namely; Psychrophilic temperature (< 25°C), mesophilic (25-40°C) and thermophilic (45-60°C) (El Mashad, 2004).

Biogas technology amongst other processes (including thermal, pyrolysis, combustion and gasification) has in recent times also been viewed as a very good source of sustainable waste treatment / management, as disposal of wastes has become a major problem especially to the third world countries (Arvanitoyannis et al., 2007). The effluent of this process is a residue rich in essential inorganic elements like nitrogen and phosphorus needed for healthy plant growth known as biofertilizer which when applied to the soil enriches it with no detrimental effects on the environment (Bhat et al., 2001). The content of the biogas varies with the material being decomposed and the environmental conditions involved (Anunputtikul and Rodtong, 2004).

Potentially, all organic waste materials contain adequate quantities of the nutrients essential for the growth and metabolism of the anaerobic bacteria in biogas production. However, the chemical composition and biological availability of the nutrients contained in these materials vary with species, factors affecting growth and age of the animal or plant (Wolfe, 1971). Various wastes have been utilized for biogas production and they include amongst others; animal wastes, industrial wastes, food processing wastes, plant residues. Many are still being researched on as potential feedstock for biogas production. Plantain is commonly consumed in tropical countries like Nigeria. Apart from individual family consumers, it is also commercially traded on by sale in hotels and cafeterias. As a result, the peels abound as wastes and their disposal also poses a challenge to the consumers with the poor waste management system available especially in the developing countries. Utilizing the peels as feedstock for biogas production would provide a cheap source of energy while resolving the problem of waste management. Consequently, the need to explore its potentials for biogas production was exigent. An initial study carried out on biogas production from plantain peels alone showed that though it had the capability to produce biogas, however, the biogas production and gas flammability were not sustained due to the acidic nature of the waste slurry (Ofoefule and Ibeto, "Unpublished"). One treatment method for improving the biogas production potentials of various feedstocks is blending with animal and/or plant wastes (Mshandete et al., 2004, Adeyanju, 2008, Ofoefule et al., 2009). This study was therefore undertaken to investigate the biogas production potential of plantain peels when co-digested with some animal wastes. They were then combined as plantain peel and cow dung (PP: CD) and plantain peels and swine dung (PP: SD) in the ratio 1:1 while plantain peel alone (PP-A) served as the control.

MATERIALS AND METHODS

The plantain peels were obtained from commercial fried plantain dealers in Nsukka market and some from private homes. The Cow dung was obtained from an abattoir also in Nsukka town while the swine dung was procured from the veterinary farm, University of Nigeria Nsukka. The digesters for fermentation of the wastes were metal prototypes of 50L capacity constructed at the National Center for Energy Research and Development, University of Nigeria Nsukka (Fig.1). The study was carried out between January and February 2010 at the same Research Institute. Nsukka is located at (6.9°N, 7.4°E) and 445m above sea level. Other materials used were; Top loading balance (50kg capacity, "Five goats", model no Z051599), plastic water bath for soaking the peels, water trough, graduated transparent plastic bucket for measuring volume of gas production, thermometer (-10 to 110°C), digital pH meter (Jenway 3510), hosepipe and biogas burner fabricated locally for checking gas flammability.

