DEVELOPMENT AND PERFORMANCE EVALUATION OF A 32 LITRE CHICKEN AND GOAT WASTE DIGESTER

BY

OKAFOR, Nnamdi William
MEng/SEET/2016/6194

A THESIS SUBMITTED TO THE POST GRADUATE SCHOOL,

FEDERAL UNIVERSITY OF TECHNOLOGY,MINNA,NIGERIA,IN

PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR THE

AWARD OF MASTER OF ENGINEERING IN DEPARTMENT OF

MECHANICAL ENGINEERING (INDUSTRIAL AND PRODUCTION ENGINEERING OPTION)

OCTOBER, 2019

ABSTRACT

This research involves the use of chicken and goat waste at different mixing ratio to produce gas. A 32 litres Capacity prototype biogas plant constructed at the National centre for Energy Research and Development, University of Nigeria Nsukka was used to investigate the anaerobic digestion in generating biogas from two types of wastes: chicken waste and goat waste with different mixing ratios. Chicken waste, goat waste and co digestion of chicken and goat waste.
The ratio of the percentage distribution of chicken waste to goat waste were: (100:0), (30:70), (70:30), (50:50), (0:100) all by weight percent for digesters 1, 2, 3, 4 and 5 respectively. Goat waste alone (sample I), co digestion of chicken and goat waste (sample II), co digestion of chicken and goat waste (sample III), co digestion of chicken and goat waste (sample IV) and chicken waste alone (sample V). The digester was charged differently with these wastes in the ratio of 1:3 of waste to water respectively. The mesophilic ambient temperature range attained during the course of the experiment were 26 -38 ^{o}C and a slurry temperature of 25 - 32 ^{o}C. The result showed that sample I, sample II, sample III, sample IV and sample V were capable of producing a total of 17.3 L, 44.3 L, 74.3 L, 86.2 L and 113.2 L of biogas respectively in a 32 L digester in 30days. Chicken waste alone has the highest volume of gas production as compared to other wastes. The result obtained from the gas production showed that sample IV produced the highest methane content of 63.3 % followed by sample III with 59.4 %, followed by sample II with 59.2 %, followed by sample I with 59.1 % and sample IV has the least methane content of 57.3 %. This research has shown that goat waste can produce methane for cooking and can be combined with other animal wastes to enhance its viability for biogas production. The study showed that chicken droppings as animal waste have great potentials for generation of biogas and also high volume of biogas as compared to others.

TABLE CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

CD	Chicken dropping
GD	Goat dung
CH_4	Methane
CO_2	Carbondioxide
$H2_S$	Hydrogen sulphide
TS	Total solid
VS	Volatile solid
V_f	Volume of frustrum (cm^3)
V_{bp}	Volume of big pyramid (cm^3)
A	base area of big pyramid (cm)
H	Height of big pyramid (cm)
V_{sp}	Volume of small pyramid (cm^3)
V_s	Volume of small cylinder (cm^3)
r	Radius of small cylinder (cm)
H	Height of small cylinder (cm)
V_b	Volume of big cylinder (cm)
R	Radius of big cylinder (cm)
H	Height of big cylinder (cm)
V_i	Inlet volume (cm)
V_c	Volume of cylindrical part (cm)
V_f	Volume of frustum part (cm)
P_b	Bursting pressure (Pa)
S_t	Tensile strength of the pipe (Pa)
D_m	mean diameter (mm)

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Global depletion of energy supply due to continuous over-utilization is a major problem of the present and future world community. Today's life-style is strength demanding, so we want to discover and make the most new sources of energy which are renewable as well as eco-friendly. Energy is generally classified in either renewable or non-renewable. Biogas comes in the category of renewable energy sources. Renewable energy is energy that is generated from natural resources which can be replenished within a short period of time. Some renewable energy sources include biomass, water (hydro-power), geothermal, wind, and solar (Godi *et al*., 2013).

The livestock industry is growing day by day concentrated within the urban as well as rural community. The number of livestock for goats and chickens in Malaysia was estimated around 505 and 208 million, respectively; these abundant faeces may release nitrate and ammonia gas causing water pollution, odor pollution and health problems to human beings. The alternative degree to oversee this issue is to utilize these feces as crude materials in biogas generation. Biogas comprises of a blend of methane gas, hydrogen gas, carbon dioxide and other gases coming about from deterioration of natural matter by anaerobic microscopic organisms within the nonappearance of oxygen. Biomass is defined as ecologically dried materials from living organisms that present in certain periods for each unit of earth surface (Manyi-Loh *et al*., 2013). Biomass energy is defined as energy from the plants and raw materials from industrial and municipal waste (White, 1981). Biogas technology affords a very fascinating route to utilize categories of biomass for meeting partial energy needs. Anaerobic digestion (AD) is a technology widely used for treatment of organic/biological waste for biogas production and

provides a source of energy while simultaneously resolving ecological and agrochemical issues (krishan et al.2014). The anaerobic fermentation of manure for biogas production does not reduce its value as a fertilizer supplement, as available nitrogen and other substances remain in the treated sludge (Alnaney and Liden 2008).

Anaerobic digestion (AD) is a natural biological decomposition of organic material in a controlled environment in the absence of oxygen (Nitin *et al.*, 2012). In this deoxidized- zone, bacteria are employed to decompose the proteinaceous and carbonaceous materials producing biogas and sludge (krishan *et al.*2014). Depending on the type of raw material, biogas contains on average 50 -70 % methane, 30-40 % carbon dioxide, 1-2 % nitrogen, 5-10 % hydrogen, and trace amounts of hydrogen sulfide and water vapor (Nitin *et al.,* 2012).

One of the burning issues confronting the world nowadays is the administration of all sources which endangers the presence of human life. Biogas production is a complex biochemical reaction found to take place under the action of delicately pH sensitive microbes mainly bacteria in the presence of little or no oxygen (Krishan *et a*l., 2014). Three major groups of bacteria (Hydrolytic, Acidogenesis, Acetogenesis and Methanogenesis) are responsible for breaking down the complex polymers in biomass waste to form biogas at anaerobic conditions (krishan *et al.*2014). Biogas production is slightly slow at the starting and the quit duration of observation. This is envisioned due to the fact that biogas production rate in batch situation is directly proportional to precise growth charge of methanogenic bacteria in the bio digester (Nordberg and Edstrom, 2005). The present study aims at producing biogas from chicken droppings and goat waste.

1.2 Statement of the Problem

Over the years, kerosene is one of the most commonly used fuel for lighting and cooking in Nigeria, most consumers of kerosene are faced with ridiculous increase in the prices of kerosene due to its overwhelming demand; yet it remains scarce and limited in supply. As a result of this challenges, larger percentage of the populace seek solutions to their energy needs from other sources which in most cases are detrimental to the environment. For instance, there was a 5.5 % increase in the dependence on wood fuel for cooking between 2007 and 2008 (Nigeria Bureau of Statistics, 2009). More so, 79.6 % of the households depend on wood fuel for their cooking while kerosene, coal, gas and electricity come behind from distant 18.51, 1.1, 0.6 and 0.2 % respectively (Nigeria Bureau of Statistics, 2009). As a result of the ever growing populace in the country, most researchers have worked on several biogas production from various biodegradable materials hence, it is necessary to research on alternatives to make the production process faster by enhancing the rate of digestion through addition of additives. Also, the excessive waste generated from various farms across the country if not properly handled can cause adverse environmental and health issues. Goat waste and chicken droppings are such waste if channeled towards biogas production instead of the current habit of using them for landfills or as fertilizer without pretreatment can help in environmental cleanup.

1.3 Aim and Objectives of the Study

The aim of this study is to develop and carry out performance evaluation of a 32 litre chicken and goat waste digester.

The objectives of this study are to:

1. To develop a mini prototype to obtain biogas.

2. Produce biogas from chicken and goat wastes independently, and from different blends of chicken and goat waste.
3. Compare the biogas production between chicken waste and goat waste.

1.4 Significance of the Study

Many countries are facing enormous problems associated with overproduction of organic wastes from industry, agriculture and households. Biogas production is an excellent way to comply with increasingly restrictive national and International regulations in this area and to utilise organic wastes for energy production, followed by recycling of the digested substrate as fertilizer.

The findings of this study will contribute to better understanding of the causes of low production and adoption rate of biogas technology. If the responsible government institutions and other stakeholders will adequately promote biogas technology, many people will adopt it and have an alternative sustainable source of energy. As pointed out earlier, biogas dissemination and adoption will reduce deforestation, save time wasted in firewood collection and in turn increase women participation in other productive work. Organic fertilizer yielded as the end by-product of the technology will improve crop yields hence enriches the lives of users.

Furthermore, the findings of this study could be used as inputs for decision-making by the policy makers, planners, non-governmental organizations, and implementers of bio-energy technologies and other works of similar nature. In addition the findings would provide additional knowledge on the present literature on bio-energy technologies about the potential of agro-forest residues to be used as raw materials for renewable energy source. It is anticipated further that the study would also stimulate interest on more researches in the field of renewable energy sources.

1.5 Scope and Limitation of the Study

The scope of the work carried out covers the design, fabrication and performance evaluation of a 32 litre biogas digester plant using chicken and goat waste independently and different blends of chicken and goat waste. However the limitation to this work is that Total viable count which enables the waste for biogas production free from infectious diseases was not adopted during the course of the research. Also, the 32 Litre Digester is a small scale design which cannot be used for industrial purpose, therefore effort should be made to increase the size of the digester to a larger capacity for industrial use.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Theoretical Fundamentals

2.1.1 Theory of anaerobic digestion

Anaerobic digestion is the controlled degradation of organic waste in the absence of oxygen and in the presence of anaerobic micro-organisms (Ojolo *et al.,* 2007). The digestion process is carried out using an airtight reactor and other equipment used for waste pre-treatment and gas retrieval. This process generates a product called "biogas" that is primarily composed of methane, carbon dioxide, and compost products suitable as soil conditioners on farmlands (Koberle, 1995). Anaerobic digestion can be utilized either to treat biodegradable squanders or deliver saleable items such as heat/electricity, soil alteration etc. the most profitable utilize of anaerobic digestion is to combine both squander administration and the utilize of the bi-products Monnet (2003). It is unlikely that anaerobic digestion will be a viable treatment without using the biogas and the digestate (Monnet, 2003). The traits of the biogas and digestate will differ relying on the feedstock and its contamination. Furthermore, the use of biogas and digestate can also involve further treatments, such as composting of digestate.

Monnet (2003) in any case expressed that the method of anaerobic digestion can be further isolated into four stages: pre-treatment, assimilation, gas overhauling and digestate. He also detailed that the level of pre-treatment depends on the sort of feedstock, for illustration, excrements got to be blended while municipal solid wastes (MSW) are sorted and destroyed. The digestion stage takes place in the digester. There are different types of digesters with different temperature, mixing devices. The digestion can either be dry or wet depending on the solid

content. This suggests that the feedstock can be mixed with water and other appropriate liquid wastes such as sludge or re-circulated liquid from digester effluent (Monnet, 2003).

The final stage which is the upgrading of the biogas is necessary because it may contain impurities that can damage boilers or engines depending on what the gas is used for. Hydrogen sulphide and water vapour need to be removed for boilers and combined heat and power units. Removal of carbon dioxide will be required if the gas is to be used as natural gas or vehicle fuel (Monnet, 2003).

2.1.2 Biochemical processes in anaerobic digestion

Biogas originates from bacteria in the process of bio-degradation of organic material under anaerobic (without air) condition. Biogas is a mixture of gases that is composed mainly of methane (CH_4): 40 – 70 vol %, Carbon dioxide (CO_2): 30 – 40 vol %, hydrogen (H_2): 0 – I vol % and hydrogen sulphide (H_2S): 0.3 vol % (Nitin *et a*l., 2012). The characteristic properties of biogas are pressure, retention time and temperature dependent. They are also affected by the moisture content. The factors of main interest are: change in volume as a function of temperature and pressure, change in water-vapour content as a function of temperature, pressure and retention time. Anaerobic digestion is a biochemical process in which particular strains of bacteria digest biomass in an oxygen-free environment under suitable temperature and humidity environments.

The full process of anaerobic digestion occurs in the following four stages (Monnet, 2003, Verma, 2002, Igboro, 2011);

- **hydrolysis**, in which complex molecules are broken down to constituent monomers;
- **acidogenesis**, in which acids are formed;

- **acetogenesis**, or the production of acetate; and
- **methanogenesis,** the stage in which methane is produced from either acetate or hydrogen**.**

Mata-Alvarez et al., (2003) noted that digestion is in complete until the substrate undergoes all of these stages mentioned above, each of which has a physiologically unique bacteria population responsible that requires disparate environmental conditions.

Hydrolysis:

In the first stage, complex organic materials are broken down into their constituent parts in a process known as hydrolysis. The result is soluble monomers: Proteins are converted to amino acids; fats to fatty acids, glycerol and triglycerides; complex carbohydrates such as polysaccharides, cellulose, lignin, starch and fiber are converted to simple sugars, such as glucose. Fermentative bacteria are responsible for the creation of monomers, which are then available to the next group of bacteria. Hydrolysis is catalyzed by enzymes excreted from the bacteria, such as cellulase, protease, and lipase. If the feedstock is complex, the hydrolytic phase is relatively slow. This is especially true for raw cellulolytic waste, which contains lignin (Mata-Alvarez *et al.,* 2003). For this reason, woody waste is not an ideal feedstock for the Anaerobic Digestion process Carbohydrates, on the different hand, are recognized to be more rapidly converted by way of hydrolysis to simple sugars and because of this fermented to volatile fatty acids (Mata-Alvarez *et al.*, 2003).

