaerobic digestion of complex organic matter is well known and has been applied for years as part of domestic sewage treatment to stabilize organic wastes (Sagagi *et al.*, 2009). Biogas was produced as early as 3000 years ago from animal dung, human sewage and organic waste consisting generally of household waste, agricultural waste, human and animal waste (U.S Environmental Protection Agency, 2008). Evidence point out that biogas was used for water bath heating in Assyria in the 10th century BC. Persia, on the other hand started to use biogas in the 16th century AD. Organic waste was recognized as source of energy for the first time when Davy in 1808 recognized that methane was produced from decomposition of cattle manure but it was not until the end of 19th century that methanogenesis was associated to microbial activity (Philip,2008). There have been a considerable development in this modern times, as this idea was later exploited and many new technologies that are now used to produce and purify such gas (biogas) begun to spring up (Özmen and Aslanzadeh, 2009).

In 1906, the first anaerobic waste water treatment plant was established in Germany but it was not until 1920 when the first sewage plant in Germany collected biogas and connected it into the public gas supply system. Baker's biochemical studies contributed considerably to the identification and knowledge of the methane bacteria, which is still relevant and utilized in many established biogas plants all over the world. This study aided the development of methane generation in Bombay in the 1930s by using farm manure and was again developed for use by Indian villagers by KVIC (Khadi and Villagers Industries Commission) in the early 1960s. However, the present technology of anaerobic digestion has up till now not attained its full potential for energy production.

Biogas is a flammable gas composed mainly of a mixture of methane and carbon dioxide. Biogas-generating technology is a favorable dual-purpose technology, at present: the biogas that is generated can be used to meet energy requirements; thus a renewable energy that can be used for heating, generating electricity, and many other operations such as used in vehicles, where it can fuel an internal combustion engine.

The secondary product of the process is a sludge residue (digestate) that can be directly used as soil amendment (Sagagi *et al.*, 2009) or as starting material for high quality compost preparation (Nguyen, 2012).

In principle, many types of biomass can be used for biogas production. In agricultural biogas plants, the input material or substrate used includes fresh or ensiled plant material (e.g. maize, grass, cereal, beet or clover), animal excrements (e.g. slurry or manure), residues from agricultural or food production (e.g. feed remnants, chaff, whey, glycerine, straw) and waste materials (e.g. organic household waste, fruit waste, vegetable waste). In Ghana, the commonest and most important commodities to find in abundance on the market are fruits and vegetables. Its production and consumption rate has been increasing yearly, consequently generating high volumes of waste. Fruit and vegetable wastes are highly perishable and this makes their landfill disposal quite challenging, thus, this generates high environmental complications even for short-term disposal (Scano *et al.*, 2009). Heaps of rotten organic refuse encourage the breeding of flies and vermin and runoff can pollute nearby streams. Conversion of these fruits and vegetable wastes into biogas provides some energy that can have a beneficial effect on the environment. Besides, as a waste management strategy, the cost for raw material is cheap, available in high quantities and the biogas yield is relatively the same as biogas produced from manure (Deublein and Steinhauser, 2008).

1.2 Problem statement

There is an increase in production and consumption of fruits and vegetables, resulting in accumulation of fruits and vegetable wastes on Ghanaian markets. This is as result of;

- Inadequate containers or equipment for storing and transporting solid waste, and
- Lack of definite schedule for collecting waste from storage to disposal sites.

Waste collectors may show up every week, every three weeks or even after one month. Such irregular waste collection programme leads to overflow of waste at storage points. Consequently when these wastes are being conveyed in trucks to the dumpsites, due to their overflowing nature, they end up falling off the trucks and litter the very place they are trying to keep clean. This situation not only create uncomfortable condition in the markets but also, since fruit and vegetable wastes are quickly degraded when not attended to, poses serious environmental problems such as soil and groundwater pollution, being washed into streams and other water bodies when it rains, thereby contaminating the water bodies and also adds to the accumulation of greenhouse gases. Therefore an appropriate method to treat waste is needed to overcome the problems caused by accumulation of fruit and vegetable waste at market sites.

1.3 Justification

Energy could be derived from the fruit and vegetable wastes in the form of biogas and also the by product could be used for soil amendment, which would be beneficial from the view point of both environmental protection and economic development.

1.4 Objectives

1.4.1 Main objective

To enhance the management of fruit and vegetable wastes by converting it into biogas.

1.4.2 Specific objectives:

- To find the carbon and nitrogen contents of some selected fruits and vegetables.
- To determine the yield of biogas from the selected fruit wastes, vegetable wastes and a mixture of the fruit and vegetable wastes.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Anaerobic digestion

2.1.1 Overview

Breakdown of organic materials in the absence of oxygen produces biogas. The process is known as anaerobic digestion and performed through the biological activity of microorganisms (Elango *et al.*, 2007). The biogas consists mainly of methane (50%–80%) and carbon dioxide (20%–50%) and trace levels of other gases such as hydrogen, carbon monoxide, nitrogen, oxygen and hydrogen sulphide (Antonio *et al.*, 2014). It burns with pale blue flame and has a calorific value of between 25.9-30 J/m3 depending on the percentage of methane in the gas (Sagagi *et al.*, 2009).

The phenomenon occurs also naturally in anaerobic environments such as marshes and wetlands, and in the digestive tract of ruminants (Özmen and Aslanzadeh, 2009). The bacteria are also active in landfills where they are the principal process degrading landfilled food wastes and other biomass. Temperature and the composition of the feedstock are two important factors that should be taken into consideration due to the sensitivity of the process (Rouse and Ali, 2008). Anaerobic digestion is a technology that has many environmental benefits which includes reducing organic content of the waste before being sent to landfill, the utilization of household, animals, agricultural waste which contribute to waste management issues and the biogas provides solution of reducing dependency on fossil fuels (Anti, 2012).

2.1.2 Stages of anaerobic digestion

Generally, biogas production is based on 3 main stages consisting of hydrolysis, acid formation and methane formation (Nguyen, 2012; Anti, 2012). Different groups of bacteria will dominate different the stages of digestion and products of one group will serve as feed for another group (Gerardi, 2003). Methane-producing bacteria are the final link in a chain of a micro-organism that degrade organic materials and return the decomposed products into the environment (Özmen and Aslanzadeh, 2009).