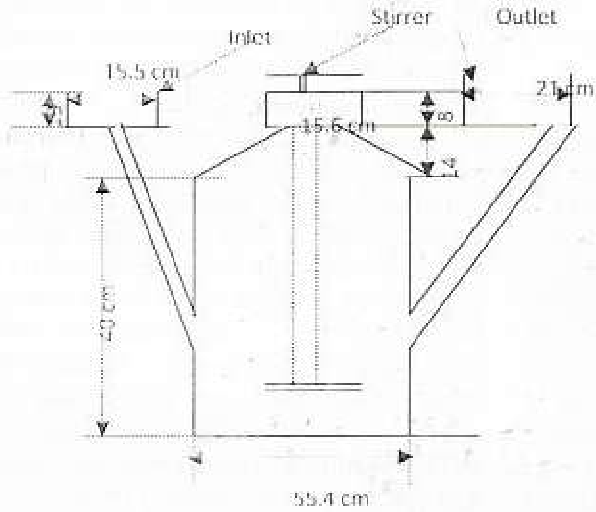

Fig. 1: Schematic diagram of the biodigester

Digestion Studies

Preparation of Wastes

The plantain peels was allowed to degrade for a period of two weeks for partial decomposition to aid faster digestion. It was then soaked in a plastic water bath overnight to allow for partial decomposition of the peels by aerobic microbes which has been reported to aid faster digestion especially for plant wastes (Fulford, 1998), and the pH was noted. For the PP-A, 8kg of the plantain peel was mixed with 27kg of water, while for the blends (PP: CD and PP: SD), 4kg of Plantain peel was mixed with 4kg each of the cow dung and swine dung separately giving a total of 8kg of wastes and they were then mixed with 27kg of water, all giving water to waste ratio of approx. 3:1. The moisture content of the wastes determined the water to waste ratio (Table 1).

Charging of Digesters

The different variants were charged into the 50L metal prototype digesters as originally weighed out. The wastes were charged up to ¾ of the digester leaving ¼ head space for collection of gas. The digester contents were stirred adequately and on a daily basis to ensure homogenous dispersion of the constituents of the mixture. Gas production measured in dm^3/kg. slurry was obtained by downward displacement of water by the gas.

Analyses of Wastes

Physicochemical analyses

Ash, moisture and fibre contents were determined using AOAC 1990 method. Fat, crude nitrogen and protein contents were determined using soxhlet extraction and micro-Kjedhal methods described in Pearson (1976). Carbon content was carried out using Walkey and Black (1934) method. Energy content was carried out using AOAC method described in Onwuka (2005), while total and volatile solids were determined using Renewable Technologies (2005).

Biochemical analysis

The pH of the plantain peels soaked in water was taken before charging of the waste while the ambient and influent temperatures of all the wastes were monitored daily throughout the retention period.

Microbial analysis

Total viable counts (TVC) for the wastes slurries were carried out to determine the microbial load or the population of the microbes of the samples using the modified Miles and Misra method described in Okore (2004). This was carried out at four different periods during the digestion; at the point of charging the digester, at the onset of gas flammability, at the peak of gas production and at the end of the retention period.

Statistical Analysis

The standard deviation was carried out using SPSS 15.0 version.

