The International Journal Of Engineering And Science (IJES)
|| Volume || 4 || Issue || 5 || Pages || PP.38-44|| 2015 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Comparative Evaluation of Fiber-glass Reinforced Plastic and Metal Biogas Digesters

[1]Menkiti Nnamdi I., [2]Ndirika Victor I. O.

[1]*Department of Agricultural and Bio-resources Engineering, Nnamdi Azikiwe University Awka, Anambra State, Nigeria.*

[2]*Department of Agricultural and Bio-resources Engineering, Michael Okpara Federal University of Agriculture, Umudike, Abia State, Nigeria.*

ABSTRACT

A 0.35m^3 capacity anaerobic digestion unit for producing biogas from poultry waste in the rural communities was designed, fabricated and tested for performance. The entire unit was made of fiber glass reinforced plastics (FRP) to ensure good quality of the product. After construction and assembly, the biogas digestion unit was tested and compared with a metal bio-digester of the same capacity. In each digester, 90kg poultry waste was diluted with 191 kg of water and subjected to a retention period (45days) to make a substrate (slurry) of 8% total solid (TS). Results showed a cumulative gas yield of 2.28m^3 for the metal digester and 1.33m^3 for the FRP digester after 45 days retention period at average substrate temperature of between 25^{0}C and 34.5^{0}C while the daily ambient temperatures varied from 24.5^{0}C to 32^{0}C and a pH of 7.92 to 9.57 for the FRP digester and 8.01 to 9.67 for the metal digester. T-test analysis of the parameters showed significant differences in the pH, biogas volume and in temperature. It is recommended that further research be carried out on the FRP digester using other waste substrates/co-digestion of substrates to test its efficiency in terms of biogas production.

Keywords *– Biogas production, digester, pH, temperature, volume.*

Date of Submission: 16-May-2015 | Date of Accepted: 05-June-2015

I. INTRODUCTION

Biogas originates from bacteria in the process of bio-degradation of organic material under anaerobic (without O_2) conditions. Biogas, the metabolic product of anaerobic digestion, is a mixture of methane and carbon dioxide with small quantities of other gases such as hydrogen sulfide [1]. Methane, the desired component of biogas, is a colorless, blue burning gas used for cooking, heating, and lighting [2].Many different types of biogas reactors are used throughout the world. In general, designs used in developing countries for digestion of livestock waste are classified as low-rate digesters, being simpler than those in more temperate regions and lacking heating and stirring capability. Ezekoye and Okeke [3] worked on the generation of biogas using spent grains and rice husk, mixed together. A 300 gallon plastic bio-digester was designed, constructed, and used to obtain biogas from these wastes. The digestion of the slurries was undertaken in a batch operation. The wastes started producing combustible gas 20 days after they were charged. The maximum volume of biogas obtained from the wastes was 150 litres on the 47th day. Observation shows that rice husk increased the number of microbes in the spent grains and quickened its gas production. It was discovered that the waste has a longer retention time. The conditions within the digester suitable for the anaerobic microbes were under mesophllic temperatures (20-45^{0}C). Eze et al. [4] designed a 11m^3 Chinese- type fixed dome biogas plant, constructed at the National Center for Energy Research and Development, University Of Nigeria, Nsukka which was characterized through measurement of its actual volume and intensive three weeks kitchen performance tests. Results of the measurement of the plant showed that its actual volume is 11.0m^3. Anaerobic digestion of cow dung using the plant was carried out. The plant was found to utilize 2000 kg of the waste with 4000kg of water giving a waste to water ratio of 1:2. The experiment was conducted under semi-continuous batch process within a retention period of 90 days and mesophilic temperature range of 26°C and 38°C. The volume of gas production at full capacity of the plant was found to be 1.13 L / kg. TS with pressure of 0.147 bar.