Hydrolysis

In hydrolysis, which is the first stage of biogas production, extracellular enzymes, such as celluloses, amylases, proteases and lipases released by the bacteria, hydrolyse the organic material (Özmen and Aslanzadeh, 2009). The hydrolysis stage is also known as the polymer breakdown stage where the complex chain of carbohydrates, proteins and lipids are decomposed into shorter compounds. The hydrolysis of carbohydrates takes place within a few hours which obtain sugar monomers as products, while protein and lipid are hydrolysed within few days (Anti, 2012). According to Deublein (2008), hydrolysis of protein and lipid obtain fatty acids and amino acids as hydrolysis products.

Acid formation

Acidification is the second stage in the process of biogas production where acid-producing bacteria transforms the monomers and fermentation products produced in stage I, into acetic acid (CH_3COOH),hydrogen (H_2) and carbon dioxide (CO_2) (Özmen and Aslanzadeh,2009). Acid formation during consist of two main phases namely acidogenic and acetogenic.

During acidogenic phase, the monomers formed in the hydrolytic stage are taken up by anaerobic bacteria and are degraded into shorter chain and converted into alcohols, hydrogen, ammonia, carbon dioxide and organic acids, such as butyric acid, propionic acid, acetic acid. Some products (hydrogen, carbon dioxide and acetic acid) from the acidogenic phase will skip the acetogenic phase and be utilized directly in the final stage by methanogenic bacteria (Deublein, 2008; Ostrem, 2004).

During acetogenic phase, the products from the acidogenic phase are transformed by acetogenic bacteria into hydrogen, carbon dioxide and acetic acid as hydrogen plays an important intermediate product in this stage (Anti, 2012). It is necessary for hydrogen to have a low partial pressure in order to allow the conversion of all the acids (Lantz *et al.*, 2007).

Methane formation

In the final stage, the reaction takes place under strictly anaerobic condition during which methanogenic reaction converts the hydrogen, carbon dioxide and acetic acid into methane gas (Anti, 2012). Thus, the methane producing bacteria decompose further the compounds with a low molecular weight to form methane and carbon dioxide by utilizing hydrogen, carbon dioxide and acetic acid (Özmen and Aslanzadeh, 2009).

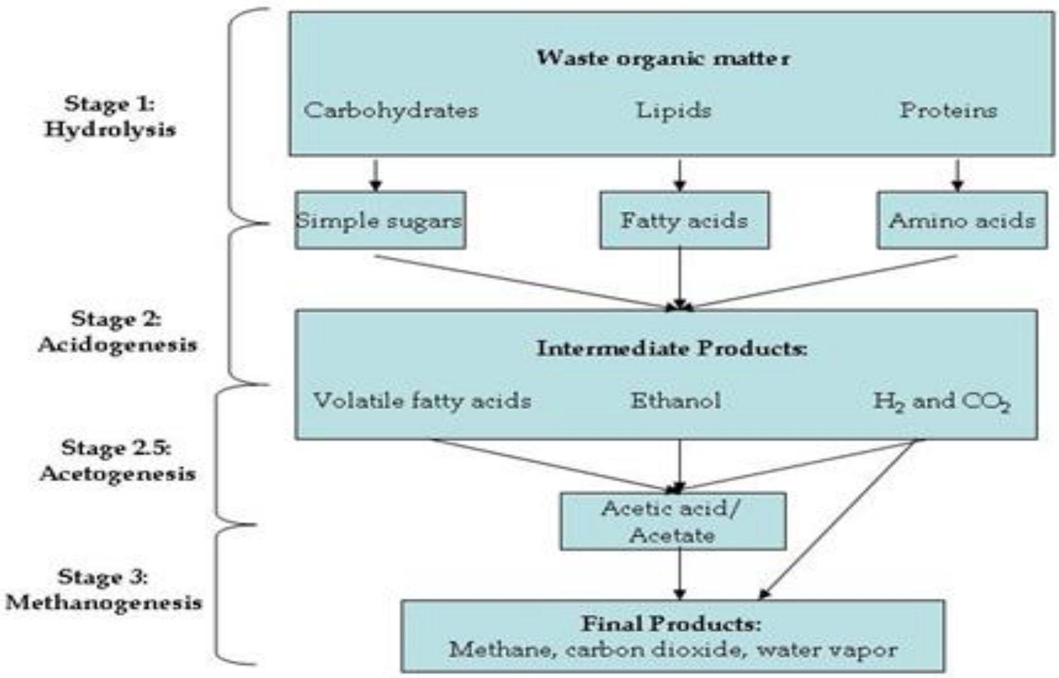

Figure 1. Various stages of anaerobic digestion

2.1.3 Factors that Influence Anaerobic digestion

There are some factors that can influence the anaerobic digestion process. The factors include the following:

Temperature

Small changes in temperature can cause significant decrease in activity of microbial and gas production up to 30%; therefore, the temperature should be kept exactly in the range of +/- 2ºC (Deublein, 2008). The involved bacteria are active within limited range of temperature, especially methanogens that are the methane-producing bacteria (Özmen and Aslanzadeh, 2009).

According to Deublein (2008), anaerobic digestion can be carried out at three different temperature ranges, which are psychrophilic (below 25ºC), mesophilic (30ºC – 42ºC) and thermophilic (43ºC – 55ºC) and Al Seadi *et al.* (2008) also indicated that, one can apply different temperature in anaerobic digestion, which are mesophilic in the hydrolysis stage while thermophilic condition in the methanogenic stage).In a research article by Elaiyaraju and Partha (2011), where biogas production from co-digestion of orange peel waste and jatropha de-oiled cake in an anaerobic batch reactor was studied, the anaerobic digestion of the substrate was carried out at ambient temperature that ranged from 27°C to 32°C.