RESULTS AND DISCUSSION

The experiment was carried out under ambient temperature range of 26°C to 36°C and influent temperature of 32 to 42°C within a retention period of 44 days. The daily biogas production is graphically presented in Fig 2. The other digester systems commenced biogas production within 24 hr of charging the digester whereas the PP: SD commenced gas production from the 5th day (Fig 2). The onset of gas flammability took place at different lag periods (which is from the time of charging the digester to the onset of gas flammability) (Table 2). The plantain peels alone (PP-A) had the shortest onset of gas flammability of 1 day with low cumulative biogas yield. Even though, the lag period was short, the system drastically reduced gas production to almost nil after 5 days and throughout the retention period while the little gas produced was no longer flammable. Biogas that will satisfy the basic needs for cooking and lighting must be flammable. If it burns, it means that the methane content is at least 45%. If it does not burn, it means the methane content is less than 45% and contains mainly CO_2 and other gases (Anonymous, 2003). The PP had adequate physicochemical properties to effect reasonable biogas production (Table 1); however, this did not translate to a high yield of the gas. Physicochemical properties of wastes are the properties inherent in the wastes that enable them to produce biogas the way they do. Its ash content was higher than those of the blends. Ash content gives an indication of the mineral content of the waste showing that it would be a very good biofertilizer providing enough mineral sources to the soil. Its volatile solids (VS) (which is the biodegradable portion of the waste) was good enough and even higher than the PP: SD but lower than the PP: CD. The energy content was also higher than those of the blends, showing that it would be a very good feedstock for biogas production if properly utilized. Adequate physicochemical properties are known to favour effective and efficient biogas production (Anon, 1989). However the carbon to nitrogen (C/N) ratio was slightly higher than the optimum range given to be in the range of 20-30:1 (Dennis and Burke, 2001). This is because the microbes that convert wastes to biogas take up carbon 30 times faster than nitrogen. Even though the C/N ratio was slightly higher, it was not enough to have affected the performance of this waste so adversely. However, plant wastes are known to be difficult to biodegrade. This is because of the presence of lignin, cellulose, hemicelluloses, pectin and plant wax in the wastes (which are not easily broken down during the process of hydrolysis) with attendant acidic condition (Fulford, 1998). The microbes that convert wastes to biogas are sensitive to pH and survive optimally at pH range of 6.5 to 8.0 (Anon, 1989). This may have contributed to the poor performance of the waste. Blending PP with swine dung and cow dung improved the cumulative biogas yield by more than 100% and 360% respectively even though their onset of gas flammability were longer (Table 2). This is considered better since the gas flammability were sustained after they had set in and were still producing even beyond the chosen retention period. Cow dung and swine dung are reported to be a very good biogas producers and have been used in blending other wastes like agricultural and industrial wastes that are difficult to biodegrade (Ofoefule and Uzodinma, 2006; Uzodinma and Ofoefule, 2009). The blend with swine dung was very slow in gas production at the beginning and only picked up seriously from the 27th day. The C/N ratio was poor and fell below the optimum range required for effective biogas production. The energy content and nutrient (fat etc) were also lower. These factors may have contributed to the performance in terms of onset of gas flammability. Animal wastes are known to be good starters for the poorer producing ones since they are better biogas producers. They have also been used for optimizing biogas production for various plant wastes (Ofoefule and Uzodinma, 2006; Uzodinma and Ofoefule, 2009). However, blending the PP with swine dung did not improve appreciably the physicochemical properties of the waste but experienced a delayed onset of gas flammability which after it had set in, was sustained till the end of the retention period (Fig. 2). The blend with cow dung brought the C/N ratio within the optimum range needed for effective biogas production while improving the other physicochemical properties like the nutrients (fat and protein, volatile solids, energy etc as well as stabilizing the waste for sustained gas flammability throughout the retention period. The result of the microbial Total viable count (TVC) shows the progression of the microbes that converted the wastes to biogas (Table 3).

The microbial load started out lower, increased towards the peak of gas production and reduced towards the end of the retention period which shows the death curve of the microbes. Although the microbial load of the PP was higher at the beginning, the microbes could not survive much towards the end of the chosen retention period, therefore blending the waste with cow dung and even swine dung helped to sustain the microbes during the period of digestion.

CONCLUSION

The study has shown that plantain peels which is considered a nuisance and create environmental pollution have the potentials and capability to generate biogas but not on its own. Blending the peels with animal wastes tremendously improved the potential for biogas production by increasing the biogas yield, improving the sustained gas flammability and retention time. This is expected to help the rural populace access energy at cheaper rates. Apart from swine and cow dung, other animal wastes like rabbit, goat and poultry wastes can be utilized to optimize the biogas production of plantain peels.

Table 1: Physicochemical properties of the wastes

Parameters	PP-A	PP:CD	PP:SD
Moisture (%)	4.20	2.60	11.40
Ash (%)	43.70	31.75	36.60
Fiber (%)	16.20	32.60	20.10
Crude nitrogen (%)	1.46	1.43	1.46
Crude protein (%)	9.10	8.93	9.20
Fat content (%)	2.40	2.60	1.4
Total solids (%)	95.80	97.40	88.60
Volatile solids (%)	52.10	65.65	52.00
Carbon content (%)	47.88	27.78	23.94
Energy (Kcal/g)	4.19	3.54	3.45
C/N ratio	32.79	20.00	16.40
pH at charging	6.20	8.00	7.00

PP-A= Plantain peel alone, PP: CD= Plantain peel: cow dung (1:1), PP: SD= Plantain peel: swine dung (1:1).