Mahmuda, [5] worked on the design, construction and performance evaluation of a 100litre capacity portable biogas digester, which was used in anaerobic degradation of agro-based waste to produce energy-biogas. A fermentation process was employed in assessing the potentials of the waste in biogas within a 30day period. It was concluded from the experimental results that chicken droppings is a better source of biogas, and a potential source of the combustible methane gas commonly used for house hold cooking.

Many small scale anaerobic digesters in developing countries fail for various reasons, including: design, high capital cost, construction, maintenance, operational problems, or availability of materials for maintenance [6]. Anaerobic digester designs must be implemented that are best suited to the end user and location, the process variables must be optimized to the extent possible, trained maintenance personnel must be available to the user, and government support must be present [6]. This study seeks to address these issues with the aim of designing a long lasting biogas digester for household purposes where the events/parameters occurring in the plant can be effectively and accurately measured and without leakage of any sort.

In developing countries such as Nigeria, due to the disadvantages of the current bio-digesters in use (plastic, concrete and metal bio-digesters), there is still need for some basic research, mostly on the quantity and potential biogas yield of fermentable organic wastes available, the size, type and construction details of biogas digesters which can be economically viable for the potential consumers of the biogas technology. Therefore this research work would develop a fiberglass reinforced plastic digester, and compare its performance with a metal digester of the same size using poultry waste as substrates.

II. MATERIALS AND METHODS

This work was carried out at National Center for Energy Research and Development (NCERD), University of Nigeria, Nsukka, Enugu state, Nigeria.

2.1 Materials

The poultry droppings used in this research work were collected from a poultry farm in Nsukka. The matrix material used consisted of room temperature curing unsaturated isophthalic polyester resin and corresponding catalyst (Methyl ethyl ketone peroxide), accelerator (cobalt naphthanate), E-glass fibers, blue pigment is used as colour. Universal mould release wax and polyvinyl alcohol was applied as release agent.

The following equipment was used in the study.

i. **Weighing balance:** to determine the weight of poultry waste samples.
ii. **PH meter:** to measure the pH of the digested materials.
iii **Thermometer:** used to measure the temperature in the metal bio-digester as well as ambient temperature.
iv. **Transparent jerry-can and a water trough**: to measure the volume of water displaced by the biogas generated.

2.2 Fabrication process

The mould is first checked for defects, any scratches, etc. are filled. The mould is then polished with a wax polish to a very smooth, high quality finish. Next, a very thin film of a liquid release agent (polyvinyl alcohol) is applied. The wax and the polyvinyl alcohol are there to prevent the glass fiber product from sticking to the mould. A layer of resin (gel coat) mixed with a blue pigment is then applied all over the inside of the mould. When the resin has cured, a layer of E-glass fiber which has been cut to size is laid inside the mould and a measured amount of unsaturated isophthalic polyester resin mixed with the catalyst (Methyl ethyl ketone peroxide), accelerator (cobalt naphthanate) and blue pigment is stippled and rolled into the reinforcing layer. This layer is also allowed to cure. More layers are applied until the required thickness is achieved. When the product has fully cured, it is removed from the mould. The coloured gel coat that was on the inside of the mould is now the exterior covering of the GRP digester. Any blemishes in the mould will have been reproduced in the finished moulding. A 1” galvinazed iron pipe was used to construct the stirrer. Special rubber flanges were used as a gasket to ensure leak-free joints during the coupling of the top cover digester component.

2.3 Methods

2.3.1 Determination of Moisture content

The A.O.A.C method [7] was used. Porcelain crucibles is 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 is placed into weighed crucibles and then put inside the oven set at 105^{o}C for 4 hours. The samples is then removed from the oven after this period, then cooled and weighed. The drying is continued and all the samples with the crucibles weighed until a constant weight is obtained.

% moisture = $\frac{A-B}{A} X \frac{100}{1}$ ……………………………………… (1)

Where A = Original weight of sample
B = Weight of dried sample

2.3.2 Determination of Crude nitrogen

The micro-Kjedahl method as described in Person [8] is used.