According to Kemausuor (2015); The AD process can take place at different temperatures, divided into three temperature ranges:

Thermal stage	Process temperature	Minimum retention time
Psychrophilic	below 25°C	70 to 80 days
Mesophilic	25°C – 45°C	30 to 40 days
Thermophilic	45°C – 70°C	15 to 20 days

Hydraulic retention time

Hydraulic retention time is the measure of the average length that a compound remains in a storage unit.

Where;

T= hydraulic retention time

V= volume of digester

Q= volume of feedstock (Kemausuor, 2015.)

Substrate

Substrate is material and energy source for the microorganism which is consumed by microorganism and converted to methane as well as the use for growth. Types of substrate determine the rate of the digestion process, and lack of substrate ends the metabolism of the microorganism as well as determining the time of digestion, since more complex substrate will take longer time for degradation by microorganism (Anti, 2012).

In principle, many types of substrate (biomass) can be used for biogas production. Variety of feed-stocks that can be used for anaerobic digestion range from organic residues from agriculture (crop residues), waste from animals (manure), municipal organic waste, industrial waste, sewage sludge, by-products from production of bioethanol and biodiesel, energy crops and algae etc. (Lantz *et al.*, 2007). In agricultural biogas plants, the input material or substrate used includes fresh or ensiled plant material (e.g. maize, grass, cereal, beet or clover), animal excrements (e.g. slurry or manure), residues from agricultural or food production (e.g. feed remains, chaff, whey, glycerine, straw) and waste materials (e.g. organic household waste, fruit waste, vegetable waste).

pH

pH is an important factor that affects microbial activity and control the anaerobic digestion process as the pH of the substrate influences the growth of methanogenic bacteria.eg. Anti (2012) indicated that, anaerobic digestion operated in a pH below 6.5 decreases the organic acid production by hydrolytic bacteria, as well as decreases the methane production.

According to (Özmen and Aslanzadeh, 2009) in order to obtain the best-optimized condition for biogas production, where the methane producing bacteria exist, the pH value of input mixture in the digester should be between 6 and 7. Other researches in their works indicated that (Deublein, 2008; Gerardi, 2003),in the digester, the pH value is kept in a neutral range and this condition is ensured by two buffering systems, carbon dioxide/hydrogen carbonate buffer system for strong acidification and ammonia-ammonium buffer system for weak acidification.

Volatile fatty acids and alkalinity

Volatile fatty acids (VFA) are substrates for methanogenic bacteria and include acetate, propionate, butyrate, lactate, etc. produced in the acidogenic and acetogenic stages as accumulation of volatile fatty acids has direct relationship to alkalinity (Anti ,2012). However, accumulation of volatile fatty acids leads to decrease pH as well as failure of the anaerobic digestion process. Alkalinity is used as a buffer to keep the pH in the allowable range, that is, when large amounts of organic acids are produced in the beginning of the fermentation, the pH inside the digester might decrease below 5 whiles after stabilization of the fermentation process under anaerobic condition, the pH value end up between 7.2 and 8.2 due to the buffer effect of increased ammonium concentration. Alkalinity is usually used as a buffer in the form of bicarbonate. The ratio of recommended volatile fatty acids and alkalinity for a good digestion process is 0.1 and 0.35, respectively for a proper digestion process (Verma, 2002).

C/N Ratio

Both nitrogen and carbon is essential for microorganisms in order to assimilate these into their cell structure. Too low value of the C/N ratio in the substrate causes an increase of ammonia production and this will increase the pH value of the content in the digester i.e. pH value higher than 8.5 will start showing a toxic effect on methanogen population and this will lead to the inhibition of the methane production. On the other hand, too high value of the C/N ratio gives negative effect in protein formation, thus the nitrogen will be consumed rapidly by methanogens for meeting their protein requirements and will no longer react on the left over carbon content of the material. As a result, gas production will be low. Based on studies, the metabolic activity of methanogenic bacteria is possible to be optimized at a C/N ratio around 8 to 20, however, depending on the characteristics of the substrate, the optimum point can vary (Özmen and Aslanzadeh, 2009). According to Kivaisi and Mtila (1998), the optimum C: N ratio for microbial activity involved in bioconversion of vegetable biomasses to methane is 25-30. The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the Carbon/Nitrogen (C/N) ratio. Materials with high C/N ratio could be mixed with those of low C/N ratio to bring the average ratio of the composite input to a desirable level.

2.2.1 Generation of wastes

Fruit and vegetables are quickly degraded by contaminating microorganisms and this takes place faster when they show signs of mechanical damage or are excessively ripe (Efisio *et al.,* 2014). According to FAO UN (2011), the main fruit and vegetable waste stream originates from agricultural production which include the losses due to improper harvest operation, postharvest handling and storage, processing which produces waste composition such as peels, seeds, waste pulp, distribution which involves losses during transportation from storage to market or retailers and consumption which includes waste from consumption of fresh fruit in the household.

The global fruit and vegetable losses are dominated by agriculture production losses and followed by consumption and at least 10% of fruit losses come from agriculture production, mostly due to improper handling during harvest or postharvest, and causes rejection by retailers (Anti, 2012). About 20 – 40% of fruit production in developing countries becomes food losses due to pest and pathogens (Kantor *et al.,* 1999).

2.2.2 Global waste production

About 20 – 40% of fruit and vegetable production in developing countries becomes food losses due to pest and pathogens. According to Hui (2010), the global production of fruit waste can be estimated to 30% from world fruit production. The abundant amount of waste create environment problems since it potentially causes contamination of groundwater, soil contamination, generation of greenhouse gaseous, spreading of diseases vectors etc..

