RESEARCH ARTICLE OPEN ACCESS

Biogas Production From Agricultural Waste (Chicken Droppings)

Umawudhola Chinekezhim Solomon
(Department of Chemical/petrochemical Engineering, Rivers State University, Port Harcourt, Rivers State)

Abstract:

Biogas production is not new to the earth, as an Englishman Donald Cameron had earlier constructed a special septic tank which was used for biogas collection and since then till now, other works has emerged. However, this work offers a new and broader idea on biogas production through the process of inoculation whereby an inoculant (a biological catalyst in slurry form) was used to facilitate and stimulate the formation of the biogas. This was confirmed during this analysis as the time (number of days) taken for the production was shortened and yield increased. The result obtained from this work shows that temperature, type of substrate, nature of substrate, micro-organism etc. are key factors to the volume of biogas produced and the results been in consistency and agreement with previous works. This work presents several advantages: wastes are recycled – which offers the best medium for waste treatment, biogas produced – which is a renewable source of energy for heating and electricity and the by-product (digestate) obtained which has been tested for Nitrogen, Phosphorus and Potassium as an excellent bio-fertilizer used for agricultural cultivation. Hence, this work has great contributions to renewable energy resource, increased agricultural production as well as in environmental waste remediation.

Keywords — Biogas, inoculation, renewable energy, digestate, waste**.**

1.0 INTRODUCTION

In recent times, the deleterious effect of wastes has become even more pronounced as a result of increase in population and fast growing rate of humans. Industrialization and production are twin inseparable activities that have brought about tremendous generation of waste in our environment. Wastes ranging from commercial, industrial, domestic and agricultural greatly threatens the existence of life and hampers the hope of development as money or fund meant for developmental projects are channelled to waste management. Beside other sources of waste, agricultural waste constitutes a greater proportion of problems to the environment as it is generated day to day, month to month and year to year in huge proportion. Everyday people must eat and the food production processes leaves behind a huge quantity of agricultural waste.

However, should we stop agricultural, industrial, commercial and productive activities because of the waste remnants associated with them that pose a great threat to life and our environment? Here therefore comes the essence of this mini-novel research work: "*biogas production from agricultural waste (chicken droppings).*" It is oblivion to many how wastes could not only be controlled but turned to one of the greatest resource in the globe. This research work explores how the agricultural wastes which cause an astronomical nuisance to life and our environment could be remediated and equally be used in the production of biogas, a renewable and dependable source of energy compared to fossil energy (coal, wood, petroleum etc.) which are non-renewable, scarce, exorbitantly affordable and limited.

Hence, this research work provides a double panacea to the world's problem.

Biogas production both has a natural and an artificial background. Just as every human picture have a story from nature, the production of biogas could likewise be traced to nature. Surprisingly, biogas is produced naturally on swamps, bugs, rice paddies etc. and in the sediment at the bottom of lakes and oceans where anaerobic conditions prevails at a certain depth, and the product majorly methane can be collected in an upturned bottle with a funnel. The bottle for the collection of the methane gas should be filled with water from the start so that the rising methane can replace the water without getting mixed with atmospheric air. Methane is also created in the rumen of ruminant animals (cows, sheep, deer, camels, lamas, etc.)

People have known of the existence of naturally produced gas since the 17th century and experiments with the concentration of actual biogas systems and plants started as early as the mid 19th century. One of the oldest biogas systems is the septic tank, which has been used for the treatment of wastewater since the end of the 19th century and is still used for isolated properties where there is no sewerage system. In this type of plant however, the biogas is not collected and used.

In the 1890's, the Englishman Donald Cameron constructed a special septic tank, from which the gas was collected and used for street lighting. In Denmark, the construction of biogas plants for wastewater treatment started in 1920's. The gas was initially used to heat the plant digester tank and the main purpose was therefore not to extract energy, but to decompose organic matter in the wastewater and thus reduce and stabilize the sledge, which is a product of the treatment process.

In the following period and until shortly after the Second World War (September 1, 1939 – September 2, 1945), there was a substantial growth in biogas industry, particularly in Germany, Britain and France, and the technology also gradually found its way into agriculture with energy production as the main purpose.

At the end of the 1950's, its development nearly stopped, however, due to the cheapness of the fossil fuel oil and gas. The interest in biogas was not reawakened until the mid 1970's following the oil crisis in 1973. The Dannish state initiated a research and development programme with the aim of testing and constructing different types of biogas plant using animal manure as the main source of biomass.