An approximate chemical formula for the mixture of organic waste is $C_6H_{10}O_4$ (Igboro, 2011). A hydrolysis reaction where organic waste is broken down into a simple sugar, in this case glucose can be represented by the following:

$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2 \qquad (2.1)$$

Acidogenesis: Hydrolysis is immediately followed by the acid-forming phase of acidogenesis. In this process, acidogenic bacteria turn the products of hydrolysis into simple organic compounds, mostly short chain (volatile) acids (e.g., propionic, formic, lactic, butyric, or succinic acids), ketones (e.g., ethanol, methanol, glycerol, acetone) and alcohols. The specific concentrations of products formed in this stage vary with the type of bacteria as well as with culture conditions, such as temperature and pH (Ostream, 2004). Typical reaction in the acid-forming stages are shown in equation (2.2). Equation (2.2) expresses how glucose is converted to ethanol.

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2 \qquad (2.2)$$

Acetogenesis: The next stage of acetogenesis is often viewed with acidogenesis to be phase of a single acid forming stage. Biological Oxygen Demand two (BOD) and Chemical Oxygen two Demand (COD) are decreased through these pathways.

The next stage of acetogenesis is often considered with acidogenesis to be part of a single acid forming stage. . Acetogenesis occurs through carbohydrate fermentation, in which acetate is the main product, and other metabolic processes (Themelis and Verma, 2004).

The result is a combination of acetate, CO_2, and H_2. The role of hydrogen as a mediator is of critical importance to Anaerobic Digestion reactions. Long chain fatty acids, formed from the hydrolysis of lipids are oxidized to acetate or propionate and hydrogen gas is formed. Under standard conditions, the presence of hydrogen in the solution inhibits the oxidation. The reaction only proceeds if the hydrogen partial pressure is low enough to thermodynamically allow the conversion. The presence of Hydrogen Scavenging Bacteria

(HMBs) that consume hydrogen, thus lowering the partial pressure, is necessary to ensure thermodynamic feasibility and thus the conversion of all the acids. Mata-Alvarez et al. (2003) noted that the concentration of hydrogen, measured by partial pressure, is an indicator of the health of a digester.

For example, the free energy value of the reaction that converts propionate to acetate, shown in equation (2.4), is +76.1kJ, so that this reaction is thermodynamically impractical. When acetate and hydrogen are consumed by bacteria, however, the free energy becomes negative. In general, for reactions producing H_2, it is necessary for hydrogen to have a low partial pressure for the reaction to proceed.

$$CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+ + HCO_3^- + 3H_2 \qquad (2.3)$$

The evolution of the substrate from organic material to organic acids in the acid forming stages causes the pH of the system to drop. This is beneficial for the acidogenic and acetogenic bacteria that prefer a slightly acidic environment, with a pH of 4.5 to 5.5, and are less sensitive to changes in the incoming feed stream. On the other hand, this drop in pH is challenging for the bacteria involved in the next stage of methanogenesis (Igboro, 2011).

Methanogenesis: Finally, in the last stage methane is produced by bacteria called methane formers (also known as methanogens). The methanogenic anaerobic bacteria involved in this stage, known as methanogenesis or methane fermentation, are the same particular bacteria that occur naturally in deep sediments or in the rumen of herbivores (Igboro, 2011). They lift out methane formation either by way of capacity of cleavage of acetic acid molecules to generate carbon dioxide and methane, or with the aid of discount of

carbon dioxide with hydrogen. Methane production is higher from reduction of carbon dioxide but limited hydrogen concentration in digesters results in that the acetate reaction is the primary producer of methane (Monnet, 2003). The methanogenesis reactions can be expressed as follows:

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (2.4)$$

(Acetic acid) (Methane) (Carbon dioxide)

Equation 2.4 show that many products, bye products and intermediates are produced in the process of anaerobic digestion of organic wastes before the final product (methane) is produced (Verma, 2002). Methanogens are very sensitive to changes and prefer a neutral to slightly alkaline environment. If the pH is allowed to fall below 6, methanogenic bacteria cannot survive. Methanogenesis is the rate-controlling portion of the process because methanogens have a much slower growth rate than acidogens (Igboro, 2011). Although anaerobic digestion can be considered to take place in these four stages, all processes occur simultaneously and synergistically, since the first group has to perform its metabolic action before the next can take over, and so forth. More so, Monnet (2003) noted that some organic materials, such as lignin, remain effectively undigested, as of course do non-organic inclusions within the waste. Figure 2.1 shows the anaerobic digestion process. Reducing environment is maintained to promote their growth. Although anaerobic digestion can be considered to take place in these four stages, all processes occur simultaneously and synergistically, since the first group has to perform its metabolic action before the next can take over, and so forth (Alfa, 2014).

There are four main groups of bacteria involved in the digestion of wastes (Brown and Tata, 1985)

1. Hydrolytic and fermentative bacteria.
2. Acetate and hydrogen producing bacteria
3. Methane forming bacteria
4. Hydrogen utilizing methane bacteria.

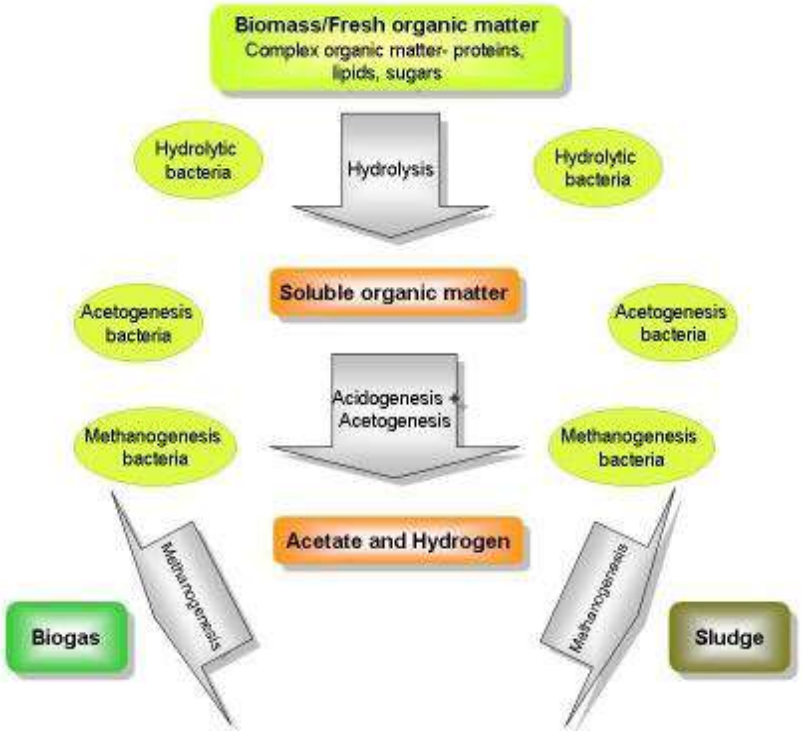

Figure 2.1: Process flow during anaerobic digestion. (Godliving, 2007)

Figure 2.1 shows the schematic representation of stages of Anaerobic Digestion.

2.2 Review of Related Literatures

2.2.1 General overview

The first digestion plant was constructed at a leper colony in Bombay, India in 1859 (Meynell 1976). Anaerobic Digestion reached England in 1895 when biogas was once recovered from a "carefully designed" sewage treatment facility and used to gasoline street lamps in Exeter. The development of microbiology as a science led to research in the Thirties to discover anaerobic bacteria and the conditions that promote methane production (Buswell and Hatfield 1936).

In Europe, the development of biogas plants that co-digest manure with other wastes has been aggressive over the last two decades. This has resulted because of economic, social, and environmental pressures. The Kyoto Protocol, which requires countries to meet 1990 levels of greenhouse gases, is a very significant driver .The following is a summary of some of the efforts co-digesting manure with alternative waste streams to produce biogas from a few counties in Europe: In countries like Denmark, with a relatively large livestock population and with a small and base, the development of biogas plants was needed, Many of these plants have been subsidized by their national government in order to make them economically viable.

Denmark has been a world leader in anaerobic digestion development and implementation, especially for generating manure to electricity systems. One of the driving forces in Denmark is their goal of having 33 % of their total energy produced derived from renewable energy sources by the year 2030. It is believed that the biogas production in Denmark will be increasing by a factor of 10 by the year 2020. In 2002, there were more than 30 biogas plants that were operational in Denmark (Braun and Wellinger 2002). The United Kingdom (UK), like Denmark, has had government initiatives driving the anaerobic digestion and renewable energy industry. Notably, the “Climate Change Levy” and the “Renewable Obligation” are UK energy initiatives

that are helping the development of anaerobic digestion. Although, the application of anaerobic digestion in the UK has not been as wide spread as other European countries. Regulations are driving the use of renewable energy and environmental beneficial technology like anaerobic digestion. One area of focus is the co-digestion of manure with animal bi-product wastes (Monnet, 2003).

2.2.2 Biogas projects in africa

Biogas projects are on the rise throughout the world. They provide a method to produce methane used for cooking and lighting from the waste of animals and humans. In countries such as Nepal there is a large push to increase the number of biogas plants in the country. These projects usually use cow manure to produce the gas, but by making a small adjustment, a household latrine can be connected to a digester increasing gas production and providing an easy way to manage the human waste (Ocwieja, 2010). In 2006, Biogas Innovation West Africa Ltd won the Ashden Grant by building sewage frameworks for healing centers, schools and colleges utilizing underground brick work arch frameworks of 60 to 160 m^3 volume. The water recuperated was utilized to flush the toilets whereas gas was collected and utilized for cooking (Fulford, 2011). In Nigeria, investigate into biogas innovation and its down to earth application is on-going, in spite of the fact that, has not truly gotten the merited consideration.

2.3 Factors affecting the Production of Biogas

Biogas production is a microbial process and as such, it requires the maintenance of suitable growth conditions for biogas producing bacteria. To maintain a viable micro-organism and hence maximum yield of methane, the following factors must be considered (Stiner *et al.*, 1978).

2.3.1 Strict anaerobic environment

All microbes that play important role in biogas production are strictly anaerobic. They include acid producing bacteria and methane producing bacteria. The later are so sensitive to oxygen that digestion could be inhibited by even the slightest trace of oxygen.

2.3.2 Nature of waste

All organic waste materials except mineral oil and lignin are suitable substrates for the production of biogas. Some organic materials such as animal manure, vegetable matter and the effluents of some industries are more easily digested. Observations have been done that dry vegetable matter produces more gas than fresh green vegetable matter (Colberg, 1988).

2.3.3 Temperature

For maximum efficiency, a suitable temperature is necessary. The two kinds of bacteria that will bring about this production operate at two different temperatures: Mesophilic and Thermophilic ranges (Verma, 2002). Any chosen environment for the digestion must maintain one of these temperature ranges. Methanogens are dormant in extreme high and low temperatures. The optimum temperature is usually 40 ^{o}C for the Mesophilic range while that for the thermophilic fermentation is 65 ^{o}C. During gas production when the ambient temperature goes down to 10^{o}C, it is no longer viable thus it stops. Gases produced that are useful take place at the mesophilic range between 25 and 40 ^{o}C (Verma, 2002) and 50 to 65 ^{o}C for the thermophilic range. Temperatures that are very high shorten the retention time but can lead to increased rate of biogas production (Verma, 2002).

2.3.4 pH

pH is a measure of the acidity or alkalinity of a solution. The acetogens and methanogens are easily affected by pH. Optimum biogas production is achieved when the pH value in the digester is between 6.5 and 7.5 (Garba *et al.*, 1996).

The pH is a function of the bicarbonate alkalinity, the CO_2 partial pressure and the volatile acids concentration as well as the retention time. Speece and McCarthy (1964) reported that biogas production would always continue as long as the digester slurry pH is maintained between 6.6 to 7.6 with optimum range between 7.0 and 7.2. Below 6.2, the bacteria become inactive. When pH value is below 6.5, the methanogens are very sensitive thereby they do not survive. However, the concentration of ammonia rises as digestion continues due to digestion of nitrogen which can increase pH value above 8. When the methane production level is stabilized, the pH range remains buffered from 7.2 to 8.2 (S.D, 1997). Any value of PH that is higher than 8.5 will show toxic effect.

2.3.5 Carbon – nitrogen ratio

For optimum biogas production, it is important to mix various materials in accordance with the carbon- nitrogen ratio requirement for fermentation. A carbon – nitrogen ratio of 20:1 to 30: 1 is considered good for anaerobic digestion, though a C/N ratio of 30:1 is optimum. It should not go beyound 35: 1 (Garba *et al.*, 1996). shortage of nitrogen limits the growth and activity of bacteria but much quantity of it will result in the liberation of more ammonia which is toxic in excess amount.

2.3.6 Total solid content

Anaerobic digestion techniques can be classified in accordance to the total solids (TS) content of the slurry in the digester reactor. Low solids systems (LS) incorporate less than 10 percent TS,

medium solids (MS) incorporate about 15 %-20 %, and high solids (HS) processes range from 22 % to 40% (Verma, 2002, Monnet, 2003). When the total solid content is increased, the volume of the digester decreases, due to low water requirements (Monnet, 2003).