2.2.3 Management of wastes produced

The waste produced usually ends up in a landfill because it is the easiest and quickest way to handle this waste. However, this method does not really solve the environment problems. European commission reported that the environmental impacts of fruit and vegetable production in the EU27 are estimated 9.2E+10 (kg CO2 eq. /yr.) and (kg PO4 eq. /yr.) for GWP 100 and eutrophication, respectively (European Commission (DG ENV) Directorate C, 2010). Today, source separation, composting together with biogas production is more and more being considered as a replacement to land filling and incineration strategies (Özmen and Aslanzadeh, 2009). Conversion of these fruit and vegetable wastes to produce biogas will provide some energy that can have a beneficial effect on the environment: beside as a waste management strategy, the cost for raw material is cheap and also available in high quantities

2.3 Biogas production from fruits and vegetable waste

According to Prakash and Singh (2013), fruits and vegetable waste are solid organic waste having high calorific value and nutritive value to microbes that's why the efficiency of methane production can be increases by several order. The easy biodegradable organic matter content of vegetables waste with high moisture facilitates their biological treatment and shows the trend of these wastes for anaerobic digestion (Bouallagui *et al.,* 2003). Scientific literatures contain several studies on anaerobic digestion of fruits and vegetable waste but just in a few studies have the results been obtained using the fruits and vegetable waste as single substrate (Efisio *et al*., 2014). Most literatures also show that anaerobic digestion of Fruit and vegetable wastes without any co-substrate is a challenging task because their high simple sugars often promotes fast acidification of the biomass with a resulting inhibition of methanogenic bacteria activity. Further study also shows that D-limonene abundant in orange peel is known as an anti-microbial agent. In other words, bacteria will be inhibited by D-limonene, resulting in the failure of anaerobic digestion. Therefore, effect of D-limonene will become one important factor for anaerobic digestion if orange peel is used as feedstock (Siles *et al*., 2010). Efisio *et al*., 2014 indicated that, to maximize the yield of biogas and to improve quality (high methane content and low sulphide content), the following strategies can be followed. Firstly, the use of a well balanced mix of fruits and vegetable waste in the feeding substrate is required where the use of substrates with contents of simple sugars lower than 40% ensures process stability and good methane production. Secondly, to reduce the sulphide content of the produced biogas, the use of leafy vegetables (which are characterized by sulfur contents) must be carefully managed.

An interesting option for improving yields of anaerobic digestion of wastes are co-digestion, which employs a co- substrate that has the benefit of improving the biogas yields due to positive synergism established in the digestion medium and the supply of missing nutrients for microorganisms (Rungvichaniwat, 2003). So, using co-digestion of fruit and vegetable wastes is an alternative way to improve biogas technology.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was conducted at the department of Agricultural Engineering, Kwame University of Science and Technology, Kumasi.

3.2 Materials

The materials used for the experiment are as follows;

- 3 L plastic containers
- Feedstock (fruit wastes; pineapple peels, watermelon peels, orange peels, banana peels and pawpaw peels, vegetable waste; carrots, cabbage, lettuce, onion and eggplant)
- 2 L plastic containers
- Electronic beam balance
- Blender
- Thermometer (liquid in glass)
- pH meter
- Hoses
- Socket valves
- k'17 plastics
- Sodium hydroxide (NaOH)
- Water

The 3 L plastic container was used as digester. A thermometer (liquid in glass) was attached to each digester to measure temperature. The 2 L plastic containers (gas receiver and the water displacement apparatus) were used to collect and measure the gas volume respectively, while pH of the mixtures was measured with a digital pH meter. Weighing of the samples was done using an electronic beam balance.

3.3 Methods

3.3.1 Substrate Collection

The waste materials were collected fresh at Ayeduase market. Fruit wastes (comprising orange peels, pineapple peels, banana peels, pawpaw peels and watermelon peels) and vegetable wastes (comprising carrot, cabbage, lettuce, eggplant and onion) for the present study were collected from the fruit and vegetable sellers.

The waste materials were hand-picked and utmost care was taken to ensure that just a particular type of waste was used.

3.3.2 Sample Preparation

Each class of fruit wastes (orange, pineapple, pawpaw, banana and watermelon peels) and vegetable wastes (carrot, cabbage, lettuce, eggplant and onion) were cleaned, the cleaned samples were then weighed with the aid of an electronic balance by taking 1 kg of fruit wastes (consisting of 200 g each of orange, pineapple, pawpaw, banana and watermelon peels), 1 kg of vegetable wastes (consisting of 200 g each of carrot, cabbage, lettuce, eggplant and onion) and 1 kg of mixed fruits and vegetable wastes (consisting of 100 g each of the individual fruit and vegetable wastes).

3.3.2.1 Preparation of slurry

- From the weighed samples different slurries were prepared as a mixture of different fruits and vegetable wastes by blending using an electronic blender to aid in the easy and faster decomposition of the feedstock which were then stored in a fridge till it was needed.
- 1 kg of the blended fruit wastes (consisting of 200 g each of orange, pineapple, banana and watermelon peels) was taken and mixed with 1 litre of water.
- 1 kg of the blended vegetable wastes (consisting of 40 g each of carrot, cabbage, lettuce, eggplant and onion) was taken and mixed with 1 litre of water.
- 1kg of the blended mixed fruits and vegetable wastes (consisting of 20g each of the individual fruits and vegetable wastes) was taken and mixed with 1 litre of water.
- The water was added in order to dilute the organic substances and to increase the breeding of microorganisms (Prakash and Singh, 2013).

3.3.2.2 NaOH pre-treatment of slurries

5M of NaOH was added to the slurry to help neutralize the acidic content of the slurry to enhance the biogas production.

3.3.3 Experimental Design and Setup

3.3.3.1 Construction of digesters

- The digesters (3 L containers) were three (3), each representing fruit waste, vegetable waste and a mixture of fruit and vegetable waste.
- A 2 mm hole was made at the center of the lid of the 3 L container.

- Socket valve and the k’17 plastic were inserted into the hole, and a strip of rubber was used as a gasket to ensure air tightness of the socket valve (to prevent air from entering the digester). A hose was then fixed into the k’17 plastic.

3.3.3.2 Construction of receivers

Two plastics containers (2 L) were used, for each digester, one containing water and the other was empty to receive displaced water.

- For the container containing water: 2 holes were bored in the lid (2 mm and 1 mm respectively). And a third hole (2mm) was bored at the side, 2 mm from the bottom of the plastic container.
- Socket valve and the k’17 plastic were fixed in the 2 mm hole on the cover of the plastic container, with a strip of rubber to make it seal and very tight, and the gas valve was fixed in the 1 mm hole.
- Another socket valve and the k’17 valve were fixed in the 2 mm hole at the side of the plastic container and a hose fixed into it.
- For the empty container: A hole (2 mm) was also bored in the lid of container and also fixed with socket valve and the k’17 plastic to receive the displaced water.