Recently, there are about 60 biogas facilities installed at sewage treatment plants. In addition, around 20 communal biogas plants of various sizes have been constructed to treat manure, slurry in particular, from a number of livestock farms. These biogas plants also take in large amounts of organic waste from the food industry and slaughter houses, whereby the energy from the waste is being extracted and the nutrients recycled to the agricultural sector. But from the mid 1990's, the expansion of the biogas sector once again stagnated in Denmark due to lack of economic activities.

Some countries hampered by natural abundance or inadequate distribution of energy supplies have often adapted biogas technology (*an alternative energy source which utilizes various organic wastes in order to produce biogas for cooking, heating, lighting and its residue as fertilizer*), to meet rural energy needs. In the 1970s, when renewable energy became recognized as a separate subject, a conference on biogas was held at Imperial College, University at London. The participants agreed on the big potential for biogas technology in many parts of the world like Nigeria.

Artificially, animal droppings from cow, poultry, pig, crop residues and agricultural wastes have been used in different countries. The degree of success of biogas technology varied for the different countries that employed biogas technology for rural energy supply.

In some parts of Nigeria, pilot biogas plant projects have been executed in some parts of Nigeria by ECN, UNDP, JICA and some tertiary institutions. There was a $10m^3$ biogas plant at Achara, Nsukka LGA, Enugu State which was executed by NCERD/UNN, for women cooperative garri processing. The plant feed on domestic animals, cassava peels and waste from the milling of cowpea, and bambara nut from the nearby food processing plant.

ECN-SERC/UDU in 1998 built $20m^3$ fixed dome bio-digester which was fed on pig waste and produces gas for cooking and natural manure which members use in their farm. At NAPRI, Zaria, a $20m^3$ biogas plant was constructed in 1996 by SERC and in 1998, the centre constructed $30m^3$ biogas digester for Zaria prison, which fed from human wastes. UNDP sponsored construction of $10\text{-}20m^3$ digester in Kano, Yobe, Kebbi States, etc. Unfortunately, there are so many other biogas plants in other parts of the country that are currently not working due to an increase in the number of poor quality constructions and it is damaging people's faith in the technology. Also, lack of maintenance have contributed to poor biogas plant in the country and almost rendered them functionless.

As a result, many investors and company have diverted to oil and gas sector. This thoughtless dependence on oil and gas has totally blocked the idea of biogas technology in the country in recent times. However, the fossil fuel produced by these oil and gas industry is limited, scarce, non-renewable and exorbitantly unaffordable not only to the mean men but also to the main men with addition to inflation. Hence, the imperative of redirecting our mentality to biogas, one of most efficient and reliable alternative to the energy challenge in the country as well as the world at large via this research work.

The world's biggest problem is that of environmental pollution in which waste is a major precursor. In order to meet the need of growing populace in terms of food production, agricultural activities are currently on the increase, adding to the need to diversify the economy. As a result, agricultural waste constitutes a greater proportion to environmental pollution.

In addition, the growing need to increase the rate of agricultural productivity has led to the unquenchable demand in fertilizer. Chemical fertilizers are costly and so can't be afforded by the subsistence farmers who contribute a great quarter to agricultural productivity. Also, these chemicals do have adverse effect on crop, destroys the soil texture and pollutes the air as a result of their toxic smell, the land as a result of their harmful nature and the water when channeled to water bodies like sea, ocean, river and stream by surface and underground water.

This research work provides a definite solution to these aforementioned problems, thereby revealing its level of distinctiveness. The agricultural wastes are being remediated, anaerobic digestion residue from the agricultural waste serves a rich source of fertilizer which can be used by farmers of all categories in their farms. Majorly, the biogas produced from these agricultural wastes serves a substitute or replacement of fossil fuel which can be used in cooking, heating and even upgraded to be used as fuel for vehicles, electricity etc. The assessment of this study equally helps in the political, social and economic issues of the country as well as for the government, Non-Government Organizations (NGO) and an eye opener for investors and stakeholders.

