Experimental Investigation of Energy Potentials of Kitchen Organic Waste

O. O. E. Ajibola, T. T. Fagbamila and O. J. Balogun
Department of Systems Engineering, University of Lagos, Lagos, Nigeria
Email: waleisiro@yahoo.com

Abstract

In sub-Sahara Africa, kitchen wastes (KWs) are worthless product that are disposed freely on open refuse sites causing environmental pollution and aiding the spread of pathogenic diseases. With increasing population, demand for energy is constantly on the rise. Persistent rise in prices of fossil fuel products often result in shortage in supply of energy for both domestic and industrial applications in most developing nations. To solve the imbroglio created by the shortfall of energy, renewable energy can be explored: one viable source of such is the biomass. However, KWs have very high Carbon – Nitrogen ratio (C:N) of 35:1. The preceding statement then implies that if co-digested in appropriate ratio with human faeces and allowed to degrade inside an anaerobic digester, KWs have a disposition to drastically reduce the problems of inadequacy in energy supply. In this paper, the slurry obtained from KW, human excreta (HE) and water (W) was anaerobically digested in batch digesters A, B and C under mesophilic conditions in ratio 5:1:6, 1:1:2 and 1:5:6 respectively. The results obtained were analyzed to determine the slurry with the highest biogas yield. The digester with label A has the highest yield of 8164 mL of biogas as against digesters B and C which produced 7060 mL and 2307 mL respectively from the same volume of slurries. This is attributable to the higher ratio of kitchen waste in digester A. The result obtained from this study is expected to promote a better understanding of biogas technology.

Keywords: anaerobic digestion, batch digestion, biogas, human excreta, Kitchen waste, slurry.

1.0 INTRODUCTION

Energy plays a vital role in the sustenance of socio-economic development and improved quality of life (Hamawand and Baillie, 2015). And, it is a basic requirement for sustainability for all living things, plant or animal (Lungkhimba *et al*., 2010). Energy is therefore an essential part of all entities, living or non-living. Energy can exist in two main forms: non-renewable and renewable. Nonrenewable resources are resources that cannot be recovered once expended. Non-renewable energy resources are therefore exhaustible. For instance, fossil fuels such as crude oil and coal are nonrenewable sources of energy. And both are exhaustible. However, renewable energy refers to energy, which can be derived from the environment and the movements of natural endowments. Resources attributable to renewable energy include: sunshine, which is primary to all others, heat of the earth, wind, the movement of water as can be found in rivers and the seas, and, the activities of plants and animals. These energy resources can be replenished (Ibidapo-Obe and Ajibola, 2011). They are obtainable from the transformation of energy from the sun and its primary alternate forms namely the movements of wind as translated into river flow. The transformation usually occurs without the attending pollution from combustion into forms of energy such as electricity. Some examples of forms of renewable energy are: biomass, fuel cells, geothermal, and wind energy to mention but a few. The roles of renewable energy resources in the provision of sustainable energy and in reduction of atmospheric pollution cannot be overemphasized (Elaiyaraju *et al*., 2012). Most countries majorly depend on fossil fuel products for their energy consumption with very little contribution from renewable energy. The result of burning fossil fuel in air is a major contributor to global warming and other environmental and health hazards. This is as a result of the release of greenhouse gases that are mainly CO_2 and CH_4 into the atmosphere (Lungkhimba *et al*., 2010). The depletion of fossil fuels, the hike in its price and their rampant health challenges are enough justification for developing an environment friendly, clean and sustainable but renewable energy resources (Ajibola and Suley, 2012; Fagbamila, 2016). To this end, this paper seeks to explore the energy prowess of kitchen waste.