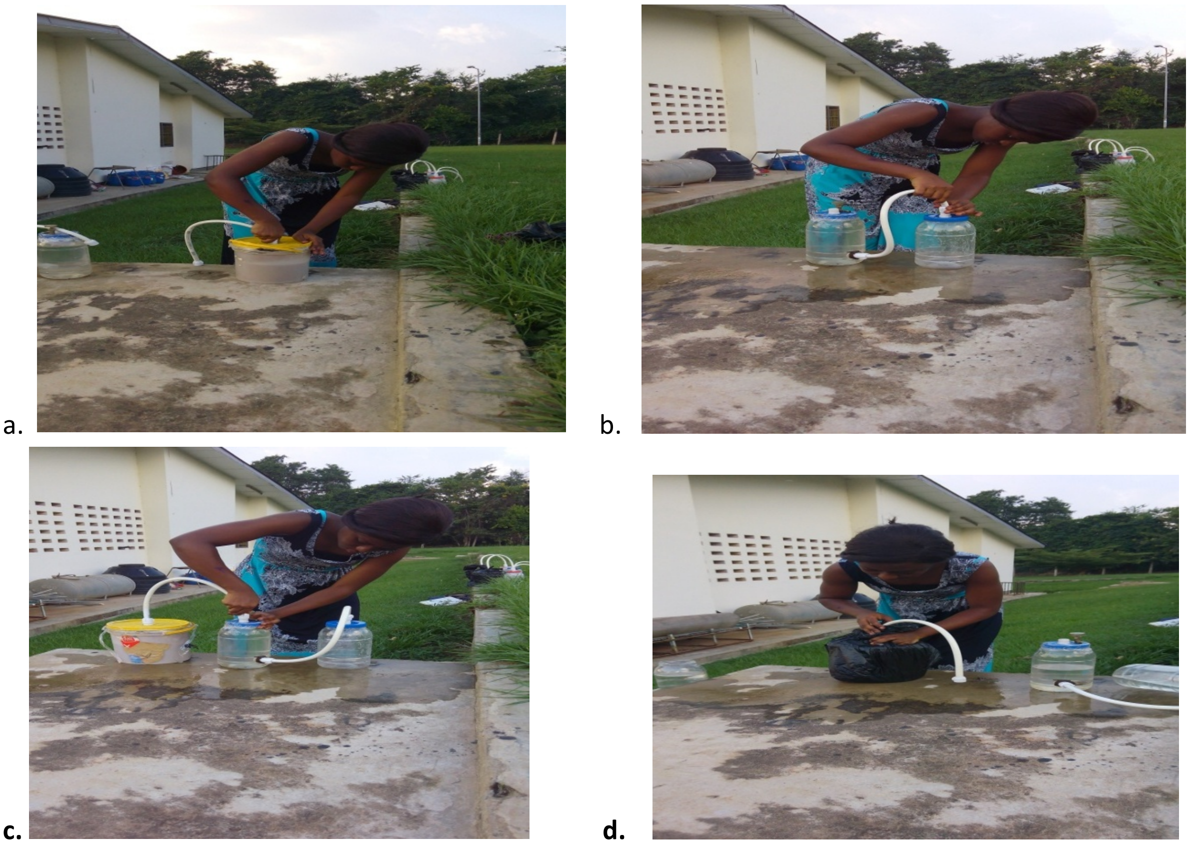

Figure 2. Contruction of the digester and receivers.

3.3.3.3 Operation of digesters and receivers

The hose on the cover of the digester was fixed into the k'17 plastic on the cover of the plastic container containing the water, and it was closed tightly with its cover. The gas valve on the other side of the cover was closed to prevent biogas from escaping, and this gas valve was opened only when biogas was ready to be tapped. The hose on the side of the plastic container was also fixed into the hole in the cover of the plastic containers for the displaced water, and the plastic container was also closed.

The digester was filled with the various feedstock slurry containing in each 5M of NaOH; fruit waste, vegetable waste and a mixture of fruit and vegetable waste. The digester was tightly closed with its cover to prevent any air from entering into the digester. When the biogas was produced in the digester, it moved through the hoses to the plastic container containing the water and then compressed the water in the plastic container, displacing water into the other plastic container.

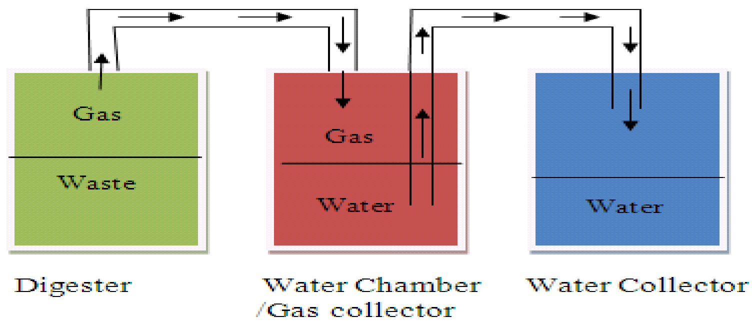

Figure 3: Schematic Diagram of Experimental Setup (adapted from Prakash and Singh, 2013)

Figure 4. Experimental setup

3.4 Collection of Data and Analysis

3.4.1 C/N ratio

Laboratory analysis was done to determine the carbon and nitrogen contents of the various fruits and vegetables used.

3.4.2 pH determination

The pH of the slurry was determined using a pH meter before and after adding 5M of NaOH.

3.4.3 Temperature measurement

The temperature in each digester was measured on daily basis using a thermometer (liquid in glass).

3.4.4 Biogas yield/production

The water displacement method was used where the volume of water displaced into the empty plastic container equal the volume of biogas produced. The volume of water displaced was measured and recorded on daily basis.