The following problems brought the desire and birth of this research study:

- The ignorance of waste recycling
- Environmental pollution
- Dearth of the solution to agricultural waste
- Over dependence on oil and gas sector
- Scarcity, limitation and hike in the price of fossil fuel
- The failed and failing biogas technology in Nigeria
- Lack of alternatives to energy resource

The purpose of this study is firstly to add to the knowledge of biogas production. Secondly, to carry out the production of biogas which is an alternative source of energy. Finally, to obliterate the ignorance of waste recycling through this research which I believe will expose or reveal the conversion or transformation process of agricultural wastes to useful product (biogas) and by-product (fertilizer).

This study is unique, as it not only adds to research or academic knowledge, but provides practical step to the solution of the world's problem. Significantly, this study provides solution to all the statement of problems aforementioned without exception, such as:

- Helping to educate and enlighten in order to obliterate the ignorance of waste recycling.
- It helps to provide a qualitative and quantitative solution to environmental pollution as arising from agricultural wastes.
- It brings a definite solution to the problem of agricultural waste.
- This study is key to the production of biogas.
- It helps to provide solution to the scarcity, limitation and hike in the price of fossil fuel through the production of alternative, reliable, efficient energy resource (biogas).
- Through the wealth of knowledge and presentation in this research work, it will help to perpetually awaken and resuscitate the failed and failing biogas technology specifically in Nigeria.

The benefits for the society are:

a) Provision of Renewable Energy Source:
b) Reduced Green house gas emissions and mitigation of global warming.
c) Reduced dependency on imported fossil fuel.
d) Contribution to EU energy and environmental targets.
e) Waste reduction
f) Job creation

The benefits to the farmers are:

a) Provision of additional income for the farmers involved
b) Availability of digestate which is an excellent fertilizer

During Anaerobic Digestion, very little heat is generated in contrast to aerobic decomposition (in presence of oxygen), like it is in the case composting. The energy which is chemically bounded in the substrate, remains in the produced biogas, in form of methane.

The process of biogas formation is a result of linked process steps, in which the initial material is continuously broken down into smaller units. Specific groups of micro-organisms are involved in each individual step. These organisms successively decompose the products of the previous steps. The four main process steps are:

1. Hydrolysis
2. Acidogenesis
3. Actogenesis and
4. Methanogenesis

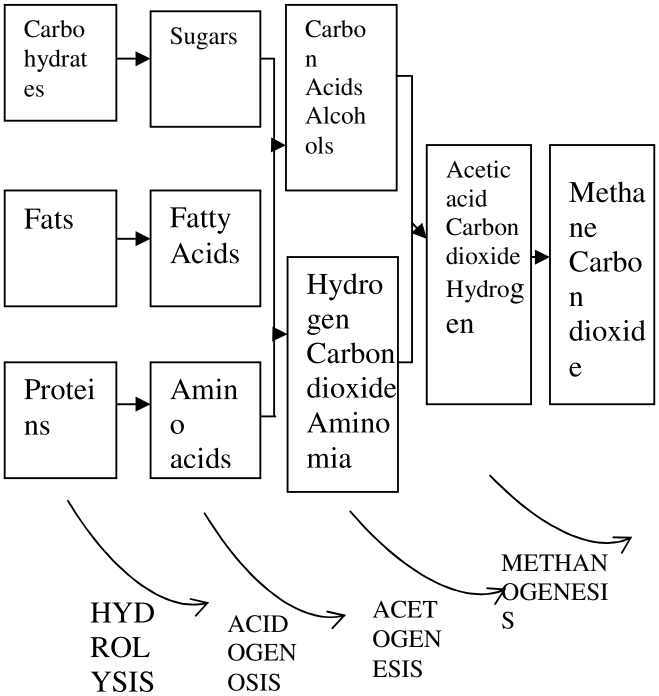

Figure 2.1 The main process steps of Anaerobic Digestion

The process steps above run parallel in time and space, in the digester tank. The speed of the total decomposition process is determined by the slowest reaction of the chain. In the case of biogas plants, processing vegetable substrates containing cellulose, hemi-cellulose and lignin, hydrolysis is the speed determining process. During hydrolysis, relatively small amounts of biogas are produced. Biogas production reaches its peak during methanogenesis.

