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Alternative Energy Production for Environmental Sustainability

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Abstract:

The co – digestion of cow dung, with water hyacinth, and elephant grass for biogas production at laboratory scale was investigated. The study was carried out at a temperature range of 24ºC - 30°C and pH range of 5.08 – 6.96 for a period of 60 days with a total solid concentration of 7.4% in each of the digester sample (fermentation slurry). The biogas produced was collected by water displacement method which was subsequently measured. Digester 1, which consists of water hyacinth, elephant grass, cow dung and water, gave a biogas yield of 2.303 litres at the end of the 60 days of the experiment after which there was no further production. Digester 2, which is made up of elephant grass, cow dung, and water produced 2.1982 litres of biogas at the end of 60 days of the experiment after which there was no further production. Digester 3 is comprised of water hyacinth, cow dung, and water gave biogas yield of 2.112 litres at the end of the 60 days. It is suggested that the presence of the larger amount of both polycyclic aromatic hydrocarbon content and total aliphatic hydrocarbon content in the elephant grass makes it to give a higher yield in biogas produced as compared to water hyacinth. The net performance of the substrate is digester 1> digester 2> digester 3. The presence of the alkanes and methyl group makes the elephant grass to produce more biogas than water hyacinth as shown by the Fourier transform infrared spectroscopy (FTIR) that was carried out to identify the various functional groups. The GC analysis on the biogas produced showed 62% and 30.5% for methane (CH_4) and carbon dioxide (CO_2) respectively for digester 1, 57.09% and 35% for methane (CH_4) and carbon dioxide (CO_2) respectively in digester 2, and digester 3 gave 54% methane (CH_4) and 37% carbon dioxide (CO_2) respectively.

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1. Introduction

The growth in the world's population has resulted in an increase demand for energy; the world's energy supply has relied heavily on non – renewable fossil fuels, out of which about 90% is estimated as being consumed for transportation and energy consumption. This has now led the world to be presently confronted with double crisis of fossil fuel depletion and environmental degradation [1]. These depletion and environmental degradation gave a boost to the renewable and sustainable energy alternatives to the non – renewable fossil fuel. Water hyacinth and elephant grass are waste that can be transformed either by chemical and or biological means. Water hyacinth is recognized as a very aggressive species of aquatic plant, which grows very fast and eliminates other aquatic species in its composition [2]. In many places in Niger Delta area especially Delta State, Nigeria, water hyacinth continues to present daunting environmental and economic problems to the community. The biological process may be accomplished either aerobically or anaerobically, depending on the availability of oxygen. Biogas is a term used to represent a mixture of different gases produced as a result of the action of anaerobic micro – organisms on domestic and agricultural waste [3]. It usually contains 50% and above for methane and other gases in relatively low proportions namely, carbon dioxide (CO_2), hydrogen (H_2), nitrogen (N_2), and oxygen (O_2) [4, 5]. The mixture of the gases is combustible if the methane content is more than 50% [6]. Biogas production proceeds via three steps:

1. Hydrolysis: This is the stage at which organic polymers are converted into monomers (with the help of hydrolytic bacteria). $(C_6H_{10}O_5)n + n\ H_2O \rightarrow n(C_6H_{12}O_6)$

2. Acid formation (Acidogenesis): This involves conversion of monomers into simple compounds such as acetic acid, propionic acid, CO_2, NH_3, and H_2, using a group of acid forming bacteria (acetogenic bacteria).

$n(C_6H_{12}O_6) \rightarrow nCH_3COOH$

3. Methane formation: Involving conversion of simple compounds into methane CH_4 and CO_2, utilizing anaerobic [5]. $3nCH_3COOH \rightarrow nCH_4 + CO_2$. Anaerobic co-digestion is reported to offer several benefits over digestion of separate materials, such as increased cost-efficiency, increased biodegradation of the treated materials, as well as increased biogas production [7, 8].