3.4.5 Data Analysis

MS EXCEL version 2013 was used in the graphical presentation and analysis of data collected.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the results and discussions of analysed data from the laboratory analysis and experimental work. The results are presented in tables and graphs

4.0 C/N ratio of feedstock

Table 1: C/N ratio for specific fruits and vegetable waste

FEEDSTOCK	% TOTAL ORG C	% TOTAL N	C : N RATIO
Garden egg	45.09	2.574	18:1
Lettuce	40.70	3.602	11:1
Cabbage	45.09	4.031	11:1
Carrot	45.89	1.006	46:1
Onion	47.48	0.947	50:1
Pawpaw	41.90	3.014	14:1
Pineapple	44.29	0.947	47:1
Banana	36.31	1.406	26:1
Orange	46.68	0.911	51:1
Watermelon	39.50	1.160	34:1

Table 2: Average C/N ratio of the feedstock

FEEDSTOCK	AVERAGE C:N RATIO
FRUIT WASTE	34:1
VEGETABLE WASTE	27:1
MIXTURE (fruit and vegetable waste)	30:1

C/N ratio of fruit waste was highest (34:1) followed by that of the mixture of both fruit and vegetable waste (30:1). Vegetable waste recorded the least C/N ratio (27:1) as compared to the two other feedstocks.

4.1 pH values of the various feedstock before and after adding 5M NaOH.

Table 3: pH values of the various feedstock before and after adding 5M NaOH.

FEED STOCK	PH BEFORE 5M OF NAOH WAS ADDED	PH AFTER 5M OF NAOH WAS ADDED
FRUIT WASTE	4.0	5.0
VEGETABLE WASTE	5.0	7.0
MIXTURE OF FRUITS AND VEGETABLES	4.5	6.0

It was observed that the pH values of the various feedstock increased after treatment with 5M NaOH. All feedstocks showed to be acidic before and after treatment with 5M of NaOH, except vegetable waste which obtained a neutral pH (7.0) after treatment. Fruit waste showed the highest acidity (5.0) followed by the mixture of both fruit and vegetable waste (6.0).

4.2 Temperature and biogas yield

The volume of biogas and average temperature were monitored and measured on a daily basis. The temperature for the 30 days hydraulic retention time was between 26ºC to 34°C. However an average temperature of 29°C was observed to boost biogas production within the 30 days.

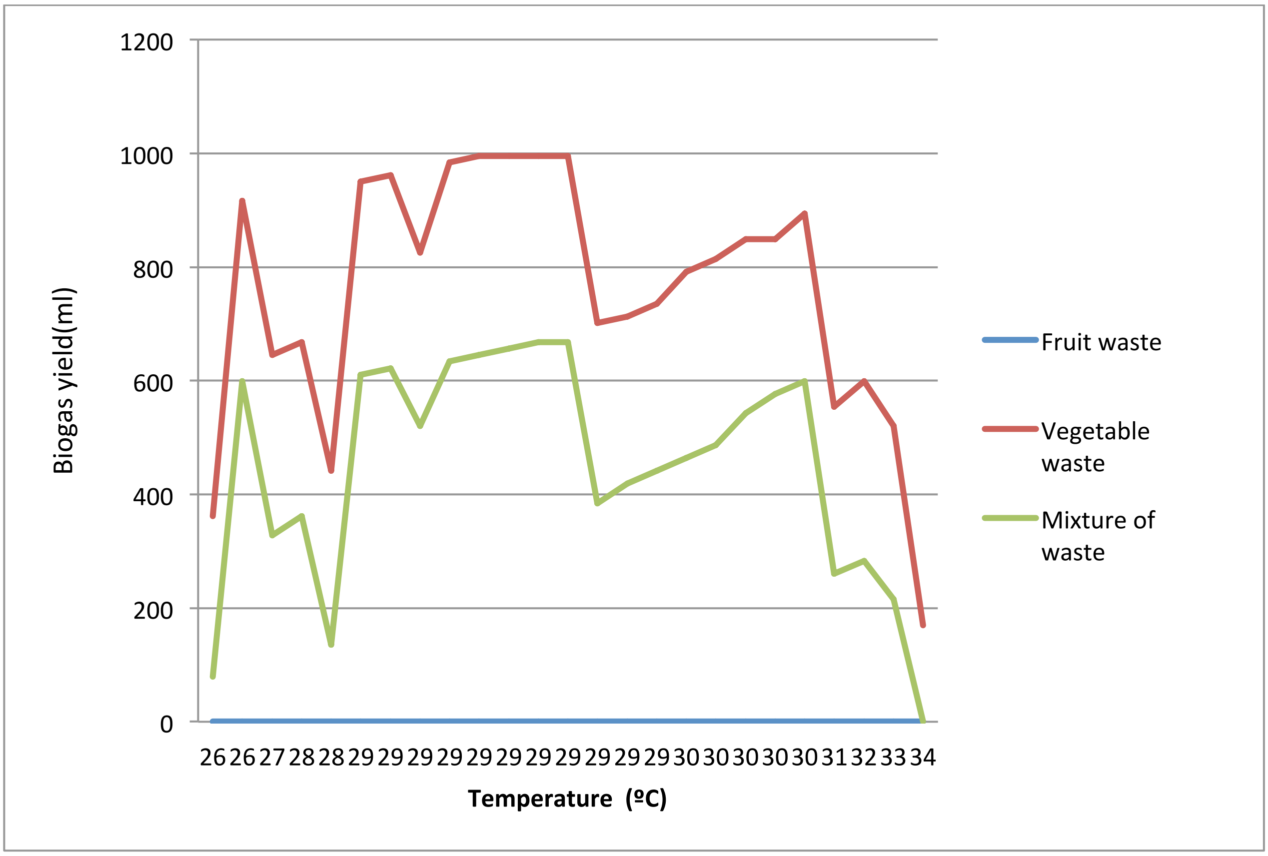

Figure 5. Biogas yield against temperature of various feedstock.

4.3 Daily biogas yield

The volume of biogas produced on a daily basis was monitored and measured. Gas production began on the 4th day for vegetable waste and on the 7th day for mixture (fruits and vegetables) but no yield for the fruit wastes for the entire retention period of thirty days. There was a small and linear increase in the biogas produced from the eighth (8th) day to the 26th day, the biogas production got to its peak on the 27th day and thereby there was no gas production from the 28th day to the 30th day.