Hydrolysis

Hydrolysis is theoretically the first step of Anaerobic Digestion during which the complex organic matter (polymers) is decomposed into smaller units (mono and oligomers). During hydrolysis, polymers like carbohydrates, lipids, nucleic acids and proteins are converted into glucose, purines and pyridines. Hydrolytic micro-organisms excrete hydrolytic enzymes, converting biopolymers into simpler and soluble compounds as shown below:

$$\text{Lipids} \xrightarrow{Lipase} \text{fatty acids, glycerol}$$

$$\text{Polysaccharide} \xrightarrow{Cellulase, cellobiase, xylase, amylase} \text{Monosaccharide}$$

$$\text{Proteins} \xrightarrow{Proteasee} \text{Amino-acids}$$

A variety of micro-organisms are involved in hydrolysis, which is carried out by exoenzymes, produced by those micro-organisms which decompose the undissolved particulate material. The products resulted from hydrolysis are further decomposed by the micro-organisms involved and used for their own metabolic processes.

Acidogenesis

During acidogenesis, the products of hydrolysis are converted by acidogenic (fermentative) bacteria into methanogenic substrates. Simple sugars, amino acids and fatty acids are degraded into acetate, carbon dioxide and hydrogen (70%) as well as into volatile fatty acids (VFA) and alcohols (30%).

Acetogenesis

Products from acidogenesis, which cannot be directly converted into methane by methanogenic bacteria, are converted into methanogenic substrates during acetogenesis. VFA and alcohols are oxidized into methanogenic substrates like acetate, hydrogen and carbon dioxide. VFA, with carbon chains longer than two units and alcohols, with carbon chains longer than one unit, are oxidized into acetate and hydrogen. The production of hydrogen increases the hydrogen partial pressure. This can be regarded as a waste product of acetogenesis and inhibits the metabolism of the acetogenic bacteria. During methanogenesis, hydrogen is converted into methane. Acetogenesis and methanogenesis usually run parallel, as symbiosis of two groups of organisms.

Methanogenesis

The production of methane and carbon dioxide from intermediate products is carried out by methanogenic bacteria. 70% of the formed methane originates from acetate, while the remaining 30% is produced from the conversion of hydrogen (H) and carbon dioxide (CO_2), according to the following equations:

$$\text{Acetic Acid} \xrightarrow{Methanogenic\ bacteria} \text{Methane + Carbon dioxide}$$

$$\text{Hydrogen + Carbon dioxide} \xrightarrow{Methanogenic\ bacteria} \text{Methane + water}$$

Methanogenesis is a critical step in the entire anaerobic process, as it is the slowest biochemical reaction of the process. Methanogenesis is severally influenced by operational conditions. Such operational conditions are:

a) Composition of feedstock
b) Feeding rate
c) Temperature
d) pH

Digestion overloading, temperature changes or larger entry of oxygen can result in termination of methane production.

2.0 MATERIALS AND METHOD

2.1 Materials and Apparatus for Analysis

Some of the materials used for the analysis are:

- Chicken dropping
- Inoculant
- Distilled water

Apparatus used are:

- Gas pipe and balloon for gas collection
- 4-minute gum
- Bucket
- Retort Stand
- Mercury in glass thermometer
- Electronic weighing balance
- Fabricated Biogas Digester

2.2 Data Collection

The chicken dropping was collected at Madam Comfort's poultry farm located at Eagle Island while the Inoculant was collected at the Research and Teaching Unit (Biogas Unit), Livestock farm at the University of Port Harcourt (UNIPORT) Abuja campus.

2.3 Method/Experimental Procedure

1. 12g of the chicken droppings was weighed using an electronic weighing machine.
2. Thereafter, the weighed chicken dropping was introduced into the bio-digester.
3. Distilled water of 6ml was weighed and poured into the bio-digester.
4. The content above was then stirred properly for even mixing.
5. The inoculant was collected and 8ml of it weighed and added into the bio-digester. Then the content stirred properly.
6. The bio-digester was then completely and properly sealed and then with the gas pipe and balloon connected to it for the trapping of the biogas.
7. The experimental setup was then left for monitoring for a specific time period (precisely 1-7 days) at an ambient condition until a decline in gas production was observed. During the period of experiment, the temperature of the bio-digester and the volume of gas produced was measured.

Furthermore, analysis and characterization is made on the collected biogas. Also, the digestate was also characterized and its suitability as fertilizer for agricultural cultivation determined.

2.4 Study Area or Location

This study is done under the jurisdiction of Rivers State within Port Harcourt metropolis precisely the prestigious Rivers State University (RSU), in Nkpolu-Oroworukwo. This investigation was carried out in the department of chemical/petrochemical engineering of the faculty of engineering, RSU.