2.3.3 Determination of Ash

The ash is taken as a mineral content of the raw waste. The A.O.A.C method [7] was used.

2.3.4 Determination of Carbon

Walkey-Black method [9] is used. 0.05g of finely ground sample is weighed into a 500ml conical flask. 10ml of 1M potassium dichromate is poured inside the flask and the mixture is swirled. 20ml of concentrated H_2SO_4 is added and the flask is swirled again for 1minute in a fume cupboard. The mixture is then allowed to cool for 30minutes after which 200ml of distilled water; 1g of NaF and 1ml of diphenylamine indicator is added. The mixture is then shaken and titrated with ferrous ammonium sulphate. The blank is also treated the same way.

% Carbon = $\frac{B-T \; x \; M \; x \; 1.33x \; 0.003 \; x \; 100}{g}$ ……………………………… (2)

Where: B = Titration volume (Blank)
T = Titration volume (Sample)
M = Molarity of Fe solution
g = Weight of sample

2.3.5 Determination of Total solids

Total solids is made up of digestible and non digestible material in the waste. Maynell method [10] is used. 3g of the raw waste is dried in an oven at105^{o}C for 5 hours. The dried sample is then cooled in a dessicator and then weighed. The weight after all moisture loss is the total solid.

% Total solids (TS) = $\frac{B-C}{g} \; X \; \frac{100}{1}$ ……………………………….. (3)

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

2.3.6 Determination of Volatile solids

The method of Meynell method [10] is used.

2.4 Experimental Design and Procedure

The slurry was prepared by weighing 90kg using a “Five Goats” brand model Z059599 weighing balance which was graduated in imperial and metric scales of 0-110Lb and 0-50kg respectively. Each weighed sample was poured into a small drum. Tap water weighed at 191kg was added to the waste inside the drum in the ratio of 1:2 (waste to water). The slurry was fully stirred manually with a piece of wood until there were no lumps. The waste was transferred to the FRP and metal bio-digester. The digester was stirred occasionally with the built-in stirrer that was attached to the digester. Subsequent stirring followed to prevent scum formation at the surface of the slurry and to free trapped gases in the bio-digester. The temperature of the slurry was observed daily through the thermocouple that was inserted into the FRP digester. The pressure of the gas produced was monitored daily using the pressure gauge that was fixed on top of the digester. The pressure gauge (a VDO pressure gauge) which ranges from 0-0.25 bars was used. Volume measurements of biogas produced was done by water displacement. The method used was adopted from Ezeoha and Idike [11]. The biogas collector and measurement unit used consisted of a graduated 20 litre transparent jerry-can and a water trough. Pressure in the digester tends to displace a given volume of water in the jerry-can; the water displaced enters the water trough, the volume of water displaced is the volume of gas produced. The experiment was conducted at ambient room temperature without any form of temperature regulation, pH adjustment, pretreatment of substrates, etc. Biogas production was monitored and measured for forty five days. Figure 1 shows the FRP and metal digesters.

Figure 1: FRP and Metal Digesters

2.5 Statistical Analysis

Charts and line graphical analysis is used to show the comparism of temperature (ambient and slurry), pH, biogas volume between the metal digester and the FRP digester. T-test statistical analysis was carried out on the data generated using SPSS 17.0 version

III. RESULTS

3.1 Physiochemical properties

The physiochemical analysis are shown in Table 1;

Table 1: Physico-chemical characteristic of the waste

Parameters	Metal digester Analysis (%)	FRP digester: Analysis (%)
Ash	0.79	0.9
Volatile solid (VS)	11.35	9.86
Total solid (TS)	30.96	34.5
Moisture	94.00	96.08
Carbon	6.98	5.10
pH	8.01	7.92
Nitrogen	0.26	0.17
Total Ammonia (mg/g)	3.94	4.2

Determination for total solids of waste is an effective way of finding out the amount of nutrient that will be available for bacterial action during digestion. The total solids in this study are within the range for biogas production when compared with [12]. The amount of methane to be produced depends on the quantity of volatile solid that is the amount of solids present in the waste and their digestibility or degradability. Again, the volatile solids are within the range for biogas production [12]. Higher ash content also corresponded with higher volatile solids content as can be seen from Table 1.