Ekwenchi et al [9] investigated the possibility of obtaining gaseous fuel from fungal degradation of lignocelluloses from elephant grass at 33ºC using four cellulolytic fungi and a bacterium, which were harnessed from air, isolated in pure form and identified. The analysis of the gaseous products obtained showed that the biogas contained methane (CH_4), propane (C_3H_8), and carbon dioxide (CO_2). It was also found that the saturates content of the bio-liquid of the fermented slurry was very high with no polars at all while the bio-liquid of the unfermented slurring was rich in poly-aromatics with very little saturates. The research also revealed that two species of fungi, Curvularia Spp. and Penicillium, were responsible for the degradation. Ekpenyong et al [10] studied the biogas production potential of un-extracted nutrient – rich elephant grass. The work revealed that crushed un-extracted elephant grass straw is biodegradable by mixed microorganisms as effectively as by pure cultures. The work also showed that support with potato dextrose agar as well as nutrients such as urea is essential for attaining substantial gas yield. Co-digestion is the simultaneous digestion of more than one type of waste in the same unit [6]. Advantages include better digestibility, enhanced biogas production / methane yield arising from availability of additional nutrients, as well as a more efficient utilization of equipment and cost sharing [11, 12]. Results of co – digestion of food waste and dairy manure in a two – phase digestion system conducted at laboratory scale showed that the gas production rate of co – digestion was enhanced by 0.8 – 5.5 times as compared to the digestion with dairy manure alone [13]. Temperature has a significant effect

on digestion rate with most processes occurring at temperatures in the mesophilic temperature range 75 – 100ºF, but anaerobic digestion also can be carried out at the thermophilic temperatures (125 – 140ºF). It is well known fact that the thermophilic is more efficient than the mesophilic in terms of retention time, loading rate, and nominal biogas production but it needs a higher energy input, more expensive technology, and greater sensitivity to operating and environmental variables, which makes the process more problematic than mesophilic digestion [1]. Biogas is a promising alternative source of energy to Nigerians compare to the high cost of energy from fossil fuel that is available to the common man in Nigeria and non-availability of this fossil fuel energy source.

It is environmentally friendly and cheap to produce by almost every Nigerian. This work was carried out to study the comparative yields of biogas produced with co – digestion of cow dung using water hyacinth and elephant grass in mesophilic condition.

2. Materials

The water hyacinth was harvested from a river in Ibrede community in Delta State while elephant grass was gotten from bushes around Ozoro community in Delta State. Cow dung was procured from government approved Abattoir in Agbarho, Delta State.

Sodium chloride (NaCl), tetra oxo sulphate (VI) acid (H_2SO_4), Buckner flask (500 ml), conical flasks (500 ml), mercury in glass thermometer (range between -10ºC – 100ºC, with a an accuracy of ±0.1ºC), digital pH meter (HANNA model pH – 211), distilled water, delivery tubes, corks, measuring cylinder (200 ml), muffle furnace, Oven (Genlab oven model, Mino/75/f), connecting tubes, mortar and pestle and weighing balance (model BH 600) with an accuracy of 0.01 g were used for the biogas produced

3. Characterization of Substrates

3.1. Pre –Treatment of Both Substrates

Both water hyacinth and elephant grass were sun dried for three days to remove moisture from them and thereafter oven dried at 110ºC for 8 hours. It was then grinded and sieved into small particle size <106 µm.

3.2. Determination of pH

A measured quantity of the sample slurry was transferred into a beaker. The slurry was agitated and left for 24 hours at room temperature. The pH meter (HANNA model pH – 211) was then used to measure the slurry pH [14].

3.3. Determination of Moisture Content

10 g of the pretreated sample was weighed initially in petri dish which was placed in an oven at 110ºC. The weight was taking after every 10 minutes until a constant weight was obtained (final weight). The moisture content was determined by using the formula below;

$$\%\text{Moisture content} = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100$$

The moisture content was determined using standard test ASTMD 2867 – 91 [15].

3.4. Determination of Volatile Matter

5 g of the samples were weighed initially in petri dishes and placed in a muffle furnace at 500ºC for 4 hours. The samples were allowed to cool down in a desiccator and re – weighed again. The lost in weight is now the volatile matter present in the samples.

3.5. Determination of Saturated Hydrocarbons

3.5.1. Total Digestion for Heavy Metals

1 g of pretreated substrate samples were passed through 2 mm sieve with foil paper and transferred to 250 ml conical flasks. Measured volume of well mixed perchloric acid, nitric acid (HNO_3), and sulphuric acid (H_2SO_4) in the ratio 1: 2: 2 were poured into the flask containing the samples in the fume chamber. This was heated for about (15 – 20 min) on a hot plate until a white fume is observed. It was then cooled followed by the addition of 20 ml of distilled water and boiled to bring the metal into solution. The resulting solution is filtered with a Whatman 42 filter paper after cooling. The filtrate is now analyzed with Atomic Absorption Spectrometer model (Varian Spectra AA – 200).