Figure 2.1 Experimental setup

Figure 2.2 Measurement of Biogas

Figure 2.3 Slurry, biogas and chicken droppings

3.0 RESULTS AND DISCUSSIONS

3.1 Result

During the production process, the following data was used and obtained:

Amount of chicken droppings = 12g
Amount of water = 8ml
Amount of inoculant = 9ml
Weight of balloon = 2.5603g
Weight of balloon with biogas = 3.0335g
Total volume of biogas produced = 0.4732 = $0.5cm^3$
Initial temperature of the system = 29^0C
Final temperature of the system = 30^0C
Mean temperature of the system = 30^0C

From the analysis of the biogas, it has the following constituents:

Table 3.1 Analysis of biogas

Constitute	Symbol	Percentage (%)
Methane	CH_4	60 – 80
Carbondioxide	CO_2	15 – 20
Nitrogen	N_2	1 – 2
Hydrogen	H_2	0 – 1
Carbon monoxide	CO	0 – 0.1
Hydrogen sulphide	H_2S	0 – 3
Oxygen	O_2	0-0.5
Water Vapour	H_2O	0-0.3

Table 3.2 Time (no. of days) and Temperature of production

Time (no. of days)	Temperature (^0C)
1	29
2	30
3	30
4	30
5	30
6	30
7	30

Mean Temperature (MT) = 30^0C

Table 3.3 Time (no. of days) and Volume of Biogas Production

Time (no. of days)	Volume (cm^3)
1	0.1
2	0.2
3	0.3
4	0.4
5	0.5
6	0.4
7	0.3

Total volume of gas produced = $0.5cm^3$

Slurry = Chicken dropping (12g) + water (8ml) + inoculant (9ml)

After the production, the digestate was taken foe analysis to ascertain its suitability as fertilizer for agricultural production i.e. whether it has any trace of major soil nutrients such as Nitrogen, Phosphorous and Potassium. The result below was obtained

Table 3.4 Analysis of Digestate

S/N	Parameter	Unit	Amount
1	Nitrogen	Ppm	0.1
2	Phosphorous	mg/kg	0.18
3	Potassium	Ppm	0.001

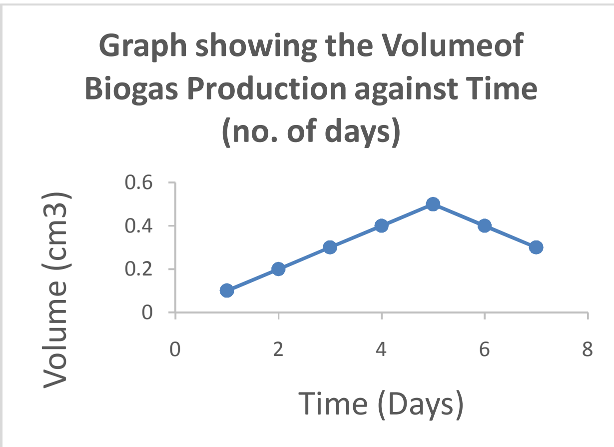

Figure 3.1 Biogas Production against Time (days)

3.2 Discussions

Temperature is a fundamental factor that affects the production of biogas. From the result obtained, the initial temperature was 29^0C which later increased to 30^0C as the decomposition continued. The mean temperature of the system was 30^0C in agreement with Hansen (2001) who reported temperature range of 28^0C to 33.3^0C as shown in table 4.2 in accordance with Lawal et al., (2001) that biogas production is favoured with an increased temperature and as the temperature drops, so the rate of biogas production declines.

From the volume of Biogas produced, as shown in table 4.3 it could be observed that the yield was not appreciably much. The low quantity of biogas produced by the chicken droppings was traceable to its laboratory nature i.e. small quantity of the chicken droppings was used in the production process. Hence, the higher the quantity of substrate, the higher the quantity of biogas that will be produced over time. Though, chicken droppings may not be the best or excellent substrate for optimum biogas production, however it offers a better yield and advantage over other solid substrate such as cassava peel, banana peel, plantain peel, fruits, vegetables etc. and serves as an excellent bio-fertilizer. Also, the low quantity of biogas produced by the chicken droppings may be attributed to its low C:N ratio of 10:1; Lawal et al., (2001) stated that poultry droppings contain a high level of urea which on decomposition produced a bulk of ammonia gas. Furthermore, the yield depends on the size of the substrate, as it has to be sliced or grinded to fine sizes or particles to allow for easy decomposition by micro-organism to produce the biogas.