2.3.7 Retention time

Karki et al. (2005) outlined the following approximate values of retention time:

i. Liquid cow manure: 20-30 days.

ii. Liquid pig manure: 15-25 days.

iii. Liquid chicken manure: 20-40 days.

iv. Animal manure mixed with plant material: 50-80 days .

Retention time (also detention time) is the average duration of time a sample remains in the digester. In a cow-dung plant, the detention time is obtained by dividing the total volume of the digester by the volume of slurry added daily (karki *et al*. 2005). Usually, for a cow-dung plant a retention time of 40 to 60 days is required depending upon the temperature. Thus, the fermenting pit should have a volume of from 40 to 60 times the slurry added daily. But for a night-soil digester, a longer detention time (70 to 90 days) is needed in order to kill the pathogens present in human faeces. For liquid manure undergoing fermentation in the mesophilic temperature range, Karki *et al.,* (2005) . If the retention time is too short, the bacteria in the digester are "washed out" faster than they can reproduce, so that the fermentation practically comes to a standstill. This problem rarely occurs in agricultural biogas systems. Moreover, the required retention time for completion of the anaerobic digestion reactions varies with differing technologies, process

temperature, and waste composition. The retention time for wastes treated in mesophilic digester range from 10 to 40 days (Verma, 2002).

2.3.8 Mixing anaerobic digester content mixing:

Within the digester improves the contact between the micro-organisms and substrate and improves bacterial population's ability to obtain nutrients. Mixing also prevents the formation of scum and the development of temperature gradients within the digester. However, excessive mixing can disrupt the micro-organisms and therefore slow mixing is preferred (Monnet, 2003). In case of co-digestion, the different feedstock should be mixed before entering the digester to ensure a sufficient homogeneity (Monet, 2003). A well agitated substrate can, leaving other parameters constant, increase biogas production by 50% (Kossman *et al.,* 2000)

2.3.9 Agitation

In order to enhance contact between micro-organisms and the organic waste, the production of biogas will require mixing from time to time, thus increasing the reaction rate. If the sludge is left without stirring, scum will form at the top and this can lead to blockage of the digester. Manual stirring device is very suitable for this purpose (Richie, 1983).

2.3.10 Type of waste

Biodegradable wastes are those type of wastes suitable for biogas production. Materials rich in cellulose are better for biogas production. Those rich in lignin should not be used since they are non-biodegradable (Uzodimma, 2006).

2.4 Biogas Generation From Wastes

Alessando Volta first discovered biogas in 1776 while Humphrey Davy was the first to pronounce the presence of combustible gas known as methane in the farm yard manure as early

as 1800. Both animal and plant wastes as well as industrial wastes have been used in the production of biogas.

2.4.1 Biogas production from animal waste

The energy content of animal manure is similar to that of wood when dried (Werecko *et al.*, 1996). The energy contained in the waste can either be obtained through direct combustion or by conversion into biogas by anaerobic fermentation; people have made use of animal manure as fertilizer in the past. Also, they used animal waste as a substitute for firewood. The world energy crisis of 1970 made most countries to join in the use of animal wastes as alternative energy source. As a result, various researches have been carried out on the use of livestock wastes for generation of biogas in places like India, China, Nepal, Malaysia, Europe among others. In Nigeria, reports have been made on the generation of biogas from animal wastes such as elephant droppings (Asere *et al.*, 1992), poultry droppings (Itodo *et al.*, 1995), sheep and goat (Zuru *et al.*, 1998), Swine dung (Okogbue and Ojo, 2003), Cow dung (Itodo *et al.*, 1995).

Animals under detention would be most suitable for anaerobic digestion (Smith, 1980). This is because their droppings are moist, little degraded and suited for biogas production. Animals on free range (open feedlot) would provide manure that is exposed to degradation and surface desiccation for long periods.

2.4.2 Biogas production from plants and agro wastes

Another major source of biogas provides materials from plants and agro wastes. These wastes from crops grown specifically for food, fodder, fibre and energy have been potential sources of waste for biogas production. Waste waters from food processing plants have also been used for biogas generation. Carbohydrate residues from agro based industries like rubber, oil palm,

coconut, pineapple, sugar cane, and cassava have been used in Malaysia for biogas production (Hutagalung, 2004). Garba *et al.,* 1998 reported that water hyacinth which is a popular plant in coastal waters in Nigeria has been used to generate biogas. This seaweed has also been modified and used in the production of biogas. Grasses have been successfully used in other countries to produce biogas (Garba *et al.*, 1998).

2.4.3 Biogas production from industrial wastes

Brewery by-products such as spent grain have been used for biogas production. (Busch,1987). Ezeonu *et al*, (2002) reported that biogas could be produced from spent grain under optimal conditions using rumen microorganisms.

2.5 Residues From Biogas Production

After anaerobic digestion of the waste has been completed, the residue from biogas production is what remains. The residue is a high quality organic fertilizer containing expired bacteria bodies, undigested or partially digested organic matter (Seed Tree, 2003). Analysis of the residue shows that it contains double the concentration per weight of nitrogen, phosphorous, potassium and minerals that were in the manure fed originally to the digester (Dioha, *et al.*, 2003). This is possible because only carbon, hydrogen and oxygen were elements removed in the process of the digestion.

2.6 Storage of Biogas

Biogas, a colorless, odorless gas, burns with non-luminous blue flame. Its flame temperature is up to 800^{o}C. The gas has a calorific value of 5650kcal/m^3 of gas. The natural gas has a heating value of about 1000 Btu/ft^3 (Seed Tree, 2003). Biogas cannot be practically compressed into a liquid because of its low density. As a result, its storage is a problem. Only immediate use was

common (Jewel, 1976; Smith *et al.,* 1979). In recent times, alternative storage for biogas has been designed by Gale group, University of Missouri Colombia (Higgins and Konky, 2002). The design uses carbon nanopores as the material for alternative fuel storage.

2.7 Biogas

Bacteria degradation of organic matter in the absence of oxygen known as Anaerobic Digestion generates biogas. The anaerobic digestion is an effective proven technology for handling and treating biological wastes and effluents which is used to generate heat and electricity, which is an effective means to clean our environment.

2.7.1 Biogas composition

Biogas is a mixture of gases that is composed mainly of methane (CH_4): 40 – 70 vol %, Carbon dioxide (CO_2): 30 – 40 vol %, hydrogen (H_2): 0 – I vol % and hydrogen sulphide (H_2S): 0.3 vol % (Nitin *et a*l., 2012). Biogas is the mixture of gas produced by means of methanogenic micro organism while performing upon bio degradable materials in an anaerobic condition. Usually the mixed gas is saturated with water vapour and may contain dust particles (Monnet, 2003). Methane is virtually odorless and colorless. It burns with a smokeless clear blue flame and is nontoxic. However the main constituents of biogas are CH_4 and CO_2 gases. Biogas burns very well when the CH_4 content is more than 50 %. Therefore, biogas can be used as a substitute for kerosene, charcoal, and firewood for cooking and lighting. This saves time and money and above all it conserves the natural resources such as cutting trees to get firewood (Fumen and Igboro, 2010). The composition of biogas is different than that of natural gas but it is almost the same to landfill gas which often contains significant amounts of halogenated compounds and occasionally oxygen content when too much air is sucked during the collection on the landfill.

2.7.2 Advantages and disadvantages of biogas

Advantages according to (Shireen and Payal, 2017)

i. Renewable Source of Energy; Biogas is viewed to be a renewable source of energy. Since is often produce from materials that form sewage and waste products, the only time it will be depleted is when we stop producing waste.

ii. Non Polluting: It is also considered to be non-polluting in nature. The resources are conserved by not consuming any further fuel since the production of biogas does not require any oxygen. It also decreases deforestation and indoor air pollution.

iii. Reduces Landfills: There is a decrease in soil and water pollution since it uses up the waste in landfills as well as in dumps.

iv. There is use of Cheaper Technology: Application for biogas are increasing as the technology to utilize it gets better. It can be used to produce electricity and for the purpose of heating as well. Production can be carried out through many small plants or one large plant.

v. Jobs Creation: Large number of jobs can be obtained through biogas technologies, especially in the rural areas.

vi. Little Capital Investment: Biogas is relatively easy to set up and require little capital investment on a small scale basis. Farms can easily produce sufficient biogas for its use from wastes generate by livestock, poultry and or crops (Garba *et al*., 1996).

vii. Reduces Greenhouse Effect: It also reduces the greenhouse effect by utilizing the gases being produced in landfills as forms of energy. It recycles most forms of biodegradable waste and works on simple forms of technology.

Disadvantages according to (Shireen and Payal, 2017)

i. It consists of impurities: Biogas contains a number of impurities even after refining process have been put in place. When compressed for use as fuel, these can become corrosive to the metal part of an engine.

ii. Not Attractive on Large Scale: The process of using biogas on large scale is not economically viable and is difficult to enhance the efficiency of biogas systems.

iii. Little Innovation Progression: Small unused innovation has been presented for gushing the method and making it more cost viable. As a result, expansive scale industrial biogas generation is still not on the vitality outline. In spite of the fact that it seem solve the vitality issues being confronted by nations all over the world, exceptionally few financial specialists are willing to put within the startup capital.

iv. Biogas is unstable in nature: It is also somewhat unstable, making it prone to explosions if the methane comes in contact with oxygen and become flammable in nature.

2.7.3 Uses of biogas according to (Alfa, 2013)

i. Cooking: Cooking is by far the most important use of biogas in the developing world. Biogas burners or stoves for domestic cooking work satisfactorily under a water pressure of 75 to 85 mm. The stoves may be single or double varying in capacity from 0.22 to 1.10 m^3 gas consumption per hour.

ii. Lighting: Biogas can be used for lighting in non-electrified rural areas. Special types of gauze mantle lamps consuming 0.07 to 0.14 m^3 of gas per hour are used for household lighting.

iii. Refrigeration: Biogas can be used for absorption type refrigerating machines operating on ammonia and water, and equipped with automatic thermo-siphon. Since biogas is only the refrigerator's external source of heat, the burner itself has to be modified. Refrigerators that are run with kerosene flame could be adapted to run on biogas.

iv. Biogas- fuelled engines Biogas can be used to operate four stroke diesel and spark ignition engines. Biogas engines are generally suitable for powering vehicles like tractors and light duty trucks as has been successfully experimented in China. When biogas is used to fuel such engines, it may be necessary to reduce the hydrogen sulphide content if it is more than 2 percent. Using biogas to fuel vehicles is not so much of an attractive proposition as it would require carrying huge gas tanks on the vehicle. One of the uses of biogas, which has wide application in Nepal, is to fuel engines to run irrigation pumps. A dual-fuel engine is available in India, which will run on a mixture of biogas and diesel (80 % biogas and 20 % diesel).

v. Electricity generation Generating electricity is a much more efficient use of biogas than using it for gas light. From energy utilization point of view, it is more economical to use biogas to generate electricity for lighting. In this process, the gas consumption is about 0.75 m^3 per kW hour with which 25 40-watt lamps can be lighted for one hour, whereas the same volume of biogas can serve only seven lamps for one hour (Karki *et al*., 2005).

Other benefits of biogas include (Igboro, 2011)

i. Improvement of hygienic conditions through reduction of pathogens, worm eggs and flies;

ii. Macro-economical benefits through decentralized energy generation and import substitution. Thus, biogas technology can substantially contribute to conservation and development, if the concrete conditions are favourable (Igboro, 2011).

2.8 Digester for Biogas Production

This is an air tight container in which organic wastes and waste water are fermented by bacteria in the absence of oxygen. It contains a system for gas collection and storage (Richie, 1983). Digesters are made of concrete, steel, brick or plastic. They look like silos, troughs, basins or ponds and may be placed under ground or on the surface. Metal digesters are made with iron (steel), nickel or cadmium to avoid poisoning of the bacteria during the digestion.

The modes of operation of the digestion include batch, semi-continuous and continuous operation. Batch operation involves loading the digester with organic materials and allowing it to digest. Once the digestion is complete, the effluent is removed and the process repeated.

For semi-continuous operation, the digester is fed on a more regular basis usually once or twice daily. The digested organic matter is also removed at the same interval.

In continuous operation, the organic material is fed constantly into the digester. The material moves mechanically or by the force of the new feed pushing out digested material. This kind of operation is most suitable for large scale operations. There is a steady availability of usable biogas. It is more efficient hence have higher production rate per unit digester given volume.

2.8.1 Types of biogas plant

1. Floating drum plant
2. Fixed dome plant

The floating drum plants were mainly built in India. They consist of a cylindrical or dome shaped digester and a moving, floating gas holder or drum. The gas holder floats either in the

fermenting slurry or in a separate water jacket. This type of digester is popularly known as the gobar gas plant. It is now less common in use because the steel drums are relatively expensive and maintenance intensive. Removing rust and painting has to be carried out regularly (Sasse, 1988).

The fixed dome digester is a popular digester used in most places such as Nepal, India and China. In this type, the fermentation chamber and gas holder are combined as one unit (Iloeje 1998). It consists of an underground compartment called fermentation chamber with a dome on top for gas storage.