In a developing country such as Nigeria, where wastes are not productively used, animal dung, HE as well as carbon rich KW can be effectively harnessed and converted into biogas, which can be used either for domestic and commercial purposes (Adeniran, 2014). Having developed adequate human capacity, paucity of funding from government and non-existence of research grants from donor agencies have hindered the development of the required technology in Nigeria (Dahunsi *et al*, 2013). The persistent energy crisis in Nigeria has in turn weakened industrialization in the country and thus, undermining all efforts to achieve sustainable economic growth and increased competitiveness among indigenous industries. It has also been responsible for the inability of the economy to generate employment (Simonyan *et al*., 2013). This study is designed to encourage exploration of the organic waste resources as a cost-effective and ecofriendly energy source. It relies on the richness of human faeces in microbes to catalyze the process. The ultimate aim of the study is to obtain optimum biogas yield within the shortest retention time from the slurry of KW and HE within a mesophilic temperature range of between 25 ^oC and 40 ^oC. KW includes spoilt or rotten foods and fruits that are organic in nature and have very high carbon and nutritional content required for microbial activities to thrive (Kubaská *et al*., 2010). About 75 % of human faeces weight is made up of water while the other 25 % is composed of solid substances, which consists of 30 % bacteria, 10 to 20 % fat, 10 to 20 % inorganic substances, 2 to 3 % protein, about 30 % undigested fibre and very low Carbohydrate (Barbosa, 2012). Complex carbohydrates referred to the sugar or starch in the diet: their presence in the HE is extremely low because they are readily ingested through the small intestine in the form of glucose, fructose or galactose and assimilated in blood with the exception of lactose, which is fermented in the body. Undigested carbohydrates in normal HE is usually below 0.5 %. This accounts for its low energy content. The amount of excrements is usually between 135 and 270 g for individual per day (Barbosa, 2012).

According to Dennis and Burke (2001), the process of anaerobic digestion can be affected by such factors as: the nature of waste to be digested, its concentration, its temperature, the toxicity of the materials, the pH of the substrate, the time of retention of both the liquid and solid matter, the content microorganisms in the food and the rate at which the digester is fed. According to Deepanraj *et al*. (2014), the conversion process of complex organic matter into methane and carbon dioxide is achievable in four steps as stated below (Eqs. 1-4).

- *Hydrolysis*: Conversion of complex organic polymers into simple soluble molecules through the activities of a group of fermentative bacteria (Sangeetha *et al*., 2012).

  $$(C_6H_{10}O_5)\ n + nH_2O = n\ (C_6\ H_{12}\ O_6) \quad (1)$$

- *Acidogenesis*: The process where, simple soluble compounds produced by hydrolysis are converted into carbon dioxide, ethanol, hydrogen, volatile fatty acids and some organic nitrogen (Sangeetha *et al.*, 2012)

  $$C_6H_{12}O_6 = CH_3CH_2CH_2COOH + 2H_2 + 2CO_2 \quad (2a)$$
  $$C_6H_{12}O_6 = 2CH_3CH_2OH + 2CO_2 \quad (2b)$$

- *Acetogenesis*: Conversion of volatile fatty acids into acetic acids, hydrogen and carbon dioxide with the help of bacteria called acetogens (Deepanraj *et al*., 2014).

$$CH_3CH_2COOH + 2H_2O = CH_3COOH + 3H_2 + CO_2 \quad (3)$$

- *Methanogenesis:* The last stage where methanogens converts acetic acid, hydrogen and some carbon dioxide into methane. 66 % of methane is formed from acetic acids by means of acetate decarboxylation and remaining 34 % of methane is formed from carbon dioxide reduction (Deepanraj *et al*., 2014).

$$CH_3COOH = CH_4 + CO_2 \quad \text{(Acetate decarboxylation)} \quad (4a)$$
$$CO_2 + 4H_2 = CH_4 + 2H_2O \quad \text{(Carbon dioxide reduction)} \quad (4b)$$

The ultimate goal of this work is to harmonize the aforementioned procedure to achieve optimum production of biogas within the shortest possible retention time from the co-digestion of KW and HE.