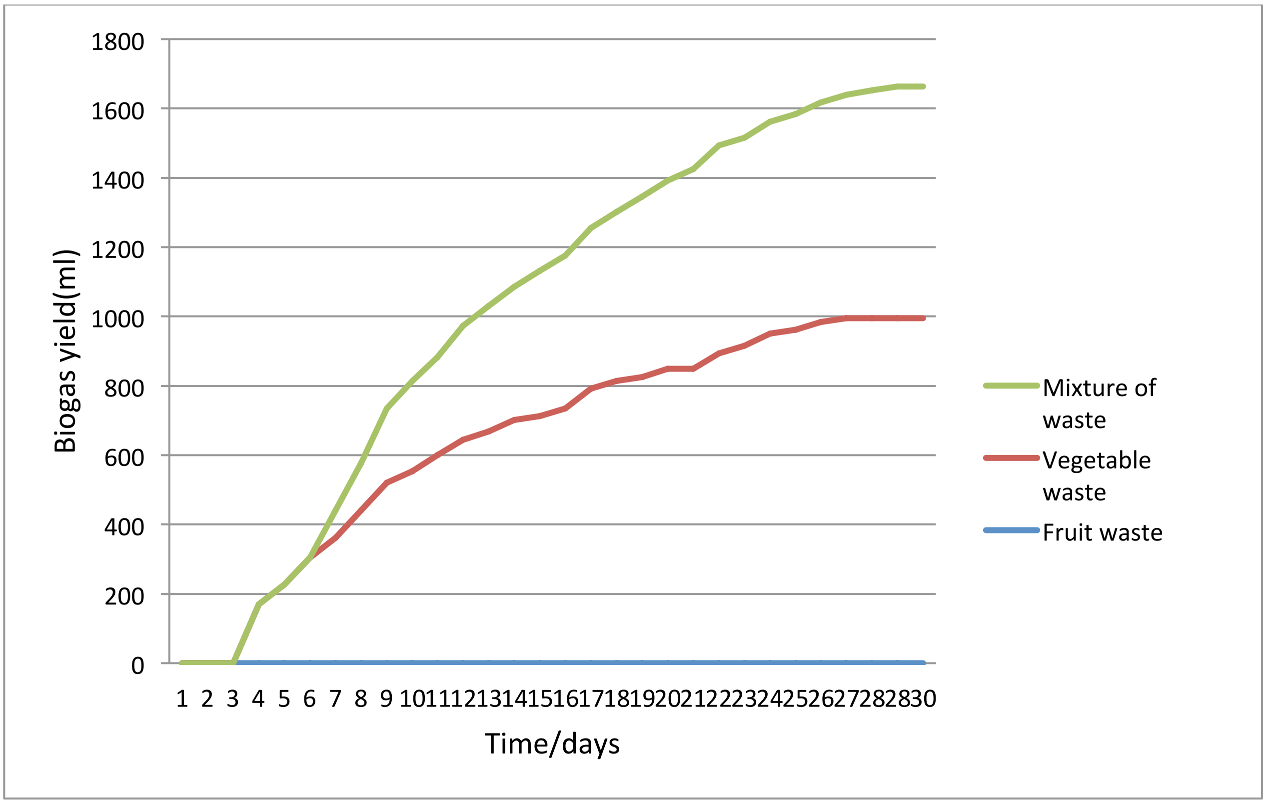

Figure 6. A graph of biogas yield against time over a period of 30 days.

4.4 Total volume of biogas produced

At the end of the retention period of 30 days, vegetable waste recorded the highest volume of biogas produced (996 ml**)** followed by the mixture of both fruit and vegetable waste (668 ml**)**. However, fruit waste recorded no yield of biogas.

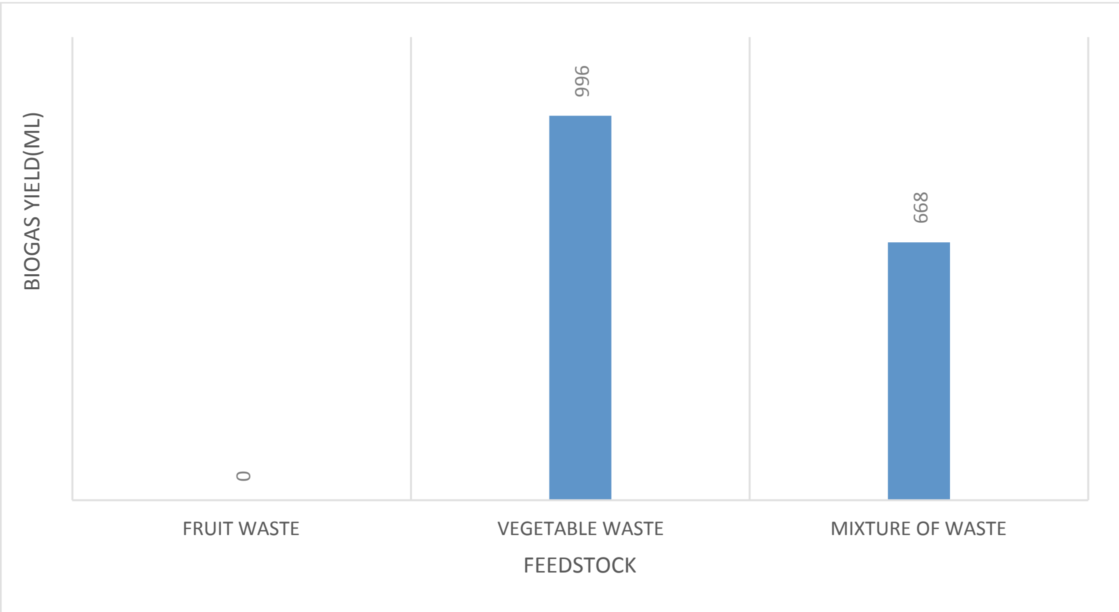

Figure 7: Total biogas yield of various feedstock

For all the feedstocks, pH for the slurry before and after treatment varied within the range of 4.0 to 7.0 (Table 3). Throughout the entire anaerobic digestion process, the ambient temperature for digestion ranged from 26°C to 34°C (Fig.5).