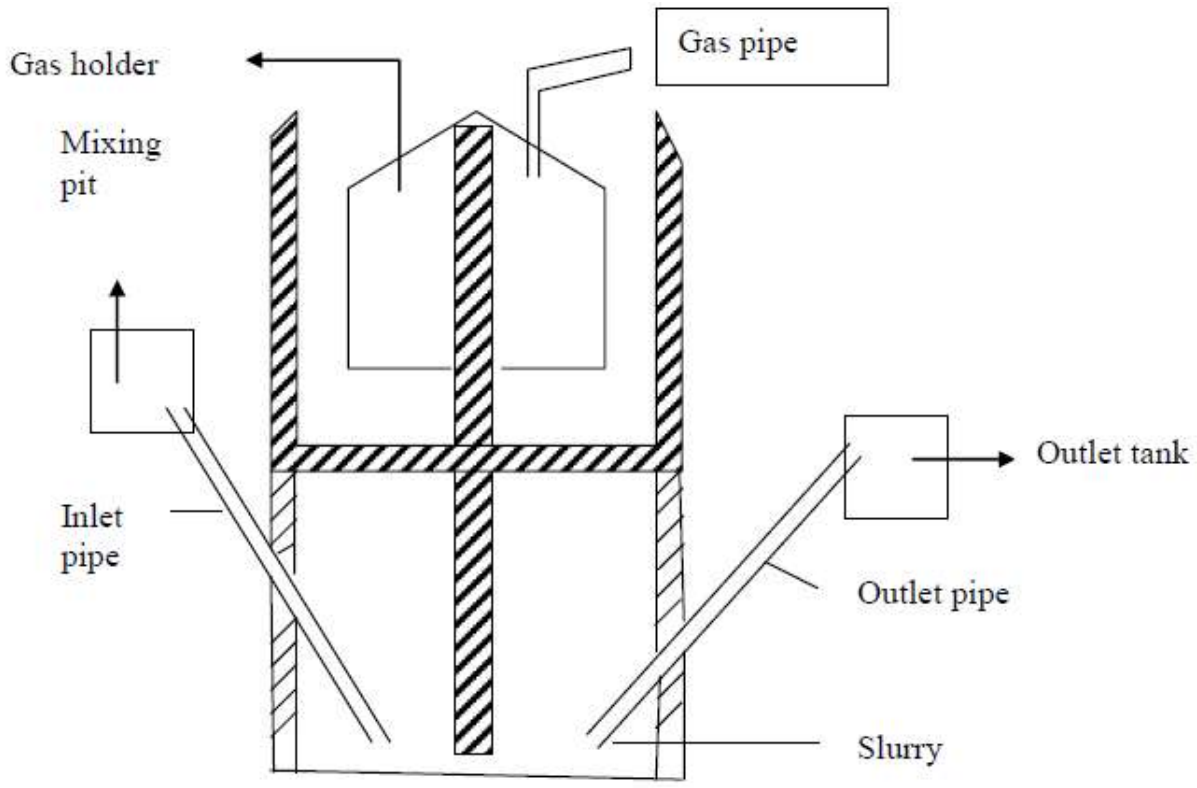

Figure 2.2: Floating drum plant (Sasse, 1998)

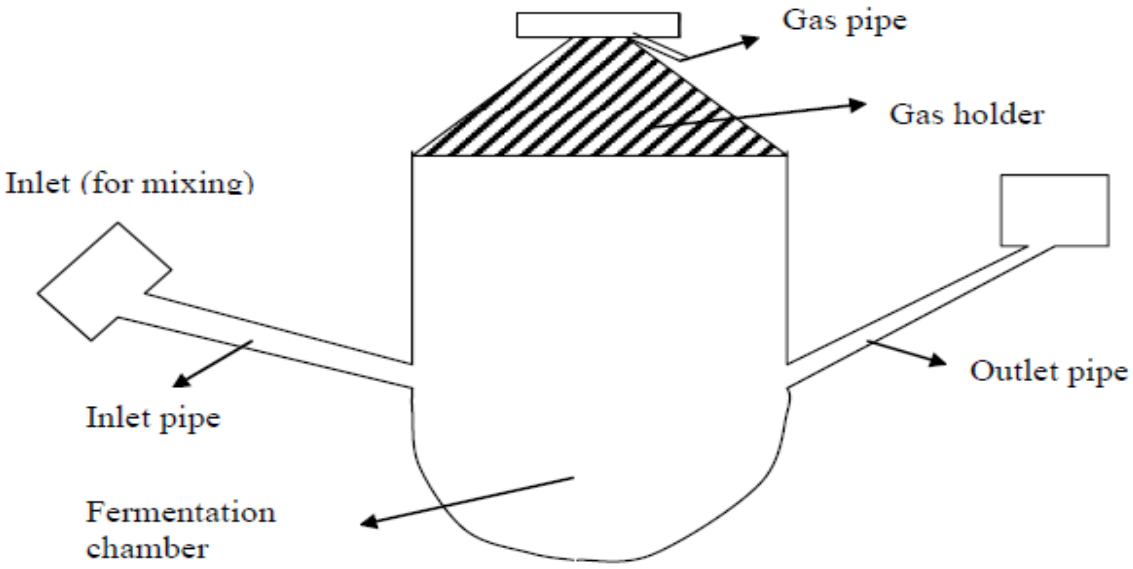

Figure 2.3: Fixed dome biodigester (Iloeje, 1998)

In this work, several individuals have worked on the concept of producing biogas with waste and the concept of adding different waste.

Agrahari *et al*. (2015) investigated the production of biogas from kitchen wastes. Different ratios of kitchen waste in a metal made portable floating type biogas plant were analysed. In the research, solar radiation, the temperature and relative humidity have been measured. The constituents of biogas, pH, volume and rate of biogas production at a different level of temperature on daily basis were also analysed. In the study, it was found that metal absorbing more sunlight to increase the temperature inside the digester in comparison to plastic made biogas plant. Also, the study was concluded that aluminum made biogas plant is costly and even its life is half than a plastic made biogas plant.

In another related study conducted by Oyewole (2016) on the production of biogas from chicken dropping and to utilize the residual sludge as bio fertilizer. Dried chicken dropping used were 2.8kg

which was added to anaerobic digester containing 3.7 litres of warm water and it was left to digest at 28 ^{o}C. In this work, the pH was determined using SUNTEX pH meter, the culture media involved were nutrient agar, mannitol salt agar and sabaurand dextrose agar. The slurry was diluted using a tenfold serial dilution. During the digestion process, 60 litres cylindrical digester tank was used within a retention period of 10 days. It was discovered that at the 18th day of digestion, the physio-chemical properties of fresh chicken droppings was increased and some decreased. Acid formers (bacillus subtilis, pseudomonas aeruginosa) and methane formers (methanobacterium sp and methanococcus sp) were the two groups of bacteria isolated from the digester. In the study, it was concluded that chicken droppings can be used for biogas production and as biofertilizer.

Okoroigwe *et al*. (2010) investigated the potential of dog waste to produce biogas or to enhance the biogas with some other animal and plant wastes. The two wastes combination of Dog waste with field grass (DG), dog waste with cow dung (DC) and one single waste. The dog wastes (D) were used in the investigations for comparing the potential of dog waste for biogas production. The equipment used for the study includes a Jenway 3510 pH meter, three 50 l digesters, conical flasks, distilled water and furnace. Three digesters were charged, 5 kg of dog waste, 5 kg of field grass and 30 kg of water was charged into digester A, 4 kg of dog waste, 6 kg of cow dung with 30 kg of water was charged into digester B. Finally, for digester C 7 kg of dog waste alone and 21 kg of water was charged. The charged digesters were monitored for 50 days under normal mesophilic temperature range of 38 to 46^{o}C. The result suggested that the Dog waste (7 kg), DG of (10 kg) and DC (10 kg) were capable of producing a total of 178 l, 218 l and 296.7 l of biogas respectively in a 50 l digester in 50 days. This implies that dog waste can be used as a source of biogas and source of catalyst for prolonging retention time of other waste samples such as field grass and cow dung. It was concluded

that dog waste is not required to be done alone due to the biomass is small and its biogas have long time to flame.

Owamah *et al.* (2014) investigated on the Optimization of biogas from Chicken droppings with Cymbopogon Citratus. The anaerobic digestion of Chicken droppings, chicken droppings with C. Citratus as well as citratus alone were carried out for a period of 30 days at an average ambient temperature of $33.1 \pm 2\,^{o}C$. Three 25 l biogas reactors (A-C) were fabricated from galvanized steel.. The ratio by mass for chicken droppings and C. Citratus was in the ratio of 3:1. The quantities of biogas produced from chicken droppings (Reactor A), co digestion of chicken droppings and C. citratus (Reactor B) and c,citratus alone (Reactor C). Results indicated that Chicken droppings produced on the average 1.8 l/kg/day of biogas, Chicken and Citratus produced 1.3 l/kg/day of biogas while C. Citratus alone produced 1.0 l/kg/day with estimated average methane contents of 41.7, 66.20, and 71.95 % for reactor A-C respectively. The water boiling rate for biogas from chicken droppings, chicken with Citratus and C.Citratus alone were 0.079 l/min, 0.091 l/min and 0.12 l/min after the gases were scrubbed with water and slaked line. It was concluded that notwithstanding the higher biogas volumetric yield from chicken dropping digested alone, the co digestion of both had better gas quality with respect to the methane content and cooking rate.

Ukpai and Nnabuchi (2012) investigated on the comparative study of biogas production from cow dung, cow pea and cassava peeling using 45 litres biogas digester. The equipment used for the study includes top loading balance; 13 l calibrated plastic transparent bucket, digital pH meter and thermometer. The ambient and slurry temperature, pH and pressure were also monitored and presented. The digester was charged differently with these wastes in the ratio of 1:2, 1:5 and 1:3 of waste to water respectively. The mixing ratio was determined by the moisture content of different wastes, the volume of biogas produced was measured by a downward displacement method using a

transparent 13 L calibrated plastic bucket. The mesophilic ambient temperatures range were 20-32 ^{o}C and a slurry temperature of 22 -36 ^{o}C. The experiment was batch operated and daily gas yield from the plant was monitored for 30 days. The result showed that cowpea has the highest carbon dioxide content of 33.2 %, cassava peelings 32.2 % of carbon dioxide and Cow dung which has 27.2 % content of carbon dioxide. The result showed that Cow dung has the highest methane content in the range of 67.9 %, Cow pea 56.2 % methane content and Cassava peeling 51.4 % methane content. Also the result showed that Cow dung has the highest total gas volume of 124.3 litres, followed by Cow pea with 97.5 litres of gas and cassava peelings with 87.1 litres of gas. It was concluded that flammable biogas can be produced from these wastes through anaerobic digestion for biogas generation. It was also concluded that cow dung as animal wastes has great potentials for biogas generation and its use should be encouraged due to its early retention time and high volume of biogas yields.

Ozor *et al.* (2014) investigated on biogas production using Cow dung from Abakaliki Abattoir in South- Eastern Nigeria. A 2 ml/g of the cow dung was used in the study. The digestion was carried out in a 10 l anaerobic digester at a temperature of 25 ^{o}C to 30 ^{o}C and uncontrolled pH for a period of 3 weeks. The equipment used for the study was 10 l Jacketed fermenter equipped with pH probe, stirrer, sampling ports and temperature controller. The digester was charged in the mixing ratio of 2:1 of waste to water. The gas was collected by downward displacement of water and the volume of displaced water was recorded as the volume of gas produced. The result showed that the highest biogas was obtained on the 22nd day with a biogas yield of 23.0 cm^{3}.The investigation revealed that biogas production was delayed till the fourth day. This can be traced to the fact that most cows feed on fibrous materials and microorganisms require a longer time to degrade fibrous materials. It was concluded that biogas production from Cow dung is a good and

cheap alternative source of energy. it is also important to note biogas can help to potentially reduce climate change as it is environmentally friendly.

Ugwuoke *et al*. (2016) investigated the production of biogas from goat dung by anaerobic digestion. The atmospheric temperature fluctuates between 27 ^{o}C to 30 ^{o}C. The materials used for the study were pH meter, thermometer. The result showed that goat dung attained 7.1 litres during the 30 days experiment. It was observed that at the beginning of the experiment there was no biogas production for the first three days. Biogas production started on the 4th day producing 0.4 litres and gradually increased to day 21. The investigation showed that the poor start up of anaerobic digestion was due to inadequate lignocelluloses breakdown and slow activities of anaerobic bacteria.

Okewale *et al*. (2018) investigated biogas production from Anaerobic Co-digestion of Corn cobs, pig and poultry droppings. The pH and temperature ranges for the study were 5.5-8.2 and 28 ^{o}C-30 ^{o}C respectively within the hydraulic retention time of 52 days. The ratio of the percentage distribution of poultry dropping to pig dropping were: (100:0), (50:50), (75:25), (25:75), (0:100) all by weight percent for digesters 1, 2, 3, 4 and 5 respectively. The equipment used were conical flasks (500 ml), mercury in glass thermometer, digital pH meter (HANNA model pH-211), delivery tubes, corks, measuring cylinders, muffle furnace and connecting tube. Result showed the Digester 2 had the maximum biogas yield of 313cm^{3} at the end of 52days of fermentation after which there was no further production. The gas chromatography analysis on the biogas produced in digester 2 showed 66.60 and 20.75 wt.% for methane and carbon dioxide. It was concluded that poultry dropping has more of the elements required for enzymes and microbial metabolism in anaerobic digestion compared to corn cob and pig dropping which makes it to be a very viable substrate for biogas production.