One special or unique feature of this project is the use of inoculant in the production of biogas and have not been explored earlier before now. The inoculant is a substance (biological catalyst in slurry form) which contains special acid and methane forming bacteria which when introduced into the bio-digester with the substrate to be decomposed enhances, stimulate and accelerates the production of biogas. Usually, the production of biogas takes longer than 7 days (2-3 weeks) and even more depending on the substrate. But through this inoculation process, the number of days required for biogas production was shortened and yield increased.

Two groups of bacteria are responsible for this, viz: the *acid formers* and the *methane formers*. The acid formers include Bacillus subtilis, Pseudomonas aeruginosa, Staphylococcus aureus and Escherichia coli. While the methane formers include Methanobacterium sp and Methanococcus sp.

Analysis on the type of bacteria responsible for the decomposition of the substrate for the production of biogas based on temperature are classified into three (3) groups, viz:

1. *Psychrophilic bacteria* (<25^0C)
2. *Mesophilic bacteria* (25^0C - 45^0C)
3. *Thermophilic bacteria* (45^0C - 70^0C)

Hence, since the Mean Temperature (MT) of production was 30^{00}C as shown in table 4.2, the mesophilic bacteria were responsible for the Anaerobic Digestion (AD) chicken dropping for the biogas production.

One of the major advantages of biogas production is that both the product (biogas) and by-product (digestate) are both of inestimable value. While the biogas serves for heating and electricity as a reliable source of renewable energy, the digestate which is the sludge after the production serves as an excellent bio-fertilizer for agricultural cultivation.

This is further buttressed from the analysis of the digestate gotten from the production process as shown in table 4.4; The result shows that the digestate contains Nitrogen, Phosphorous and Potassium which are the major constituent of soil nutrients. Beside the fact that the chicken droppings serve as an excellent bio-fertilizer, likewise the digestate enhances agricultural cultivation when used. According to Lawal et al., (2001) maize plant fortified with digestate (sludge) gave a mean growth of 1564mm while the unfortified soil gave a mean growth of 711mm. This is owing to the presence of the increased organic soil nutrient in the digestate fortified soil which serves as fertilizer to the maize plant.

4.0 CONCLUSION

This mini-novel work "*biogas production from agricultural waste (chicken droppings)*" has demonstrated an entirely new and effective way to the production of biogas from other existing works hitherto. This special and unique work was been investigated upon through the process of inoculation of the substrate i.e. the addition or introduction of an inoculant into the bio-digester with the substrate to stimulate and facilitate the biogas production. From this analysis, the number of days used for production was shortened as well as the yield increased contrary to the previous works where longer time was taken (2-3 weeks) or even more depending on the nature of substrate with a comparative low yield without the use of inoculant. This project therefore has broadened our idea and knowledge on biogas production and in addition offered a new and effective means of biogas production.

As a result of the fact the fossil fuel is a non-renewable source of energy and can be exhausted any moment according to research, this biogas production offers hope and solution to the energy problem of the country and the world at large. This is because the raw material for its production can be easily afforded even without any cost. Moreover, the biogas is a clean and effective fuel for heating and electricity and finally it has no environmental pollution effects to lives and property.

Beside these, this work offers an elixir to all waste problems. Wastes (domestic, industrial, commercial and agricultural) has in recent times become more challenging as its generation rate have greatly increased without a commensurate effort to clear and clean it up. In nut shell, little do people know that these wastes especially agricultural waste could be converted and recycled into valuable products and by-products. This work has therefore conclusively shown unequivocally how agricultural waste specifically chicken droppings can be converted to biogas and digestate.

Finally, this work is of multi-purpose perquisite. In addition to the aforementioned, the residue (by-product) called digestate from the biogas production offers an excellent and cheap source of bio-fertilizer for agricultural cultivation. From the analysis of digestate, it revealed that major soil nutrients of Nitrogen, Phosphorus and Potassium were found in the digestate in concordance with Lawal et al., (2001) that maize fortified with digestate gave a mean growth of 1564mm while the unfortified soil gave a mean growth of 711mm. this was as a result of the presence of these major soil nutrient in the digestate.