The higher gas yield from the vegetable waste might be due to the right proportion of carbon to nitrogen of 27:1 (Table 2), and this is within the optimum range ensuring proper decomposition of the vegetable waste. According to Kivaisi and Mtila (1998), the optimum C: N ratio for microbial activity involved in bioconversion of vegetable biomasses to methane is from 25 to 30. The high biogas yield from vegetable waste can also be attributed to stable pH of 7.0 (Table 3), influencing the growth of methanogenic bacteria. This confirms the findings by Deublein (2008) and Gerardi (2003) that in the digester, the pH value is kept in a neutral range to enhance biogas production.

For fruit waste no biogas yield was recorded, which shows that fruit waste is less degradable due to the high value of C/N ratio of 34:1 (Table 2). Too high value of C/N ratio gives negative effect in protein formation as carbon is in excess leading to a slowdown in decomposition. Low pH value (5.0) was one of the reasons for the failure in biogas yield by fruit waste. Anti (2012) indicated that, anaerobic digestion operated in a pH below 6.5 decreases the organic acid production by hydrolytic bacteria, as well as decreases the methane production. One other factor that hindered the production of biogas by the fruit waste is the presence of D-limonene in orange peel, one of the constituents of the fruit waste. According to Sagagi *et al.* (2009)**,** D-limonene is an anti-microbial agent inhibiting the activities of bacteria which are involved in the digestion process hence contributed to the failure of fruit waste in yielding biogas.

The mixture of fruits and vegetable waste recorded about 33% less yield in biogas as compared to that of only vegetable waste (Fig. 7). To obtain the best-optimized condition for biogas production, where the methane producing bacteria exist, the pH value of input mixture in the digester should be between 6 and 7 (Özmen and Aslanzadeh , 2009), hence the ability of the mixture of fruits and vegetable waste to produce biogas might be attributed to its pH value of 6 (Table 3). But anaerobic digestion operated in a pH below 6.5 decreases the organic acid production by hydrolytic bacteria as well as decreases the methane production (Anti 2012). This explains why there was a drop in biogas yield by the mixture of fruit and vegetable waste as compared to only vegetable waste. The C/N ratio value of 30:1 (Table 2) might also be a contributing factor to the yield of biogas by the mixture of fruits and vegetable waste. The decrease in biogas yield by the mixture of fruit and vegetable waste might also be due to the inhibition of the activities of bacteria which are involved in the digestion process by D-limonene in orange peel, one of the constituents of the mixture of waste.

There was little temperature variation effect on biogas production once biogas production began (Appendix 1). Therefore, the difference in the production of biogas to a large extent depends on the nature of the substrate. This confirms the findings by Anti (2012) that the type of substrate used determines the rate of the digestion process as well as determining the time of digestion, since more complex substrate will take longer time for degradation by microorganism.

CHAPTER FIVE

CONCLUSION & RECOMMENDATIONS

5.0 Conclusion

The study investigated the biogas yield, effect of C/N ratio, temperature, pH of biogas produced using fruit wastes, vegetable wastes and a mixture of fruit and vegetable wastes as feedstock. The study proved that,

- Fruit wastes had the highest C/N ratio followed by the mixture, whiles vegetable wastes had the least C/N ratio
- Vegetable wastes yielded the highest volume of biogas, followed by the mixture of fruit and vegetable wastes and fruit wastes yielded no biogas.
- Fruit wastes used showed no yield of biogas due to its high C/N ratio. The study further confirms that co-digestion of fruit and vegetable wastes (mixture) can also be used as a feedstock to produce biogas.

5.1 RECOMMENDATIONS

To guide or direct future studies of the study initiated, the following recommendations are being made,

- Materials with high C/N ratio such as carrot with C /N ratio of 46:1 should be mixed with those of low C/N ratio such as cabbage with C /N ratio of 11:1 to bring the average ratio of the composite input to a desirable level.
- Orange peels should be pre-treated to decrease or convert D-limonene into non-toxic substances before carrying out biogas production of orange peel.
- Another study could be done to vary the ratios of the feedstocks.

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APPENDICES

Appendix 1. A table showing days, temperature and gas yield over the retention period of 30 days.

TIME (Days)	**TEMPERATURE (ºC)**	**VOUME Of Mixture** (ml)	**VOLUME of vegetable waste** (ml)	**Volume of fruit waste** (ml)
1	34	0	0	0
2	28	0	0	0
3	33	0	0	0
4	34	0	170	0
5	32	0	226	0
6	31	0	306	0
7	26	79	362	0
8	28	136	441	0
9	33	215	521	0
10	31	260	554	0
11	32	283	600	0
12	27	328	645	0
13	28	362	668	0

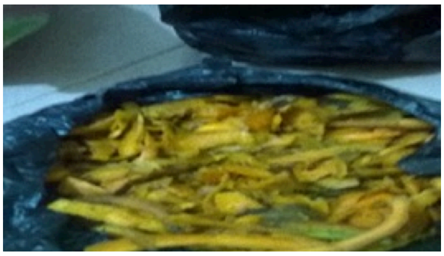
14	29	385	701	0
15	29	419	713	0
16	29	441	735	0
17	30	464	792	0
18	30	487	815	0
19	29	520	826	0
20	30	543	849	0
21	30	577	849	0
22	30	600	894	0
23	26	600	916	0
24	29	611	950	0
25	29	622	962	0
26	29	634	984	0
27	29	645	996	0
28	29	656	996	0
29	29	668	996	0
30	29	668	996	0

Appendix 2. A table showing the total gas yield for the various feed stocks after 30 days.

	FEEDSTOCK		
	FRUIT WASTE	**VEGETABLE WASTE**	**MIXTURE (FRUIT AND VEGETABLE WASTE)**
TOTAL GAS YIELD (ml)	0.0	996	668

Appendix 3. Waste materials used

Garden egg



Carrot

Onion

Pineapple

Pawpaw

Cabbage

Orange

Banana

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Lettuce

Watermelon