2.9 Research Gap

Most researchers have worked on several biogas productions from various biodegradable materials hence, it is necessary to research on alternatives to make the production process faster by enhancing the rate of digestion through addition of additives. Also, the excessive waste generated from various farms across the country if not properly handled can cause adverse environmental and health issues. Goat waste and chicken droppings are such waste if channeled towards biogas production instead of the current habit of using them for landfills or as fertilizer without pretreatment can help in environmental cleanup.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

In this study, chicken waste (dung) used was collected from Artisan market in Enugu state, south east Nigeria while the goat waste used was collected from a local farm in Nsukka south east Nigeria. The anaerobic digestion experiment was conducted at the National Centre For Energy Research and Development (NCERD), University of Nigeria, Nsukka.

The following materials (equipments) were used in the study.

i. Thermocouple thermometer: was used to obtain daily temperature of digester as well as the ambient temperature throughout the retention period.
ii. Weighing balance: was used for measuring the weight of the given waste during the period of the experiment.
iii. 10-liter plastic bucket: was used for measuring equal volume of waste to water to slurry.
iv. Digester stirrer: was used to ensure proper mixing of the waste.
v. Waterproof sacks: was used to convey waste to site.
vi. Funnel: was used to feed the slurry into the digester so as to reduce spillage of the dung.
vii. pH meter: Jenway pH meter (model 3510) was used to measure the PH of slurry everyday throughout the retention period.
viii. Nose mask: was used to prevent inhalation of unwanted odor from the waste.
ix. Protective gloves: were worn to protect the hand from smelling and contamination.
x. Burner: was used to flame the gas produced.

3.1.1 Material Selection

As a general rule, the selection of all the material was based on the following;

i. Cost-effectiveness
ii. Availability
iii. Durability

3.1.2 Material for digester construction

The material used for the experimental set up was mild steel as shown in Plate 3.1. the material was selected to meet the following requirements:

i. Poor resistance to corrosion
ii. Relatively cheap
iii. Provides gas tightness to store gas
iv. Good tensile strength, ductile and ease of rolling by machine to required design geometry.
v. Malleability

Plate 3.1: A biodigester

3.2 Methods

The most important analyses carried out on the raw waste were total solids, volatile solids and moisture content. Carbon content was also analysed.

3.2.1 Determination of moisture content

The Association of official Analytical Chemistry (A.O.A.C) method (1990) was used. Porcelain crucibles were washed and dried in an oven at 100 ^{o}C for 30 minutes and allowed to cool in a desiccator. One gramme of the raw waste was placed into weighed crucibles and then put inside the oven set at 105 ^{o}C for 4 hours. The samples were removed from the oven after this period and then cooled and weighed. The drying was continued and all the samples with the crucibles weighed until a constant weight was obtained.

$$\% \text{ moisture} = \frac{A-B}{A} \times \frac{100}{1} \qquad (3.1)$$

A = original weight of sample

B = weight of dried sample

3.2.2 Determination of Total Solids

Total solid is made up of the digestible and non digestible material in the waste. Meynell (1982) method was used. 3 g of the raw waste was dried in an oven at 105 ^{o}C for 5 hours. The dried test was cooled in a dessicator and after that weighed. The weight obtained after all moisture loss is the total solid.

$$\% \text{ T.S} = \frac{B-C}{g} \times \frac{100}{1} \qquad (3.2)$$

T.S = Total solid

B = Weight of crucible + dry residue, C = Weight of crucible, g = Original weight of sample.

3.2.3 Determination of volatile solids

The volatile solid is the true organic matter available for bacterial action during digestion. The method of Meynell (1982) was used. The solid residue from the total solid determination was heated in a muffle furnace at 600 ^{o}C for 2 hours. The heated residue was cooled in a dessicator and weighed.

$$\text{Volatile solid (VS)} = \frac{B-C}{g} \times \frac{100}{1} \qquad (3.3)$$

where,

B = Weight of dried residue from total solid determination, C = Weight of residue after further heating at 600^{o}C, g = Original weight of sample.

3.2.4 Temperature measurement during the digestion period

The daily ambient temperature and the slurry temperature were recorded using liquid in glass thermometer.

3.2.5 Measurement of pH during the digestion period

The pH of the system under digestion was monitored on daily basis as micro organisms are very sensitive to pH variation and this has a direct effect on the volume of biogas produced. The pH was recorded using Jenway pH meter (Model 3510; made in E.U)

3.3 Digestion of the wastes

Anaerobic digestion is a liquid state fermentation or submerged fermentation where the agents of fermentation were dispersed in the liquid in an anaerobic environment. The complex physiochemical biological changes were allowed to take place in a biodigester. Five biodigesters were used for the investigation. They were of fixed dome prototypes and of 32 litres capacity. They were constructed in the mechanical unit of Energy Research Centre, University of Nigeria, Nsukka.

3.3.1 Digester size and type of operation

In charging of the digesters, certain factors were considered before feeding the digester with the waste. They include:

a) Digester Size: The amount of waste and the quantity of water that should be fed inside the digester should be such that 75 % of the digester will be occupied by the waste and water while the remaining 25 % will be reserved for the gas that will be produced.

b) Type of operation – it was convenient to carry out batch operation considering the size of the digester.

3.3.2 Charging of the bio digesters

Five digesters were used for the experiment (plate 3.1). The capacity of the digesters was 32 kg each. The ratio of waste to water was 1:3. Since 75 % of the 32 kg capacity digester was occupied by waste and water that means that the waste and water took only 24 kg of the 32 kg capacity digester while the rest was for the gas.

3.3.3 Experiment:

To obtain the best mixing ratio of the co-digestion of Goat dung supplemented with Chicken droppings, five different mixing mass ratios at 70:30, 50:50, 30:70 was tested under mesophilic condition for 30 days. Unmixed Goat waste (100:0) and Chicken waste (100:0) will be anaerobically digested as controls. Digester I (goat waste) contained 6kg of chicken waste, 6kg of goat waste and 18kg of water. Digester II (chicken and goat 30/70) contained 1.8kg of chicken waste and 4.2 kg of goat waste and 18 kg of water. Digester III (chicken and goat 70/30) contained 4.2 kg of chicken waste, 1.8 kg of goat waste and 18 kg of water.

Digester IV (chicken and goat 50/50) Contained 3 kg of chicken waste, 3 kg of goat waste and 18kg of water. Digester V (chicken waste) contained 6 kg of chicken waste, 6 kg of goat dung and 18 kg of water. Both digesters I and IV served as the control.

The wastes submerged in water were properly mixed to give correct slurry concentration. The presence of water in the wastes helped to dissolve the solids in the wastes thereby creating favorable environment for micro organisms to feed on the nutrients in the waste. The digesters were then covered properly.

Daily gas production was measured using water displacement method (Itodo *et al.*, 1995).

Plate 3.2: Measurement of the volume of biogas produced using displacement method

The pH, ambient temperature, and slurry temperature were measured on daily basis while the total solid, volatile solid and moisture content were done weekly. The flammability of the gas was also monitored. The experiment lasted for 30 days at the exhibition ground of National Center for Energy Research and Development, University, of Nigeria, Nsukka.

3.4 Analyses of the Biogas Produced

The biogas produced by each digester was analysed with gas analyzer (unigas 3000 + BTU, Make: Eurotron, made in U.S.A). The gas analyzer is equipped with sensors for the determination of the percentage concentration of CO_2, NO, NO_2, CO, and O_2. The H_2S was measured using Crowcon Gasman monitor (model 19576H. made in England). Since biogas is a mixture of mainly methane (50-70 %), CO_2 (30-40 %), and traces of other gases such as CO, NO, and H_2S, the percentage concentration of methane in the biogas was determined by subtracting the percentages of other gases from 100.

3.5 Design Analyses

3.5.1 Design of total digester volume

The digester body comprises two cylindrical and a frustum part. Based on the estimated dimensions of the digester the following calculations were made to determine the total volume of the digester. These estimations were made so as to get a volume that will contain the slurry being loaded and make room for gas evolution.

$$\text{Volume of frustum } V_f = \text{Volume of big pyramid}, V_{bp} - \text{volume of small Pyramid}, V_{sp} \quad (3.4)$$

$$\text{Volume of big pyramid}, V_{bp} = \frac{1}{3} \times A \times H \text{ (Khurmi and Gupta 2005)} \quad (3.5)$$

Where.

A = base area ofbig pyramid in cm

H = height of big pyramid in cm

Volume of small pyramid, $V_{sp} = \frac{1}{3} \times A \times h_1$ (3.6)

Where, $A =$

base area of small pyramid in cm

h_1 = height of small pyramid in cm

Employing similar triangle rule:

$$\frac{h_1}{d_2} = \frac{h_1 + h_2}{d_1}$$

$$where\ H = h_1 + h_2$$

Volume of Small cylinder, $V_s = \pi r^2 h$ (3.7)

where r = radius of small cylinder in cm

h = height of small cylinder in cm

Volume of big cylinder, $V_b = \pi R^2 H$ (3.8)

where R = Radius of big cylinder in cm

H = height of big cylinder in cm

3.5.2 Inlet and Outlet Chamber Design

The inlet and outlet chamber has shapes of cylinder and frustum combined.

INLET:

Design equation for the inlet chamber is given as $V_i = V_c + V_f$ (3.9)

where V_i = inlet volume in cm

V_c = volume of cylindrical part in cm

V_f = volume of frustum part in cm

V_c = Volume of cylindrical part

$V_c = \pi r^2 h$ (3.10)

Where,

r = radius of cylinder in cm

h = height of cylinder in cm

volume of frustum, V_f

= volume of big pyramid, v_{bp} − volume ofsmall pyramid, v_{sp} (3.11)

The inlet and outlet chamber are of the same direction.

3.5.3 Design of the inlet pressure

Since the inlet pipe is cylindrical in shape, the bursting pressure was calculated using this equation

$$P_b = \frac{2S_T t_m}{D_m} \quad (3.12)$$

Where,

$P =$ bursting pressure in Pa

$S_T =$ tensile strength of the pipe (52×10^5pa)

$t_m =$ minimum wall thickness of the pipe (2.2mm)

$D_m =$ mean diameter (40mm)

3.6 Design Calculations

3.6.1 Total volume of the frustum

This can be calculated from equation 3.4

Volume of the frustum, $V_f =$ volume of big pyramid, $v_{bp} -$ volume of small pyramid, v_{sp}

$$h_2 = \sqrt{10^2 - 9^2} = 4.359\ cm$$

Employing similar triangle rule:

$$\frac{h_1}{15} = \frac{h_1 + h_2}{33}$$

But $h_2 = 4.359cm$

$$33h_1 = 15h_1 + 65.385$$

$$h_1 = \frac{65.385}{18} = 3.6325\ cm$$

$$H = h_1 + h_2 = 4.359 + 3.6325$$

$$H = 7.9915\ cm$$

Volume of the frustum, $\mathrm{V_f}$ = volume of big pyramid, $\mathrm{v_{bp}}$ − volume of small pyramid, v_{sp}

The volume of big pyramid can be calculated from equation 3.5

$$\text{Volume of big pyramid, } \mathrm{v_{bp}} = \frac{1}{3} \times \text{base area} \times \text{height}(H)$$

$$v_{bp} = \frac{1}{3} \times \pi R^2 \times H = \frac{1}{3} \times \pi \frac{D^2}{4} \times H$$

$$v_{bp} = \frac{1}{3} \times 3.142 \times \frac{33^2}{4} \times 7.9915$$

$$v_{bp} = 2278.67\ cm^3$$

The volume of small pyramid can be calculated from equation 3.6

$$\text{volume small pyramid, } \mathrm{v_{sp}} = \frac{1}{3} \times \text{base area} \times \text{height}(\mathrm{h_1})$$

$$v_{sp} = \frac{1}{3} \times \pi r^2 \times h_1 = \frac{1}{3} \times \pi \frac{d^2}{4} \times h_1$$

$$v_{sp} = \frac{1}{3} \times 3.142 \times \frac{15^2}{4} \times 3.6325 = 213.47\ cm^3$$

$$Volume\ of\ the\ frustum, V_f = 2278.67 - 213.47 = 2065.20\ cm^3$$

The volume of small cylinder can be calculated from equation 3.7

Volume of small cylinder,V_s

$$V_s = \pi r^2 h = \frac{\pi d^2 h}{4}$$

$$V_s = \frac{3.142 \times 15^2 \times 11}{4} = 1944.11\ cm^3$$

The volume of big cylinder can be calculated from equation 3.8

Volume of big cylinder,V_b

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

$$V_b = \frac{3.142 \times 33^2 \times 32}{4} = 27373.10\ cm^3$$

$$\text{Digester volume} = V_f + V_s + V_b$$

$$\text{Digester volume} = 2065.20 + 1944.11 + 27373.10 = 31382.41\ cm^3$$

$$\text{Digester volume} \approx 31\ litres$$

3.6.2 Inlet and outlet chamber design

Design equation for the inlet chamber can be calculated using equation 3.9

$$V_i = V_c + V_f$$

$$h_2 = \sqrt{7^2 - 5^2} = 4.899\ cm$$

Employing similar triangle rule:

$$\frac{h_1}{4} = \frac{h_1 + h_2}{14}$$

But $h_2 = 4.899\ cm$

$$14h_1 = 4h_1 + 19.596$$

$$h_1 = \frac{19.596}{10} = 1.9596\ cm$$

$$H = h_1 + h_2 = 1.9596 + 4.899$$

$$H = 6.8586\ cm$$

Volume of the frustum, V_{f} = volume of big pyramid, v_{bp} − volume of small pyramid, v_{sp}

Volume of big pyramid, $v_{bp} = \frac{1}{3} \times$ base area $\times$ height(H)

$$v_{bp} = \frac{1}{3} \times \pi R^2 \times H = \frac{1}{3} \times \pi \frac{D^2}{4} \times H$$

$$v_{bp} = \frac{1}{3} \times 3.142 \times \frac{14^2}{4} \times 6.8586$$

$$v_{bp} = 351.98\ cm^3$$

volume small pyramid, $v_{sp} = \frac{1}{3} \times$ base area $\times$ height(h_1)

$$v_{sp} = \frac{1}{3} \times \pi r^2 \times h = \frac{1}{3} \times \pi \frac{d^2}{4} \times h$$

$$v_{sp} = \frac{1}{3} \times 3.142 \times \frac{4^2}{4} \times 1.9596$$

$$v_{sp} = 8.21\ cm^3$$

$$Volume\ of\ the\ frustum, V_f = 351.98 - 8.21 = 343.77\ cm^3$$

Volume of the inlet cylinder

Volume of the inlet cylinder can be calculated using equation 3.10

$$V_c = \pi r^2 h = \frac{\pi d^2 h}{4}$$

$$V_c = \frac{3.142 \times 14^2 \times 13}{4} = 2001.45\ cm^3$$

$$Inlet\ volume, V_i = V_f + V_c$$

$$Inlet\ volume, V_i = 343.77 + 2001.45 = 2345.22\ cm^3$$

$$\text{Inlet volume} \approx 2\ litres$$

The inlet and outlet chamber are of the same dimension hence equal volume.