3.1.1 Biogas Production

For the 45 days of digestion, the cumulative gas produced was $2.28m^3$ for the metal digester and $1.33m^3$ for the FRP digester. Figure 2 shows the volume of biogas produced in the two digesters.

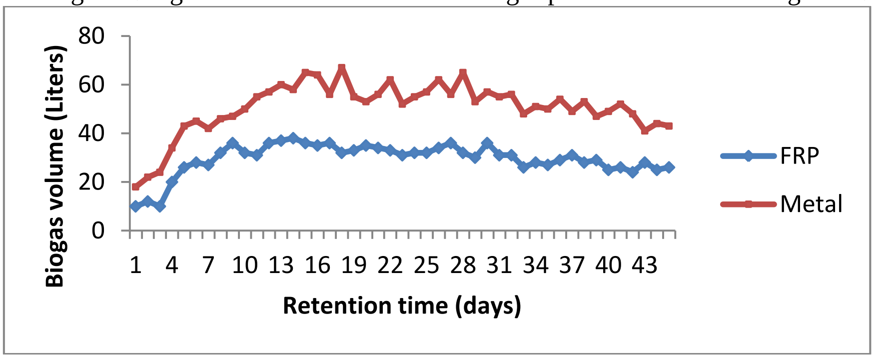

Figure 2: Daily Biogas Production

From the Figure 1, it can be seen that the biogas volume of the metal digester is clearly higher than the FRP digester. This may be attributed to the fact that metal conducts and retains more heat than plastic therefore the metal digester was able to produce more biogas than the FRP digester.

To compare the biogas volume of the two digesters, t-tests (two-tailed, equal variance) were performed as shown in the Table 2 and Table 3:

Table 2: Group Statistics of Biogas Volume

	Digesters	N	Mean	Std. Deviation	Std. Error Mean
GAS	METAL	45	50.5778	10.55610	1.57361
	FRP	45	29.4667	6.49335	0.96797

Table 3: T-Test Results of Biogas Volume

		F	Sig.	t	df	Sig. (2-tailed)
Gas	Equal variances assumed	5.241	0.024	11.427	88	0.000
	Equal variances not assumed			11.427	73.127	0.000

There is a significant difference in the biogas volumes for the metal digester (M=50.5778, SD=10.55610) and biogas volume for the FRP digester (M=29.4667, SD =6.49335) conditions; t (73.127), p = 0.000. These results suggest that biogas volume for the metal digester is significantly different from the biogas volume of the FRP digester. This may be attributed to the fact that metal conducts and retains more heat than plastic therefore the metal digester was able to produce more biogas than the FRP digester, and also the ammonia inhibition/toxicity of the poultry waste.

3.1.2 pH

The pH for the production of the biogas was from 7.92 – 9.57 for the FRP digester and 8.01 – 9.67 for the metal digester as shown in Figure 3.

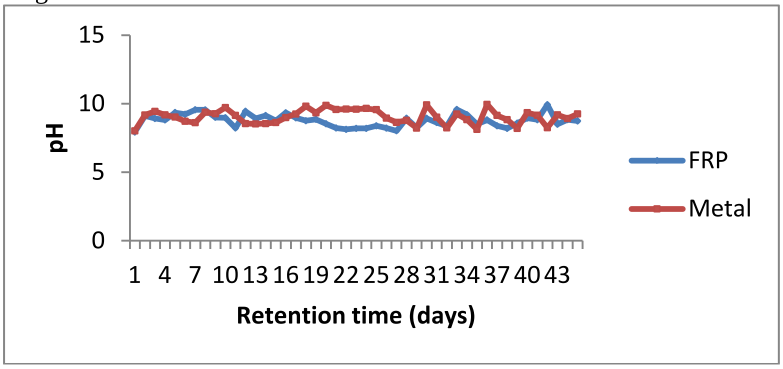

Figure 3: Changes in pH During Fermentation

To determine if the pH of both bio-digesters were similar, t-tests (two-tailed, equal variance) were performed as shown in the Table 4 and table 5