2.0 MATERIALS AND METHOD

2.1 Materials

The materials employed in the course of this study are: Adhesives: Abro 2000 Silicon Sealant, Epoxy Hardener and Super Glue, 50 kg Portable Weighing Scale, 3 units of 19 Litre plastic bottles, 3 units of 20 Litre white kegs, 3 units of 250 mL laboratory beaker, 3 units each of 16 inch motorcycle tube and tri-cycle tube, 6 units of 8 mm industrial gas tap, 3 units of 8 mm T-connector, 42 feet of 5/8" rubber hose, Digital Thermometer, PH meter, Activated charcoal, Bunsen burner and tripod stand, Black paint, Paint thinner, organic KW, human fecal matter and water. The compartments are as arranged in **Figure 1**.

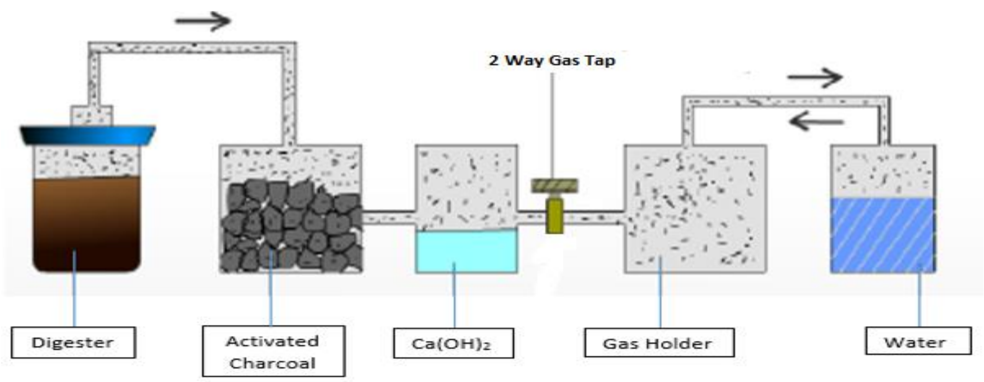

Figure 1: Schematic diagram of the anaerobic digestion process

The KW was obtained from food leftover such as; waste vegetable, boiled corn, boiled rice, sugar, overriped banana, boiled yam, bread crumbs and spoilt milk. Excreta was collected from 6 adults for 7 days, the meal that produced the excreta consists basically of carbohydrate and protein. The food wastes were blended to obtain a homogenous mixture and minimal particle size suitable for easy digestion by anaerobic bacteria and then mixed thoroughly with the excreta as illustrated in **Figure 2**. The flowchart in **Figure 3** shows the process involved in the work from the digester design stage to the gas collection stage.

Figure 2: Stepwise execution of process from slurry preparation to refined biogas production