3.6.3 Design of the inlet pipe pressure

This equation can be calculated using equation 3.12

$$P_b = \frac{2S_T t_m}{D_m}$$

Hence,

$$P_b = \frac{2 \times 52 \times 2.2}{40} = 39438\ Pa$$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

Fixed dome anaerobic digesters were fabricated for the digestion of the five substrates in this study. The experimental results obtained during the monitoring period of the study were tabulated and analyzed, which are presented in tables, graphs, and bar charts. Table 4.1 shows the physical properties of the waste (chicken and goat) carried out during the course of experiment.

Table 4.1 Physical properties of the waste

SAMPLES	Total solid (%)	Volatile solid (%)	Moisture content (%)
I (GD only)	2.22	1.52	97.80
II(30/70) CD/GD	3.43	2.66	96.60
III(70/30) CD/GD	2.23	1.53	97.80
IV(50/50)CG/GD	2.15	1.45	97.90
V(CD only)	2.63	1.75	97.40

CD= chicken droppings, GD= goat dung

From Table 4.1, it was observed that CD/GD (30/70) gave the highest value of total solid and volatile solid than others, the least were CD/GD (50/50). The amount of total solids in Table 4.1 shows the amount of nutrient capable of sustaining the micro-organisms in the waste while the volatile solid represent the percentage of the waste convertible to gas. Both total solid and volatile solid shows the viability of the waste to produce gas. It was observed that the total solids contain less than 10 % which conforms to experimental value of Monnet (2003). The results

shows a decrease in the total solids (%) and volatile solids (%) from 3.43 to 2.15 and 2.66 to 1.45 respectively. This may be due to the utilization of the wastes by microorganisms. This agrees with the reports of Oyeleke *et al.* (2003) who stated that the total solids and volatile solids reduce as methane yield increases.

Table 4.2: Carbon content and calorific value of the waste

SAMPLES	Carbon content (%)	Calorific value (kJ/kg)
Goat only	36.06	15,751.88
Chicken only	34.10	13,919.32

From Table 4.2, calorific values were higher for goat waste than that of chicken waste because of the higher carbon content of the waste since the materials of high carbon content normally release high energy in combustion. Table 4.3 shows the daily pH and volume of gas.

4.2 Biogas production from the waste

Table 4.3: Daily pH and volume of gas

	Ph					VOLUME OF GAS (Litre)				
DAYS	1	II	III	IV	V	I	II	III	IV	V
1	8.9	8.6	7.7	8.4	7.6	0	0	0	0	0.5
2	8.4	8.2	7.6	8.4	7.5	0	0	0	0	1.0
3	8.3	8.3	8.0	8.3	8.2	0	0	0	0	1.5
4	8.0	7.7	7.4	7.1	7.5	0	0.3	0.7	2.8	1.8
5	8.2	8.3	8.0	7.7	8.0	0.3	0.4	1.0	3.3	2.6
6	8.3	7.9	7.5	7.3	7.7	0.1	0.3	1.1	2.8	3.2
7	7.6	7.2	6.8	6.8	6.8	0.3	0.3	4.7	3.5	5.6
8	7.9	7.2	7.0	7.4	7.2	0.4	0.4	4.8	3.2	6.0
9	8.2	7.3	6.8	6.8	6.6	0.4	1.1	1.9	3.3	3.8
10	7.8	6.8	7.0	6.8	6.6	0.6	1.2	5.2	5.0	4.8
11	7.6	7.2	7.0	6.9	6.6	0.6	1.6	7.1	5.2	4.8
12	7.6	7.2	7.2	7.0	6.6	1.1	1.4	3.1	3.4	1.9
13	8.2	7.5	7.4	7.5	7.4	1.0	1.4	3.4	3.6	4.0

Table 4.3: Continuation of the daily pH and volume of gas

14	7.9	7.3	7.6	7.5	6.8	1.4	1.7	2.4	3.0	3.2
15	7.6	7.2	7.6	7.6	6.9	0.5	1.4	1.6	2.0	2.4
16	8.3	7.5	7.6	7.6	6.8	0.6	1.9	1.9	3.2	2.7
17	8.0	7.4	7.3	7.7	6.9	1.0	4.4	4.4	3.2	3.2
18	7.9	7.7	7.7	7.7	6.8	1.2	4.8	5.4	4.1	3.8
19	8.0	7.6	7.6	7.7	7.0	1.6	2.4	1.6	4.2	4.2
20	7.5	7.9	7.8	7.7	6.8	1.6	3.2	4.1	4.1	4.1
21	7.6	7.5	7.4	7.4	6.6	0.8	2.2	3.2	3.8	7.6
22	7.9	8.1	7.7	7.9	7.2	0.3	1.1	0.5	2.4	7.6
23	7.6	8.0	7.6	7.7	7.0	0.1	1.1	0.8	2.2	7.4
24	7.1	7.4	7.6	7.3	7.6	0.4	1.6	1.0	2.9	7.8
25	8.5	7.8	7.7	8.0	7.6	0.5	2.3	3.2	3.3	3.2
26	7.5	7.4	7.4	7.3	7.3	0.8	2.1	3.2	2.4	3.2
27	7.7	7.4	7.3	7.3	7.3	0.2	1.1	2.4	1.6	2.8
28	7.7	7.9	7.7	7.6	7.5	0.1	0.9	0.3	1.6	3.2
29	7.9	8.0	7.7	7.8	7.6	0.8	2.1	3.7	4.3	3.9
30	7.9	8.1	8.3	7.9	8.1	0.5	1.6	1.6	2.1	1.4

Table 4.4: Ambient temperature and slurry temperature

	Ambient Temperature(°C)					Slurry Temperature(°C)				
Days	I	II	III	IV	V	I	II	III	IV	V
1	32	32	32	32	32	38	38	38	38	38
2	28	28	28	28	28	34	33	33	33	35
3	25	25	25	25	25	29	29.5	29	28.5	31
4	29	29	29	29	29	33	33	33	32	33
5	28	28	28	28	28	29	33	32	32	32
6	25	25	25	25	25	30	31	31	31	30.5
7	28	28	28	28	28	33	34	33	32	33
8	29	29	29	29	29	33	33	33.5	33	33
9	29.5	29.5	29.5	29.5	29.5	31	33	33	32	32
10	30	30	30	30	30	31.5	32	32.5	32	32
11	29.5	29.5	29.5	29.5	31	35	36.9	35	35	34
12	32	30	30	30	32	33	33	32	33	37
13	30	30	30	30	30	34	34	34	32	33.5

Table 4.4: Continuation of ambient temperature and slurry temperature

14	32	32	32	32	32	34	35	35	35	35
15	22	22	22	22	22	23	24	24	24	24
16	27.5	27.5	27.5	27.5	27.5	31	31.5	32.5	31	31
17	23	28	23	23	23	26.5	26.5	27.5	26.5	27
18	27	27	27	27	27	29	30	30	28.5	28.5
19	27	27	27	27	27	34	35	35	35	34
20	23	23	23	23	23	24	24	24.5	24	24
21	26	26	26	26	26	30	29	30	29	29
22	23.5	23.5	23.5	23.5	23.5	28	28.5	28.5	28	28
23	23	23	23	23	23	28	29	29	28.5	29
24	29	29	29	29	29	34	36	35	35	35
25	30	30	30	30	30	35	35	35	34	35
26	28	28	28	28	28	33	33	33	33	33
27	23.5	23.5	23.5	23.5	23.5	26	26.5	26.5	26	26
28	23	23	23	23	23	26	27	27	26.5	26
29	32	32	32	32	32	38	38	38	38	38
30	30	30	30	30	30	34	36	36	34	34

Table 4.5: Daily volume production of the waste (litres)

Days	DIGESTER I	DIGESTER II	DIGESTER III	DIGESTER IV	DIGESTER V
1	0	0	0	0	0.5
2	0	0	0	0	1.0
3	0	0	0	0	1.5
4	0	0.7	0.3	2.8	1.8
5	0.3	1.0	0.4	3.3	2.6
6	0.1	1.1	0.3	2.8	3.2
7	0.3	4.7	0.3	3.5	5.6
8	0.4	4.8	0.4	3.2	6.0
9	0.4	1.9	1.1	3.3	3.8
10	0.6	5.2	1.2	5	4.8
11	0.6	7.1	1.6	5.2	4.8
12	1.1	3.1	1.4	3.4	1.9
13	1.0	3.4	1.4	3.6	4.0
14	1.4	2.4	1.7	3.0	3.2

Table 4.5: Continuation of daily volume production of the waste

15	0.5	1.6	1.4	2.0	2.4
16	0.6	1.9	1.9	3.2	2.7
17	1.0	4.4	4.4	3.2	3.2
18	1.2	5,4	4.8	4.1	3.8
19	1.6	1.6	2.4	4.2	4.2
20	1.6	4.1	3.2	4.1	4.1
21	0.8	3.2	2.2	3.8	7.6
22	0.3	0.5	1.1	2.4	7.6
23	0.1	0.8	1.1	2.2	7.4
24	0.4	1.0	1.6	2.9	7.8
25	0.5	3.2	2.3	3.3	3.2
26	0.8	3.2	2.1	2.4	3.2
27	0.2	2.4	1.1	1.6	2.8
28	0.1	0.3	0.9	1.6	3.2
29	0.8	3.7	2.1	4.3	3.9
30	0.5	1.6	1.6	2.1	1.4

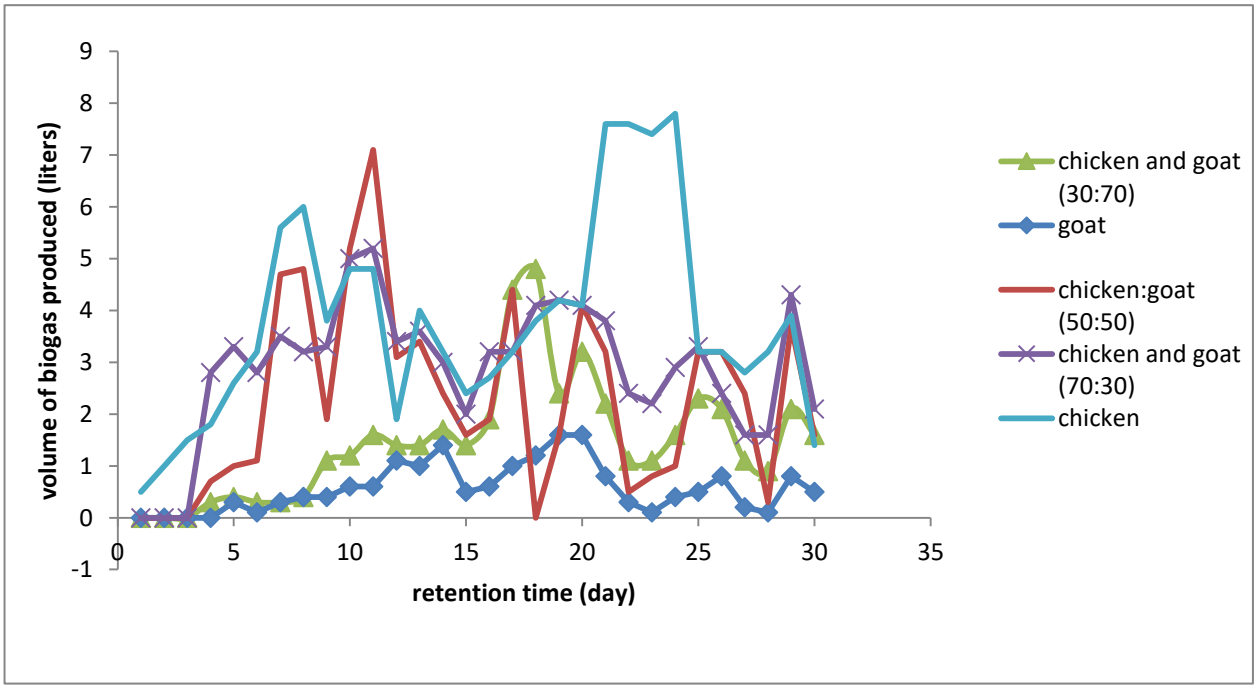

Figure 4.1: Daily volume of biogas generation of the waste

Figure 4.1 indicates the daily volume of biogas generation of the waste.The daily biogas productions by co-digestion of chicken droppings and goat dung during the 30 days of digestion were calculated under different mixing ratio. Samples from the mixing ratio of group I, group II, group III, group IV and group V were measured.