ACKNOWLEDGMENT

My foremost gratitude is ascribed unto God Almighty "*the Pillar that holds my life*" for the magnitude of His gracious attitude of fortitude by bringing me to the altitude at this juncture. With Him always by my side I live, I move and I have my being. Besides, my profound appreciation from the depth and sincerity of my heart goes to my Dad, Uncle and Brother Arc. Krismark I. Enwudor and my Project Supervisor, Engr. (Mrs.) Patience Ikenyiri who was fully instrumental to the success of this project and who through their individual prayers, support, counsel, love guidance, admonition, inspiration and contributions among others made this dream a reality.

REFERENCES:

Bodem, D. (2004) Biogas production from Chicken Droppings. Lagos, Ace group of publishers.

Evans, R. (2007). Problems Affecting the Effective Production of Biogas from Chicken droppings. New York, Lance Publishers.

Lawal, A.k., Ajuebor, F.N. & Ojosu, J.o. (2001). Characteristics of piggery wastes feedstock for determination of design parameters to biogas digester plant. Nigeria Journal of Research and Review in Science 2:193-198

Mipson, V.O. (2007). Chicken droppings and Biogas Disintegrations in farms. London Dons publishers.

Nwerlu, K. (2004). Biogas Production, Uses and Problems: A pragmatic view. Ibadan Ajaye group of publishers.

Nagamany & Ramasmy (2004). Biogas Production technology and the Indian Article. Journal of Science and Technology.

Chibuogwu, E. (2004). Alternative Energy Resource (with comment on Nigeria's position) 1st Edition. Lagos: Macmillian.

P. Jacobs & Associates. Best Management Practices: Agricultural Waste Management. Canada.

Brufau, J. & Taon, A. (Eds), (1999). Impact of Agriculture on the Environment.

Agricultural Wastes Retrieved from Wikipedia http://www.wikipedia.com/agriculturalwaste

Wahera, R.W. (2009). Assessing the Challenges of Adopting Biogas Technology in Energy Provision among Diary Farmers. Nyeri, Kenya.

Rhendelwal, K. & Mahdi, S.S., (1986). Biogas Technology: A Practical Technology, (1st Ed.) Tata McGraw Hill Publishing Company, New Delhi.

Ilaboya, I.R., Asekhame, F.F., Ezugwu, M.O., Erameh, A.A. & Omofuma, F.E. (2010). Studies on Biogas Generation from Agricultural Wastes: Analysis of the Effect of Alkaline on Gas Generation. IDOSI Publishing, ISSN 1818.4952. PMB 0006, Igbinedion University Okada, Nigeria.

Zagar, S. (April 16, 2015). A Glace at Biogas Storage Systems. Culhane, T.H., Biogas Digester. Tamera, Solar Village. Biogas from Wikipedia Retrieved from http://www.kolumbus.fi.2007

Peter, J.J. (2009), Nielson, A. B. & Bendixen, F. (Eds.) Biogas: Green Energy – Process, Design, Energy Supply and Environment (2nd Edition). ISBN 978-87-992243-2-1, Digisource Denmark.

Seadi, T.A., Rutz, D., Prassl, H., Michael, K., Tobias, F., Silke, V.& Janseen, R. (2008), Seadi (Ed.) Biogas Handbook.ISBN 978-87-992962-0-0.Unversity of Southern Denmark Esbjerg, Niels Bohr Vej 9-10

Chaiprasert, P. (2011). Biogas Production from Agriculatural Wastes in Thailand. Kong Mongkut's University of Technology Thonburi, Thailand. DG (2011)-63-65

Biogas: ads and disads Retrieved from: http://www.economywath.com/renewable-energy/advantages of biogas.html

Laskri, N., Hamdaoui, O. & Nedjah, N. (June 2015).Experimental Factors Affecting the Production of Biogas during Anaerobic Digestion of Biodegradable Waste.

Singh, J., Kaushik, N. & Biswas, S., Bioreactors: Tehnology and Design Analysis. The SCITECH Journal ISBN 2347-7318

Dadrasnia, A., Shahsavari, N. & Emenike, .U.,emediation of Contaminated Sites. Retrieved from: http://www.dx.doi.org/10.5772/51591

Bioreactor retrieved from: http://www.wikipedia.com/bioreactor

John, A.W. (March 2002). Keys to Bioreactor Selections. Environmental & Production Solution (EPS), LLC.