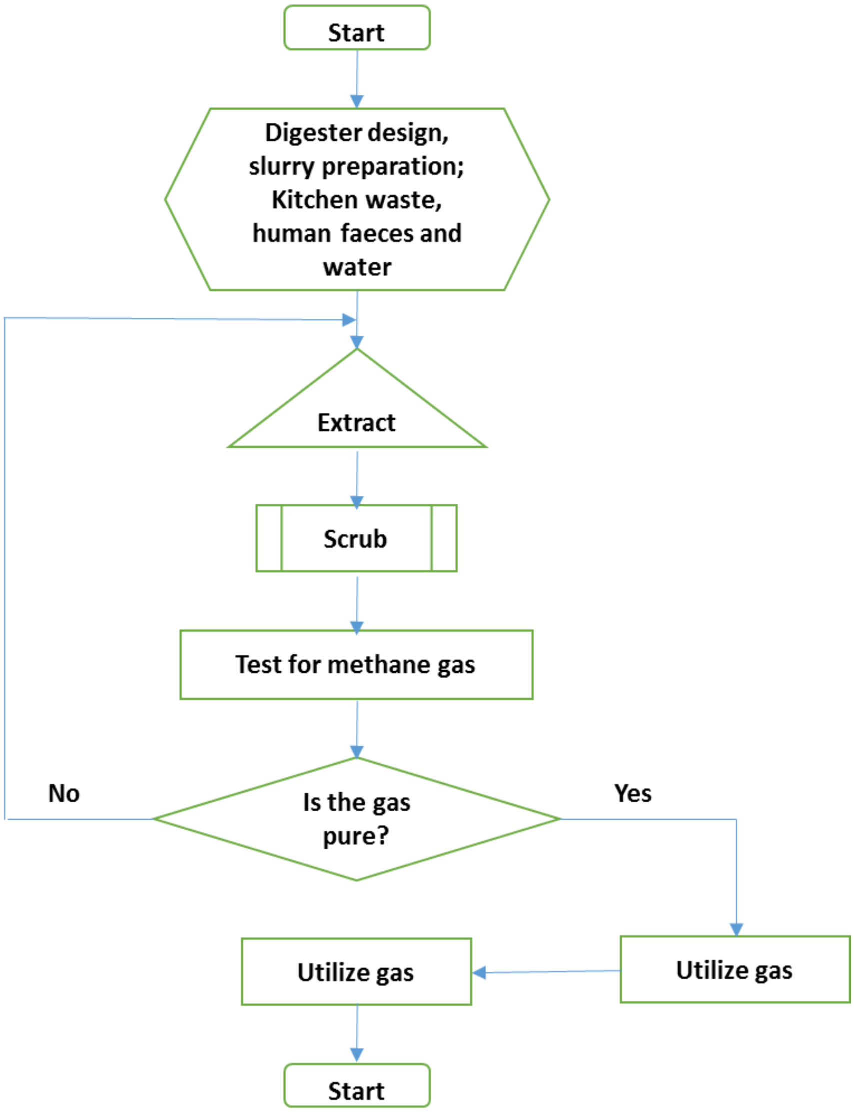

Figure 3: Flow chart of operations

2.2 Method

The batch digestive method was used in the course of this research work; thus, the organic feedstock was loaded into the digesters at once while maintaining a completely closed system throughout the entire process as shown in **Figure 4**.

In this study, varying ratios of KW and HE were used as feedstock for our bio-digesters with the purpose of determining what percentage of HE is adequate for optimum yield of biogas from a predetermined volume of KW. Three 19 liters plastic digesters were used to anaerobically digest the feedstock at a mesophilic temperature range of between 25^oC and 40^oC with initial pH values of 5.8, 6.4 and 6.7 for digesters A, B and C respectively. The digesters set up as shown in **Figure 4.**

Odour test was adopted to confirm the presence of methane gas. And the biogas from the experiment is odourless**.** The presence of methane gas was checked by testing the combustibility of the biogas produced as demonstrated in **Figure 5**.

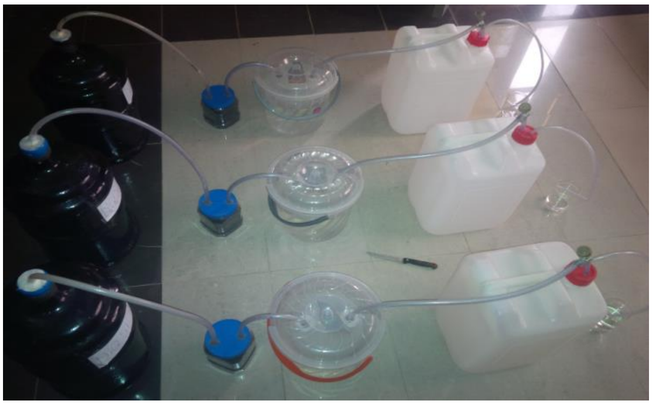

Figure 4: Biogas production experimental setup

Figure 5: Test for methane gas

3.0 RESULTS AND DISCUSSION

3.1 Results

The volume of biogas produced on daily basis was measured and recorded. The measurements were taken using water displacement method. The biogas collector is a white 20 Litre container while a 250 mL laboratory beaker is used for measuring the volume of water displaced. The biogas from the digester exerts pressure on the water inside the 20 Litre keg, which in turn displaces a volume of water equal to the volume of biogas produced (Archimedes' principle). This experiment was conducted at ambient room temperature. It neither requires regulating pH nor substrates pre-treatment. The volume of gas produced was measured and recorded daily for a retention period of 24 days. At the end of the retention period, the biogas in the 20 Litre keg was then collected over water and stored inside rubber tubes for usage. The composition of the contents of digesters A, B and C is as shown in **Table 1**.