Table 4: pH Group Statistics

	PH GROUPS	N	Mean	Std. Deviation	Std. Error Mean
PH	METAL	45	9.0467	0.51659	0.07701
	FRP	45	8.7687	0.47239	0.07042

Table 5: T-Test Results of pH

		F	Sig.	t	df	Sig. (2-tailed)
Gas	Equal variances assumed	0.492	0.485	2.664	88	0.009
	Equal variances not assumed			2.664	87.305	0.009

There is a significant difference in the pH for the metal digester (M=9.0467, SD=0.51659) and pH for the FRP digester (M=8.7687, SD=0.47239) conditions; t (2.664), p = 0.009. These results suggest that pH for metal is significantly different from FRP.

Many research works on anaerobic digestion of waste, have shown that pH of digestate has strong influence on the rate of production and yield of biogas by the substrate. The methanogenic bacteria are known to be very sensitive to pH. The most favorable pH values given by various researchers seem to vary. Jash and Ghosh [13] reported a favourable pH range of 6.6-7.8 for methanogenic bacteria. Another study by Yadvika, et al. [14] reported a favorable pH range of 6.8-7.2 for anaerobic digestion. Ngozi-Olehi et al. [15] researched on biogas potential of cow dung, poultry droppings and domestic waste using laboratory-scale digesters operated to study the effect of varied conditions of pH, and temperature. The test result showed that gas yield from all systems was maximal in the pH range 6 – 8 (neutral/near neutral) and minimal at acidic (pH 5) and alkaline (pH 9) environments. The high pH value recorded in this study could be attributed to large ammonia losses resulting from C/N ratio of poultry waste [16]. It may also occur as a result of temporary presence of inhibitors and toxicants. Fluctuation in pH can be accommodated through proper control of temperature/loading rate and adequate mixing. However, effective and tight control of pH requires the availability of sufficient alkalinity to form buffer in the system

3.1.3 Temperature

Temperature, the nature of organic matter and its concentration were among the parameters that impacted the performance of the biogas plant. The inside digester temperatures as well as the ambient temperatures were monitored every day throughout the retention period. Optimum yield of biogas can be obtained with both mesophyllic (30 – 40^{0}C) and thermophilic (50 - 60^{0}C) processes. It was observed that both the metal and FRP digester temperatures fluctuated between 25^{0}C and 34.5^{0}C, while the daily ambient temperatures varied from 24.5^{0}C to 32^{0}C. Digester and ambient temperatures are presented in figure 4.