From table 4.3 for goat waste alone it was observed that there was no biogas production from day 1- day 4. Production of biogas for goat waste started on the 5th day with a value of 0.3 litres. The maximum yield of biogas was attained on the 20th day with a value of 1.6 litres, the lowest value of biogas for goat waste was on the 28th day with a value of 0.1 litres. Also for the chicken waste and goat waste (Group II), there was no biogas production for day 1, day 2 and day 3, production of biogas started on the 4th day with a value of 0.3 litres, the maximum yield of biogas was attained on the 18th day with a peak value of 4.8 litres. Chicken and Goat waste (Group III) gas production started at the 4th day after charging the digester with a value of 0.7 litres, the maximum yield of biogas was attained on the 11th day with a peak value of 7.1 litres.

Chicken and goat waste (group IV), biogas production started on the 4thday after charging the digester with a value of 2.8 litres, the maximum value of biogas obtained was on the 11th day with a peak value of 5.2 litres. Finally, chicken waste (group V), biogas production started on the first day with a value of 0.5 litres, there was a decrease in biogas production from14th day to 17th day. The maximum yield of biogas was attained on the 20th day with a peak value of 7.8 litres. The result of experiments indicates that there was poor start- up of biogas yield at the beginning of the experiment .The poor start up of anaerobic digestion was due to inadequate lignocelluloses break down and slow activities of anaerobic bacteria. Ukwuani and Ugwuoke (2016) observed that as

the anaerobic digestion progresses to a certain stage the biogas yield decreased due to decrease in the activity of anaerobic bacteria. Ugwuoke *et al*. (2016) reported that more disintegration of lignocelluloses gives higher biogas yield. Based on the past work related to this study, it showed that biogas production was less and gradual in the first week of the investigation. This suggests that the biogas producing microorganisms are in the lag phase of growth where acclimatization or adaptations of the cells take place. This report is in consonance to that of Abubakar and Ismail (2012). It can also be deduced from this that biogas production rate is equivalent or dependent on the growth of methanogenes. From the second week of the study, results indicated a progressive increase in biogas production, in the third week there was a decline in biogas production. This indicates that the methanogenes are in their exponential stage of growth. However this agrees with the findings from the work of Rabah *et al*. (2010) in Sokoto where biogas production experienced a decline in the third week. These differences observed may be due to the different breeds of chicken and goat found in the different locations. Also climatic factors, the nature or quality of feed or pasture that the goat were exposed to, are factors that could contribute to the differences in the rate of biogas production. Rainfall greatly affected production of biogas especially on days 15 -16 and days 21-30. Increase in temperature increases the rate of biogas production. The higher and faster biogas generation in digester V (chicken waste) could be attributed to the faster rate of decomposition of animal intestinal wastes which have already undergone a form of digestion in the digestive system.

The digestion of single substrate chicken waste produced biogas earlier than others starting from the 1st day with relatively highest peak value of 7.8 litres on the 24th day. It was observed, that goat waste alone produced the smallest peak value of 1.6 litres on the 19th day. These results indicate that the single digestion of Chicken droppings and Goat dung could significantly delay

the attainment of the highest gas production. It was moreover watched that biogas generation was moderate at the starting and somewhat moderate at the conclusion period. This was in line with what was expressed by that biogas generation rate in bunch generation is specifically relative to particular development rate of methanogenic microscopic organisms within the bio-digester.The final cumulative biogas productions by the co-digestion of CW and GW at different mixing ratios are shown in figure 4.4. The cumulative biogas productions for CW / GW 30:70, 70:30, 50:50, 100:0 and 0:100 were 44.3, 74.3, 86.2, 113.2 and 17.3 respectively. Cumulatively chicken waste produced more biogas than any other substrates. Table 4.3 shows that goat waste produced the least biogas as compared to others. The cumulative volume of biogas produced increased progressively from samples I to V in the waste. This shows that cow dung (sample V) was a good substrate for biogas production.

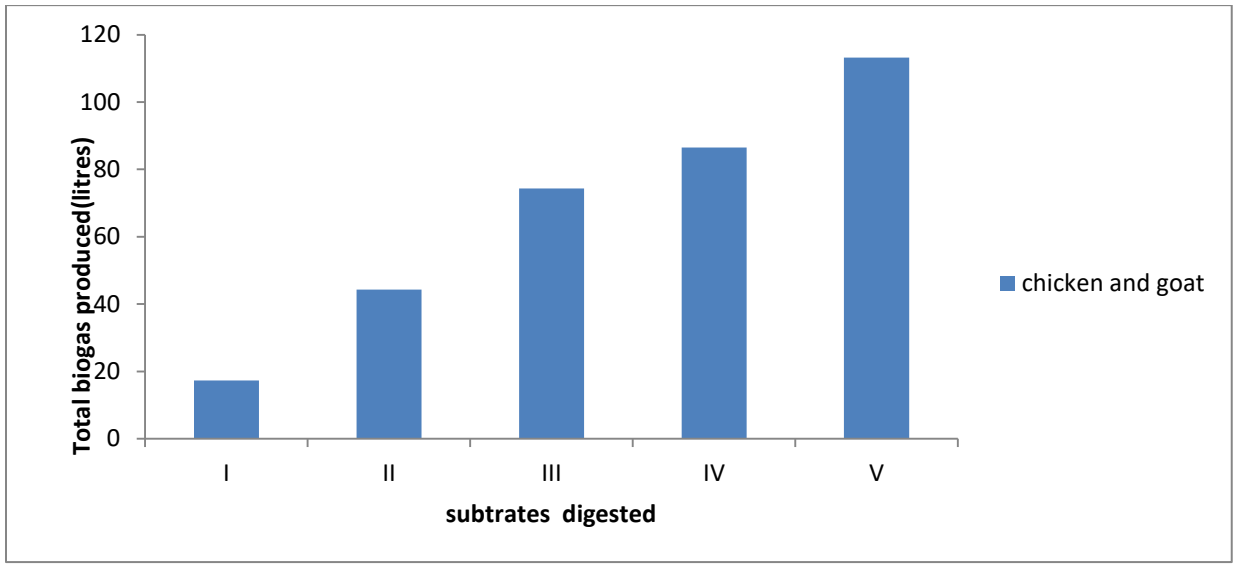

Figure 4.2: Cummulative volume of biogas produced

Figure 4.2 appears the total volume of biogas produced during the course of the try.

4.3 Digester pH

The pH of Sample I goat alone was between 7.1 to 8.9 throughout the digestion period; this ph was unfavorable for microbial growth and affected the volume of gas produced. For samples II, III, IV and V with ranges 6.8 to 8.3, 6.8 to 8.3, 6.8 to 8.4 and 6.8 to 8.2, the volume of gas produced improved. Speece and Mccarthy (1964) reported that biogas production would always continue as the digester slurry, pH is maintained between 6.6 to 7.6 with optimum range between 7.0 and 7.2.

Below pH of 6.2, the bacteria becomes inactive since the methanogens are very sensitive to ph changes and do not survive at low or high ph. This indicated that the high ph of sample I of goat waste needs to be blended with an addictive. The pH ranges obtained for chicken and goat waste of various samples II, III, IV and V were favorable for microbial growth. This was in evident of volume of gas produced. In the work of Okoroigwe *et al.*, (2010) the pH were in range of 6.6 to 7.8, this differs due to normal biological reaction of the microorganisms

4.4 Digester Temperature

Figure 4.1 shows the shows the digester temperatures for the fiv substrates observed at a point of observation within the digesters. The temperatures were recorded daily using a thermometer.

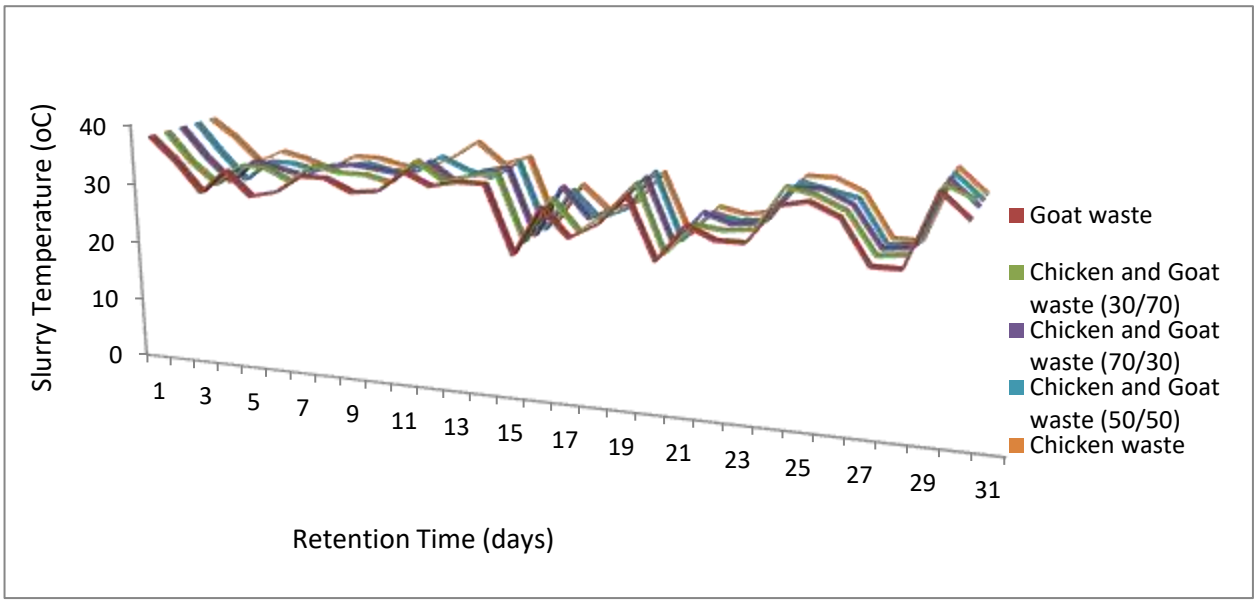

Figure 4.3: daily digester temperature of the waste

Figure 4.3 shows the digester temperature for the five substrates. The temperatures were recorded daily using a thermocouple thermometer.

The figure shows that the temperature within the digesters fluctuated optimally between 26 ^{o}C and 38 ^{o}C which conforms to the mesophilic range. This agrees with the findings of previous work Ugwuoke *et al*. (2016) and also (Verma, 2002) whose temperature was within the same range. Since all the digesters were operated simultaneously, the temperature across them was the same. Gas production was observed with increase temperature agreeing with lawal *et al*. (2001) that biogas production is favored with an increased temperature and as temperature drops, so the rate of biogas production declines.

The ambient temperature affects the rate of digestion due to the outside walls of the digester surface make direct contact with the atmosphere, hence the digester walls absorb or loose heat depending on the temperature gradient between the digester and its immediate environment. This implies that seasons affect the rate of heat loss or gain from the digester which in turn affects the

microbial activities in the slurry at each stage. The bacterial involved may not play its role completely. Ambient temperature fluctuated due to climatic conditions. The highest ambient temperature was 32 ^{o}C while the lowest was 25 ^{o}C. This condition is favourable for anaerobic digestion. The mesophilic (25 – 45 ^{0}C) is the temperature range that was identified for the slurry temperature (Ts).

4.5 Effect of blending goat waste with an additive

The addition of different wastes in biogas production called co-digestion is meant to improve biogas production. Mixing of wastes such as cattle + pig, cattle+ poultry, Poultry+ sheep have been reported. Blending of wastes in this way can lead to improved digestion process and enhancement of biogas production. The cumulative volume of biogas produced increased progressively from sample I to V. this shows that chicken dropping is a good substrate for biogas production. While for sample I goat waste alone, without blending with chicken dropping, the volume of gas produced would be relatively small.

4.6 Biogas Composition

Table 4.6: Biogas composition for the waste used in the study:

Waste Sample	CO_2 %	H_2S %	CO %	CH_4 %
Goat alone	38.2	1.4	1.3	59.1
CD:GD 30:70	37.6	1.7	1.5	59.2
CD:GD 70:30	37.4	1.6	1.6	59.4
CD:GD 50:50	33.3	1.7	1.7	63.3
Chicken alone	38.8	2.0	1.9	57.3

CD= chicken droppings, GD=Goat dung

Biogas consists of methane (50-70 %), CO_2 (30-40 %), traces of hydrogen sulphide (H_2S) and water vapor (Nitin *et al.*,2012). The relative percentages of these gases depend on the type of waste and management of the digestion process. The values obtained in the table 4.6 showed that methane content for goat waste was higher than that of chicken waste. The results falls within the quality range for biogas and agree with the reports mentioned earlier.