Table 1: Amount of human waste and kitchen waste mix, and water used

Digester Content	Digester A	Digester B	Digester C	Total weight
Waste Ratio (KW:HE:W)	5:1:6	1:1:2	1:5:6	
(Waste: Water)	1:1	1:1	1:1	
Co-digestion Process				
Kitchen Waste (kg)	6.5	3.9	1.3	11.7
Human Excreta (kg)	1.3	3.9	6.5	11.7
Water (kg)	7.8	7.8	7.8	23.4
Total weight of slurry (kg)	15.6	15.6	15.6	46.8

The ratio of solid mix to water is 1:1, and the process was monitored for a retention period of 24 days. The summary of the observations obtained from the experiment is shown in Table 2.

Table 2: Summary of results

	Digester A	Digester B	Digester C
pH before the retention period	5.8	6.4	6.7
Gas production (days)	2	6	11
Combustion time (days)	2 - 3	6	11
Approx. combustion time (hours)	55	149	269
Volume of gas produced in 24 days (mL)	8164	7060	2307

From **Table 2**, Digester A produced biogas consistently from the 2nd day. The combustibility of the biogas was tested on the 3rd day and a positive result was obtained. However, digester B produced biogas radically on the 6th day, supported combustion on the same day but took a dive 9 days afterwards. And digester C produced on the 11th day, gas production increased speedily then became steady for about 2 days and finally dropped drastically on the 14th day, the gas produced also was combustible, an indication that the scrubbing process was effective.

3.2 Discussion

The results obtained above clearly shows that biogas yield in digester A is highest due to the high carbon content in KW while the excess volume of HE in digester C attests to the catalytic property of HE. The production of biogas therein is sudden and brief due to the overwhelming population of pathogens dwelling on scarce resources. **Figure 6** shows that biogas production started early and steady in digester A and lasted through the entire retention period compared to Digester B which started production five days after with a lesser production span but higher altitude than Digester A at the initial stage. Digester C started after ten days but with the highest altitude and hence the shortest production span. The graphical analysis in **Figures 6 and 7** reveals strict compliance of processes in the three digesters with the Law of conservation of mass.

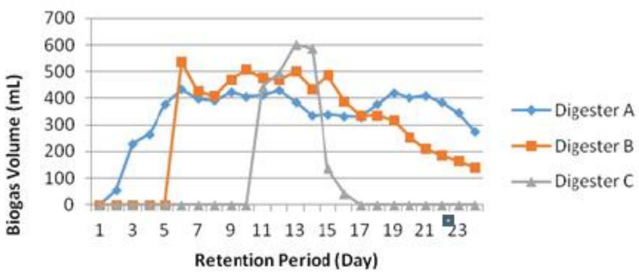

Figure 6: Volume of biogas produced versus retention period

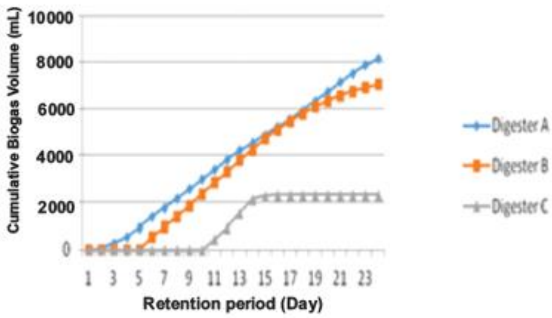

Figure 7: Cumulative Volume of biogas produced versus retention period

The HE serves as a catalyst supplying the pathogens necessary to initiate the breaking down of food particles in the KW. Biogas yields in digesters B and C started from days 5 and 10 respectively because the volume of KW, the energy reservoir, was overwhelmed by that of HE, which contributed to the late production of biogas in the system. However in Digester A, the seeding effect of HE on the KW was steady and biogas production lasted throughout the retention period.