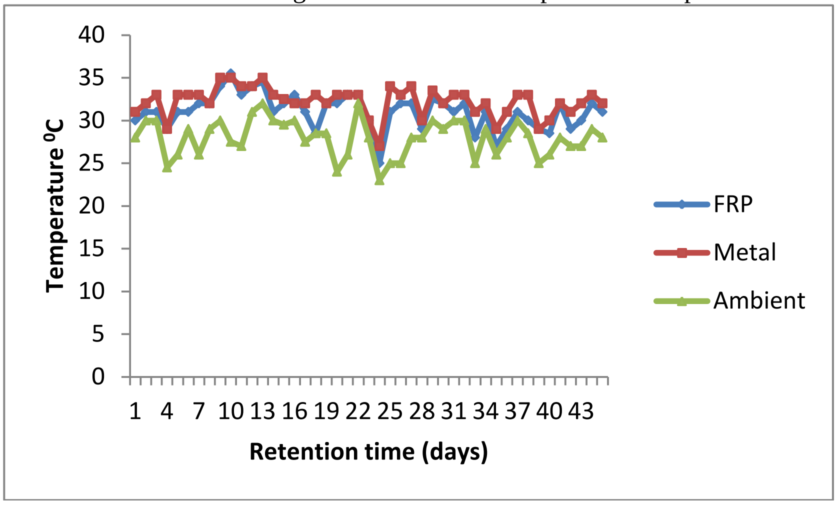

Figure 4: Temperature Variations During Fermentation

To determine if the temperatures were significantly similar, t-tests (two-tailed, equal variance) were performed as shown in the Table 6 and Table 7:

Table 6: Temperature Group Statistics

	TEMP GROUPS	N	Mean	Std. Deviation	Std. Error Mean
TEMPERATURE	METAL	45	32.222	1.6941	0.2525
	FRP	45	31.056	2.0063	0.2991

Table 7: T-Test Results of Temperature

		F	Sig.	t	df	Sig. (2-tailed)
Gas	Equal variances assumed	0.665	0.417	2.980	88	0.004
	Equal variances not assumed			2.980	85.597	0.004

An independent t-test was conducted to compare the temperatures of slurry for the FRP digester and metal digester. There is no significant difference in the slurry temperature for the metal digester (M=32.222, SD=1.6941) and slurry temperature for the FRP digester (M=31.056, SD=2.0063) conditions; t (2.980), p = 0.004. These results suggest that slurry temperature for the metal digester is significantly different from the slurry temperature of the FRP digester. This may be attributed to the fact that metal conducts and retains more heat than FRP. From the results obtained, anaerobic bacteria thrive best at a mesophilic temperature of about 37^{0}C.

Temperature has been observed by most workers to be quite critical for anaerobic digestion, since methane-producing bacteria operate most efficiently at temperatures 30.0 – 40.0ºC or 50.0 – 60.0ºC [17]. The temperature of relatively below 30^{0}C in which this experiment was conducted, during the rainy season of July to September, could have contributed to the slow development of methanogens and consequently low methane production. This is similar to the report of [17] that the recovery time for biogas production as well as the quality and quantity of biogas produced from agricultural materials are a function of the nature, and composition of the digester feedstock.

IV. CONCLUSION

A $0.35m^3$ bio-digester was constructed entirely with a light weight glass fiber reinforced plastic (FRP) material. A comparative study on the production of biogas from poultry waste was carried out in the FRP bio-digester as well as in a metal bio-digester of the same quantity. It has been found from the study that such parameters as temperature variations and pH values greatly affect the volume of biogas produced. The digesters were charged with poultry waste and water in the ratio 1:2. About 281 liters of the mixture or slurry were fed into each digester and stirring was done at least once a day for 45 days. The problem of rusting or corrosion which typically affects the production of biogas however was solved through the use of non corroding materials. For the 45 days of digestion, the cumulative gas produced was $2.28m^3$ for the metal digester and $1.33m^3$ for the FRP digester. The pH values of the slurry were observed to be between 7.92 to 9.57 for the FRP digester and 8.01 to 9.67 for the metal digester, while the temperatures of the slurry of both the metal and FRP digester temperature were observed to be between 25^0C and 34.5^0C, while the daily ambient temperatures varied from 24.5^0C to 32^0C. To determine if the parameters in the metal and FRP bio-digesters were similar, t-tests (two-tailed, equal variance) were performed. In conclusion, it was observed that temperature, pH and the biogas volume were all significantly different ($P \leq 0.05$) in both the FRP and metal bio-digester.