The biogas gotten from the co-digestion of chicken and goat waste (30/70 and 70/30) had higher methane contents (59.2 and 59.4 % respectively) than when they were digested singly (59.1 and 57.3 % respectively). It shows that co digestion of chicken and goat waste (50/50) had the highest methane content (63.3 %). As stated earlier by Oyeleke *et al.* (2003) as total solid and volatile solids decrease methane content yield increases. These results agree with previous studies by Ukpai and Nnabuchi (2012) for cow dung, cow pea and cassava peeling where the methane contents are 67.9, 56.2 and 32.2 %. The differences could be attributed to type and nature of waste used.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The development and performance evaluation of a 32 litre chicken and goat digester is designed and fabricated using locally available materials. The following conclusions were drawn during the course of the work:

The development and performance evaluation of a 32 litre biogas digester is designed and fabricated using locally available materials

Biogas digester plants were used independently for anaerobic digestion of chicken droppings, goat waste and co-digestion of chicken droppings and goat waste. The maximum yield of biogas for sample I was obtained as 1.6litres on the 20^{th} day, the maximum yield for biogas sample II was obtained as 4.8 litres on the 18^{th} day, also the maximum yield for biogas for sample III was obtained as 7.1 litres on the 11^{th} day, maximum yield for biogas for sample IV was obtained as 5.2 litres on the 11^{th} day and sample V obtained a maximum yield of 7.8 litres on the 20^{th} day.

It is concluded that chicken droppings has the highest volume of gas production than goat waste which has the least volume of gas compared to other blends and also in terms of flammability of gas, goat waste have higher methane content of 59,1 % than chicken waste which has 57.3 %. However maximum amount of 63.3 % methane content is obtained from chicken and goat waste with ratio 50/50.The temperature inside the digesters were stable fluctuating between 26-38 ^{o}C which is within the mesophilic range.

5.2 Recommendations

1. In the case of goat waste alone, it should be blended with an additive to enhance the biogas production.
2. A digester that will allow continuous flow of digestion for commercial purpose should be developed using co digestion of chicken and goat waste in the ratio 50/50.
3. The bio-fertilizer, an important residue left after biodegradation of waste could be commercialized after more research work.

REFERENCES

Abubakar, B. S., and Ismail, N. (2012). Anaerobic digestion of cow dung for biogas production. *ARPN Journal of Engineering and Applied Sciences*,7 (2), 169-172.

Agrahari, R., and Tiwari, G. (2013). The production of biogas using kitchen waste. *International Journal of Energy Source*. 3, 21-30.

Alfa, M., I. (2014). Comparative Production and Utilization of Biogas for Cooking, Using Cow Dung, Chicken Droppings, *Cymbopogon citratus* (lemon grass), MSc Thesis Presented to the Department of Water Resources and Environmental Engineering, Ahmadu Bello University, Zaria Nigeria.

Asere, A. A., Smbo, A. S., and Atanu (1992). Biogas generation from elephant droppings. Department of Mechanical Engineering Programme, Abubakar Tafawa Balewa University, Bauchi

Alnaney, R., and Liden, G. (2008). The effect of temperature variation on bio methanation at high altitude, *Bioresource Technology*, 99.7278-7284.

AOAC (1990) Official Methods of Analysis. Association of Analytical Chemists (14th edition). Arlington, Virginia, 222.

Buswell, A.M., and Hatfield, W.D. (1936). Bulletin 32, Anaerobic Fermentations. Urbana, IL: State of Illinois Department of Registration and Education.

Braun, R., and Wellinger, A. (2002).Potential of co-digestion. Institute of Agro biotechnology. Dept of Environmental Biotechnology, Lorenz Strasse

Colberg, P. J. (1988). Anaerobic microbial degradation of cellulose, lignin and mono aromatic lignin derivatives. In: Biology of Anaerobic Micro organisms. Abj zehnder, Ed John Wiley and Sons, 333-372.

Dioha, I. J., Umar, M. K., and Okoye, P. A. (2003). Studies of the qualitative and quantitative yields of biogas from cow dung and poultry droppings.

Ezeonu, F. C., Udedi, S. C., Okonkwo, C. J., and Okaka, A. (2002). Studies on Brewery spent grain's biomethanation: Optimal conditions for anaerobic digestion. *Nigeria Journal of Renewable Energy*,10 (1), 53-57.

Fulford, David (2011), Biogas Technology: Success Projects in Asia and Africa, being a Paper Presentation at Kingdom BioEnergy, available at http://www.kingdombio.com/DJF Biogas Reading presentation.pdf (17/5/2011).

Garba, B., Zuru, A., and Sambo, A. S. (1996) Effect of slurry concentration on biogas production from cattle dung. *Nigerian Journal of Renewable Energy*, 4 (2), 38-43.

Godliving, Y and Mtui, S. (2007).Trends in Industrial and Environmental Biotechnology Research in Tanzania, *African Journal of Biotechnology*, 6(25), 2860-2867.

Godi, N.Y., Zhengwuvi, L.B., Abdulkadir, S and Kamtu, P. (2013). Effect of cow dung variety on biogas production**.** *Journal of Mechanical Engineering Research., 5*(1):1-4.

Hashimoto, A. G and Varriel, R. H. (1979). Factors affecting methane yield and production rate American Society Agricultural Engineers (ASAE). ML: 49085 of http://www usaid.gov/stores/. srilanka-biogas.htm 12/2/06.

Igboro, S. B., Okuofu, C. A., Ahmadu, T. O., and Otun, J. A. (2011). Development and Evaluation of a Biogas Stove. *Nigerian Journal of Engineering*, (March) 17(2).

Igboro, S., B. (2011). Production of Biogas and Compost from Cow Dung in Zaria, Nigeria, PhD Dissertation Presented to the Department of Water Resources and Environmental Engineering, Ahmadu Bello University, Zaria Nigeria.

Iloeje, O. C (1998). Rural renewable energy needs and five apply technologies. Papers presented for the joint ECN-NYSC Rural Energy Project.

Itodo, I. O., Onuh, C. E., and Ogar, B. B. (1995). Effect of various total solid concentration of cattle waste on biogas yield. *Nigerian Journal of Energy*, 13,36-39.

Karki A. B., Shrestha N. J., and Bajgain S. (2005). Biogas as Renewable Energy Source in Nepal: Theory and Development. Nepal, BSP. Obtainable on www.snvworld.org

Koberle, E. (1995): Animal Manure Digestion Systems in Central Europe. Proceedings of the Second Biomass Conference of the Americas, *National Renewable Energy Laboratory (NREL),21-24.*

Krishan, K. V., Chourasia, P.B., and Chhipa, R.C. (2014). Study of biogas production from wastes" Cow dung and Poultry waste". *International Journal of Advances in Engineering and Scientific Research*, (August) 1(4), 35-44.

Lawal, A. K., Ajuebor, F. N., and Ojosu, J. O. (2001). Characteristic of piggery wastes feeds stock for determination of Design parameters to Biogas digester plant. *Nigerian Journal of Research and Review in Science,* 2, 193-198.

Mata-Alvarez, J., Mace, S., and Llabres, P. (2003). Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresource Technology*, 74(1), 3-16.

Maramba S. R. (1978). Biogas and Waste Recycling, available on http://www.pcierd.dost.gov.ph/ index.php/downloads/.../81-biogas-history (30/5/2011**).**

Mshandete, A. M., and Parawira, W. (2009). Biogas Technology Research in Selected Sub-Saharan Africa. *African Journal of Biotechnology*, 8(2), 116-125. Available online at http://www.academicjournals.org/AJB

Manyi-Loh, C. E., Mamphweli, S. N., Meyer, E. L., Okoh, A. I., Makaka, G., and Simon, M. (2013). Microbial anaerobic digestion (Bio-digesters) as an approach to the decontamination of animal wastes in pollution control and the generation of renewable energy. - *Int J Environ Res Public Health*, 10, 4390-4417.

Monnet, F. (2003). An Introduction to Anaerobic Digestion of Organic Waste, being a Final Report Submitted to Remade, available on http://www.remade.org.uk/media/9102/an introduction to anaerobic digestion nov.2003.pdf (30/05/2011).

Nigeria Bureau of Statistics (2009). Social Statistics In Nigeria available on http://www.nigerian stat.gov.ng/ext/latest_release/ssd09.pdf (21/09/2011)

Nitin, A. W., Thakre, S. B., Dhote, A. V., and Wankhade, P. S. (2012). Enhancement of Biogas from Abattoir Cow Liquor Waste with Some Agro-Industrial Wastes. *International Journal of Engineering Research and Applications (IJERA*), 2(5), 1383-1388.

Nordberg, I., and Edstrom, N. (2005). Co-digestion of Energy Crops and the Source sorted Organic Fraction of Municipal Solid Waste, Water Science Technology. 52, 217-222.

Ntunde, D. I., Edeh, H., Ochua, R. C., Onyia, B. I., and Atubi, T.(2016). Production of biogas from goat dung and determination of total solid Concentration. *International Journal of Research in Advanced Engineering and Technology*, 2, 157-161.

Ojolo, S. J., Dinrifo, R. R., and Adesuyi, K. B., (2007). Comparative Study of Biogas Production from Five Substrates, *Advanced Materials Research Journal*, 2(18-19), 519-525. published by Trans Tech, Switzerland online at http://www.scientific.net

Ocwieja, S. M., (2010). Life Cycle Thinking Assessment Applied to Three Biogas Projects in Central Uganda, being a Report Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Engineering, Michigan Technological University, available at http://www.cee.mtu.edu/peacecorps/studentfiles/Ocwieja-Uganda.pdf (17/5/2011).

Okewale, A., Babayemi, K., and Adesina, O. (2018). Biogas Production from Anaerobic Co–Digestion of Corn Cobs, Pig and Poultry Droppings. ABUAD *Journal of Engineering Research and Development (AJERD*), 1(2), 273-282.

Okoroigwe, E. C., Ibeto, C. N., and Okpara, C. G. (2010). Comparative study of the potential of Dog waste for Biogas Production. *Trends in Applied Sciences Research*, 5(1), 71-77.

Owamah, H., Alfa, M., and Dahunsi, S. (2014). Optimization of Biogas from chicken droppings with cymbopogon citrates. *Renewable Energy*, 68, 366-371.

Oyeleke, S. B., Onigbajo, H. O., and Ibrahim, K. (2003). Degradation of animal wastes (cattle dung) to produce methane (cooking gas). *Proceeding of the eighth annual Conference of Animal Science Association of Nigeria (ASAN)*, 168-169.

Oyewole, O. A. (2010). Biogas production from chicken droppings. *Science world Journal*, 5(4), 11-14.

Ozor, O. C., Agah M. V., Ogbu K. I., Nnachi, A. U., Udu-ibiam, O. E., and Agwu, M. M.(2014). Biogas Production Using Cow dung from Abakaliki abattoir in South-Eastern Nigeria *International Journal of Scientific & Technology Research,* 3(10), 238-239.

Rabah, A. B., Baki, A. S., Hassan, L. G., Musa, M. and Ibrahim, A.(2010). Production of *biogas* using abattoir waste at different retention. *Science World Journal*, 5 (4), 23-26.

Richie, D., J. (1983) Source book for farm energy alternatives. New York: McGraw-Hill Book Coy.

Sasse, Ludwig, (1988). Biogas Plants; a Publication of the Deutsches Zentrum für Entwicklungstechnologien GATE in: Deutsche Gesellschaft für Technische Zusammenar beit (GTZ) GmbH. Available at http://www.gate international.org/documents/publication s/webdocs /pdfs/g34bie.pdf (17/05/2018)

Seed Tree's Biogas Program and Energy Conserving Technologies (2003). Info@seedtree.org.

Shireen, B., and Payal, D. (2017). Advantages and Disadvantages of Biogas. *International Research Journal of Engineering and Technology* (IRJET), 4(10), 892-893.

Speece, R. E., and McCarthy, P. L. (1964) Nutrient requirements and biological solid accumulation in anaerobic digestion: *International Conference on Water Pollution Research*, New York. Permagon Press, 305.

Themelis, N. J., and Verma, S. (2004). The Better Option: Anaerobic Digestion of Organic Waste in Waste management world.

Rabah, A. B., Baki, A. S., Hassan, L. G., Musa, M., and Ibrahim, A. (2010). Production of *biogas* using abattoir waste at different retention. Science World Journal, 5 (4), 23-26.

Ukpai, P. A., and Nnabuchi, M. (2012). Comparative study of biogas production from cow dung, cowpea and cassava peeling using 45 litres biogas digester. *Advances in Applied Science Research*, 3 (3), 1864-1869.

Ugwuoke, E.C., Aburu, C.M., Iloani, I.C., Ezeigwe C.P., and Okoro, P.N. (2016). Production of biogas from goat dung by anaerobic digestion. *International Journal of Research in Advanced Engineering and Technology*, 2(5), 17-20.

Uzodinma E .U., Ofoefule, A.U., Eze, J.I. and Onwuka, N.D. (2006). Biogas production from blends of Agro-industrial wastes. *Trends in Applied sciences Research*, 2(6), 554-558.

Verma, S. (2002). Anaerobic Digestion of Biodegradable Organics in Municipal Solid Wastes. Unpublished M.Sc. Thesis, Department of Earth and Environmental Engineering, Foundation School of Engineering & Applied Science, Colombia University.

Wantanee, A., and Sureelak, R. (2004). Laboratory Scale experiments for biogas production from cassava tubers. *The Joint international conference on Sustainable Energy and Environment*, 1-3.

Werecko, B., Charles, Y., and Essel, B. H. (1996). Biomass conversion and Technology, Centre for Energy and Environmental Development, Ghana. John Wiley and Sons Ltd.

White, P. L. (1981): Contempo '81. Foods and Nutrition. - JAMA 245, 2239-2241.