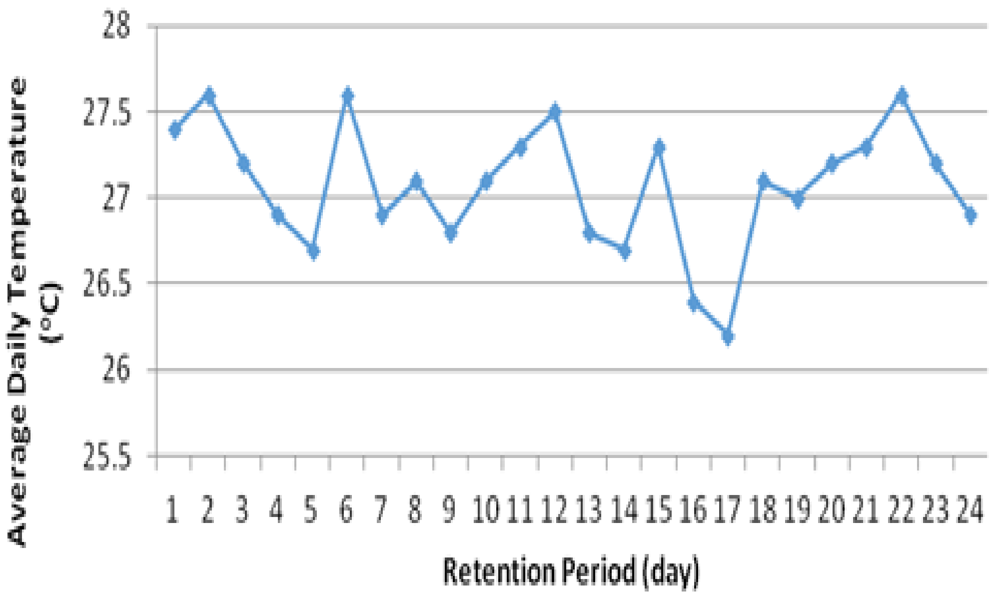

Figure 8: Average daily temperature during the retention period

A close analysis of **Figure 8** revealed that the cumulative outcome of the digestion process in digester A is unmatched with those of B and C coinciding only with that of B between days 15 and 17. Unlike KW the useful nutrients in human faeces have been used up by the human body during digestion. This reduces its macro molecular content to about 20 %, which is far less than the amount required by fermentative bacteria to be active. The macro molecular content of KW is usually in the neighbourhood of 60 % or above. This research work clearly shows that the slurry from KW and HE is indeed a veritable source of renewable energy.

The average daily temperature during the retention period was recorded as shown in **Figure 8**, biogas production was maximal on the 6th day at 27.6 ^{o}C, therefore producing 434 mL of biogas in digester A, 536 mL in digester B but there was no production in digester C until the 11th day **(Figure 6)**. Biogas production was at its lowest ebb on the

17th day at 26.2 ^{o}C giving off 330 mL of biogas in digester A, 335 mL in digester B with no production in digester C as it had already finished biogas production. It is evident therefore, that rise in temperature increases biogas production by increasing the rate of activity of the anaerobic bacteria (methanogens).

The intensity of microbial activity in the digesters is a function of the environmental temperature, especially in methanogens, wherein the degradation rate increases with temperature rise (Sebola *et al*., 2015; VIJ, 2011). It is also imperative to note that co-substrates must be dosed in optimal proportions depending on the specific properties of the substrates (Ertem, 2011).

4.0 CONCLUSION

In this work, biogas has been efficiently derived from the slurry of kitchen organic waste and human fecal matter. The study shows that the slurry from kitchen wastes and human excreta is an excellent substrate for production of biogas under anaerobic digestion in a controlled environment. The high quality biogas was obtained under 24 hours and adequate volume within 55 hours.

REFERENCES

Adeniran, K.A., Ahaneku, I.E., Itodo, I.N. and Rohjy, H. A. (2014). Relative effectiveness of biogas production using poultry wastes and cow dung. *Agric Eng Int: CIGR Journal,* 16 **(1):** 126-132.