Table 2: Lag period, cumulative and mean volume of gas production for the wastes

Parameters	PP-A	PP:CD	PP:SD
Lag period (days)	1	10	29
Cumulative gas yield (dm^3/kg. slurry)	2.26	8.06	4.50
Mean volume of gas production (dm^3/kg. slurry)	0.05±0.06	0.18±0.11	0.10±0.11

PP-A= Plantain peel alone, PP: CD= Plantain peel: cow dung (1:1), PP: SD= Plantain peel: swine dung (1:1).

Table 3: Total Viable Count for Pure and Waste blends (cfu/mL)

Period	PP-A	PP:CD	PP:SD
At the point of charging	$5.92x10^6$	$5.83x10^6$	$4.45x10^6$
At the point of flammability	$6.32x10^7$	$2.25x10^7$	$3.08x10^7$
At the peak of production	$6.32x10^7$	$5.56x10^7$	$6.78x10^7$
Towards the end of	$3.92x10^6$	$4.58x10^7$	$6.18x10^7$

production

PP-A= Plantain peel alone, PP: CD= Plantain peel: cow dung (1:1), PP: SD= Plantain peel: swine dung (1:1).

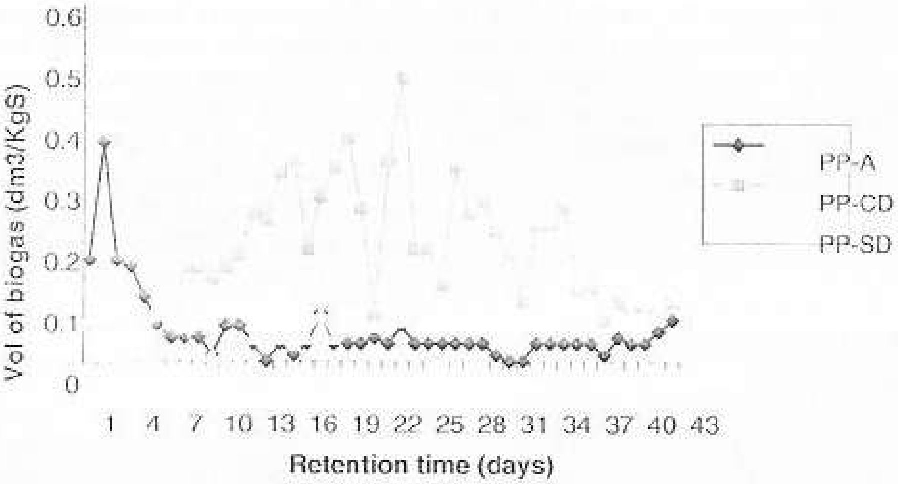

Fig 2: daily biogas production

REFERENCES

Adeyanju AA (2008). Effect of seeding of wood-ash on biogas production using pig waste and cassava peels. J. Eng. Appl. Sci. 3:242-245.

Anon (1989). A handbook of the Asian- pacific regional biogas research- training center. Biogas fermentation process adopted in China, 64p.

Anonymous. 2003. Waste Digester Design. University of Florida Civil Engineering. Retrieved 2003 from the World Wide Web: http:file//A:/Design.Tutor.htm.2003.

Anunputtikul W., Rodtong, S. (2004). Laboratory scale experiments for biogas Production fromcassava tubers. The Joint International Conference on "Sustainable Energy and Environmental (SEE)", Hua Hin, Thailand. 1-3 Dec, 2004. 238-243

AOAC (1990) Official Methods of Analysis: Association of Analytical Chemists 14th Ed.,Washington, USA, 22209.