V. RECOMMENDATION

Utilization of fiber reinforced plastic (FRP) for biogas technology is no longer in doubt. With respect to this research work conducted, the following recommendations are made:

a) Digestion of poultry waste should not be undertaken in suboptimum environmental condition to avoid ammonia inhibition. Instead poultry droppings obtained from the farm should be digested with other substrates with high C/N ratio such as dry masses, crop residue, grasses etc to obtain maximum biogas production.

b) Further research on digestion of other wastes as well as co-digestion of animal waste in a FRP digester should be undertaken whenever possible because of its higher yield with respect to single substrate digestion and better digestion performance as previous studies have shown.

c) Further research can be carried out on the comparative study of the performance characteristics between biogas produced from a metal bio-digester, concrete bio-digester and FRP bio-digester.

REFERENCES

[1]. Mckendry, P., Energy production from biomass (part 2), *Conversion technologies. Bioresour. Technol. 83*, 2002, 47-54.

[2]. Itodo, I. N., Agyo G. E., Yusuf, P., Performance evaluation of a biogas stove for cooking in Nigeria*, J. Energy S. Afr., 18,* 2007, 14-18

[3]. Ezekoye V.A and Okeke C.E., Design, Construction, and Performance Evaluation of Plastic Biodigester and the Storage of Biogas, *The Pacific Journal of Science and Technology. 7*(2), 2006, 176-184

[4]. Eze S.I, Ofoefule A.U., Uzodinmma O.U., Okoroigwe E.C., Oparaku N.F., Eze J.I., Oparaku O.U., Characterization and performance evaluation of an $11m^3$ biogas plant, *Continental J. Renewable Energy 2* (1), 2011, 1-6

[5]. Mahmuda, M.M, *Design and Construction of $0.1m^3$ Batch Operated Portable Biogas Digester,* Unpublished M.Sc. Thesis,Ahmadu Bello University Zaria, 2011

[6]. Ocwieja, S. M., *Life cycle thinking assessment applied to three biogas projects in central Uganda.* Master's Report. Michigan Technological University, 2010.

[7]. A.O.A.C., *Official Methods of Analysis of Assoc. of Analytical Chemistry* (14th edn, Arlinton, Virginia, 1990)

[8]. Pearson D., *The chemical analysis of foods* (7th Edition. Churchill Livingstone. New York, 1976)

[9]. Walkey A., Black L. A., *J. Soil Sci*., 37, 1934, 29 – 38.

[10]. Meynell, P.L., *Methane: Planning a digester* (Prism Press.Stable Court, Chalmigton, 1982)

[11]. Ezeoha, S. L and Idike, F. I., Biogas production potential of cattle paunch manure, *Journal of Agricultural Engineering and Technology (JAET), 15*, 2007, 25-31.

[12]. Ofoefule, A. U, Uzodinma, E. O. and Anyanwu, C. N., Studies on the effect of anaerobic digestion on the microbial flora of animal wastes: Digestion and modelling of process parameters, *Trends in Applied Sciences Research. 5* (1), 2010, 39-47.

[13]. Jash, T. and Ghosh, D. N., Studies on the solubilization kinetics of solid organic residues during anaerobic biomethanation, *Energy. 21*(7/8), 1996, 725-730.

[14]. Yadvika, S., Sreekrishnan, TR., Kohil, S. and Rana, V., Enhancement of biogas production from solid substrates using different techniques: a review, *Bioresources Technology, 95*, 2004, 1-10.

[15]. Ngozi-OlehiL.C., Ayuk, A.A., Oguzie,E.E., Ejike, E.N., Ijioma, B.C., Kinetics of biogas potential from animal and domestic waste, *Report and Opinion.2,* (9), 2010, 17-21.

[16]. Gray, K.R., Sherman, K., and Biddlestone, A.J., In*: Process Biochem. 6*, Part 1 & Part 2, 1971.

[17]. Ilori O.M., Adebusoye A.S., Lawal A.K., Awotiwon A.O., Production of Biogas from Banana and Plantain Peels, *Adv. Environ. Biol., 1* (1), 2007, 33-38.