Ajibola, O.O.E. and Suley, E. (2012). Cow dung – water hyacinth: a viable source of energy. *Journal of Sustainable Development and Environmental Protection*, 2 **(1):** 49 – 58.

Alexopoulos, S (2012). Biogas Systems Basics, Biogas Multifunction, Principle of Fermentation and Hybrid Application with a Solar Tower for the Treatment of Waste Animal Manure. *Journal of Engineering Science and Technology, 5* ***(4):*** 48 -55.

Barbosa, M. R. (2012). Chemical Composition and Formation of Human Feces – Problems and Solutions of Large Mergers Demographics In Developing Countries. *Tenth International Symposium on Recent Advances in Environmental Health Research.* 39

Blonskaja, V. (2014). The analysis of biodegradable waste as renewable resource for alternative energy production in Estonia. *EKOLOGIJA. 2014.60* ***(2):*** 27–37

Dahunsi S. O., and Oranusi, U.S. (2013). Co-digestion of Food Waste and Human excreta for biogas production. *British Biotechnology Journal, 3* ***(4****):* 485-499.

Deepanraj B, Sivasubramanian V, and Jayaraj. S. (2014). Review Paper: Biogas Generation through Anaerobic Digetsion Process *Research Journal of Chemistry and Environment, 18* ***(5):*** 80-94.

Dennis, A. and Burke, P.E. (2001). Dairy Waste Handbook. *Options for Recovering Beneficial Products From Dairy Manure*. Environmental Energy Company. Olympia, WA 98516

Elaiyaraju, P. and Partha, N. (2012). Biogas production from co-digestion of orange peel waste and jatropha de-oiled cake in an anaerobic batch reactor. *African Journal of Biotechnology, 11* ***(14):*** 3339-3345.

Ertem, F. C. (2011). Improving Biogas Production by Anaerobic Digestion of Different Substrates. *Master Thesis in Applied Environmental Science*. Halmstad University. Sweden.

Fagbamila, T.T. (2016). Kitchen waste-human excreta slurry: a formidable source of renewable energy. *M.Sc. Dissertation: University of Lagos, Lagos, Nigeria.*

Hamawand I. and Baillie, C. (2015). Anaerobic Digestion and Biogas Potential: Simulation of Lab and Industrial-Scale Processes. *Energies*, 8: 454-474.

Ibidapo-Obe, O and Ajibola, O.O.E. (2011). Towards a Renewable Energy Development for Rural Power Sufficiency. *Int. Conference on Innovations in Engineering and Technology (IET)*, University of Lagos, Lagos, Nigeria, 894 – 905.

Kubaská M., Sedlácek S., Bodík I., and B., K. (2010). Food Waste as Biodegradable Substrates for Biogas Production. *37th International Conference of Slovak Society of Chemical Engineering,* 6 1413–1418.

Lungkhimba H.M., Karki, A. B. and Shrestha, J. N. (2010). Biogas Production from Anaerobic Digestion of Biodegradable Household Wastes. *Nepal Journal of Science and Technology.* 1: 167-172.

Sangeetha P.A., Atharsha.S and Sri.K, S. (2012). Comparison of Viability of Biogas from Poultry Waste and Mixture of Poultry and Fish Waste. *International Journal of Innovative Research In Technology and Science,* 2 **(4):** 33-38.

Sebola M. R., Tesfagiorgis H. B., and Muzenda, E.. (2015). Methane Production from Anaerobic Co-digestion of Cow Dung, Chicken Manure, Pig Manure and Sewage Waste. *Proceedings of the World Congress on Engineering,* WCE 2015, July 1-3, Vol I, London, U.K.

Simonyan K. J. and O., F. (2013). Biomass resources and bioenergy potentials in Nigeria. *African Journal of Agricultural Research,* 8 **(40):** 4975-4989.

VIJ, S. (2011). Biogas Production From Kitchen Waste. B.Tech. dissertation, National Institute of Technology, Rourkela, Odisha, India