Arvanitoyannis I S, Kassaveti A, Stefanatos S ——(2007). Current and Potential uses of thermally treated Olive Oil waste. Int. J. Food Sci. Tech. 42 (7): 852 – 867.

Bhat, P.R., Chanakya, H.N., Ravindranath, N.H., 2001. Biogas plant dissemination. J. Energy Sustainable Dev. 1: 39 – 41.

Dennis, A. and Burke, P.E. (2001). Dairy waste anaerobic digestion handbook. Environmental Energy Company 6007 Hill street Olympia, W.A 98516. 20p.

Edehlmann, W., A. Joss and H. Engeli. 1999. Two step anaerobic digestion of organic solid wastes. In 11 International symposium on anaerobic digestion of solid wastes. Eds., Mata Alvarez, J., A.Tilche and J.Cecchi (Eds). International Association of water quality, Barcelona, Spain. Pp: 150-153.

El- Mashad, H.M. G. Zeeman, W.K.P Vanloon, A.B, Gerard and G. Lettinga (2004). Effect of temperature and temperature fluctuations on thermophilic anaerobic digestion of cattle manure. Bioresource Technology., 95: 191-201.

Fulford D (1998). Running a Biogas Programme. A hand book. "How Biogas Works". Intermediate Technology Publication. 103-05 Southampton Row, London. WC 1B 4H, UK. Pp.33 – 34.

Kaygusuz, K. and Kaygusuz, A. (2002): Renewable energy and sustainable development in Turkey. Renewable

Energy, Volume 25, Issue 3, pp 431-453, doi:10.1016/S09601481(01)00075-1.

Mshandete, A., Kivaisi, A.K., Rubindamayagi, M., Mattiasson, B. 2004. Anaerobic batch co-digestion of sisal pulp and fish wastes. Bioresource Technology. 95: 19 24.

Ofoefule, A.U and Ibeto, C.N ("Unpublished"). Investigation of the biogas production capabilities of Plantain Peels.

Ofoefule, A U, Uzodinma E O, Onukwuli O.D. (2009). Comparative study of the effect of different pretreatment methods on biogas yield from water hyacinth (*Eichhornia Crassipes*). Int. J. Phy. Sci. 4(8): 535-539.

Ofoefule, A.U., and Uzodinma, E.O. 2006. Optimization of the qualitative and quantitative biogas yield from poultry waste. In Proceedings of the IX World Renewable Energy Congress. University of Florence. Italy. 19-25 August. UK: Elsevier Publishers.

Okore, V.C (2004). Laboratory Technique in pharmaceutics and pharmaceutical Microbiology (2nd Ed.) Nigeria: EI' Demark Publishers, pp 24-26.

Onwuka, G.I (2005). Food Analysis and Instrumentation (theory and practice). Nigeria: Naphtali prints. Pp. 95 – 96.

Pearson, D (1976). The Chemical Analysis of Food. (7th Edn.). Churchill Livingstone. New York, pp. 11-12, 14-15.

Renewable Technologies (2005). Standard formula for calculating total and volatile solids. Biogas FAO.

Uzodinma E.O and Ofoefule A.U.(2009). Biogas production from blends of field grass(Panicum maximum) with some animal wastes. Int. J. Phy. Sci. 4(2): 091-095.

Virendra, K.V. Biogas Technology: A Fit Option For Rural Energy. IIT Delhi. Accessed from http://web.iitd.ac.in/~vkvijay/Biogas%20Technology.ppt on 8th of October 2010.

Walkey, A. and L.A Black, (1934). An examination of the Degtjareff method for determining soil organic matter and proposed chromic acid titration method. J. Soil Sci. 37: 29 – 38.

Wolfe, R.S (1971). Methane generation from human, animal and agricultural wastes. National Academy press- Washington D.C. pp. 1-26.