3.5.2. Total Petroleum Hydrocarbon

10 g of each sample was weighed and added to 30 ml mixture of (dichloromethane and acetone). The mixture is shaken vigorously and poured into a separating funnel. 5 ml of top extract was poured into the rotary evaporator to heat. 1ml is placed into the column chromatograph followed by the addition of 30 ml dichloromethane till a pure liquid is obtained. This is then heated again in a rotary evaporator. 2 ml of the heated pure liquid is transferred into a vial bottle for gas chromatography analysis (GC System 5890 series).

3.5.3. FTIR Spectroscopy

The substrates were examined using Buck scientific infrared spectrophotometer model 530 with the range 500 – 4000 cm^{-1} (wavelength). Potassium bromate (KBr) was used as a background material in the analysis.

4. Experimental Procedure

All the apparatus made used in this study were washed properly with distilled water, soap solution, and allowed to stand overnight in the laboratory. A set of three Buckner flasks (500 ml) was used as bio-digester. The biogas produced was measured through water displacement method. Another three set of Buckner flasks (500 ml) were used with each containing an acidified brine solution and each was connected to a particular digester by means of connecting tube. The biogas produced in the digester by fermented slurry (sample) passed through the connecting tube to the Buckner flask containing acidified brine solution. The pressure of the biogas produced caused a displacement of the acidified brine solution through the connecting tube on the other side of the conical flask. The amount of water displaced was then measured as the volume of biogas produced. 7.4% total solid concentration was used in each of the digester. The digester was operated at ambient temperatures. The first digester which consists of water hyacinth, elephant grass, cow dung and water were mixed together by mass ratio 5 g: 5 g: 10 g: 250 g respectively. The second digester which is made up of elephant grass, cow dung, and water were mixed together by mass ratio 10 g: 10 g: 250 g respectively. The third digester is comprised of water hyacinth, cow dung, and water that were mixed in the proportion 10 g: 10 g: 250 g in mass ratio respectively. The slurry was stirred manually, and readings taken within two days interval while temperature reading was taken in the morning and evening throughout the period of the study. The experimental set – up used in the current analysis is shown in Figure 1.

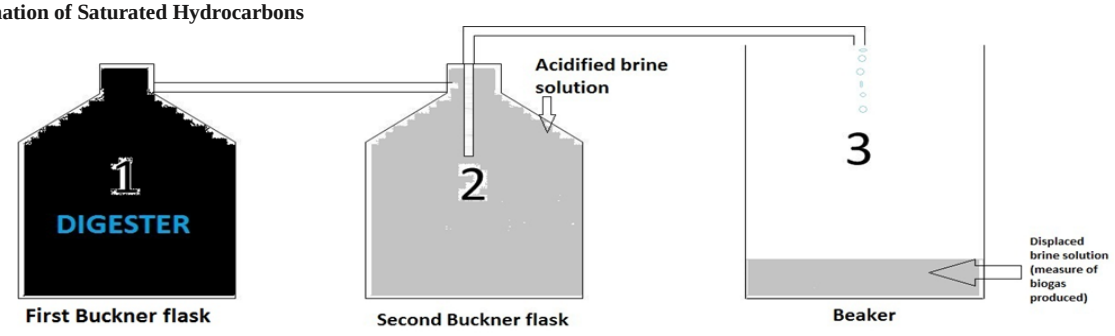

Figure 1: The experimental set – up for the biogas production

5. Results and Discussion

The concentration of heavy metals in these substrates is shown in Table 1. It indicates that concentration of the heavy metals as present in minute quantities shows that the residue of the fermentation can be used as bio-fertilizer for agricultural land and that it is not detrimental to the human and environment. The presence of the total aliphatic hydrocarbon in both samples indicates that biogas can be produced from the two samples. The larger proportion of total aliphatic hydrocarbon and polycyclic aromatic hydrocarbon in elephant grass suggest it to be a good source of biogas compared to the water hyacinth. The presence of the heavy metal in minute quantities also enhances the performance of the microorganism during methanogenesis stage of production.

Table 1: Characterization of Elephant Grass and Water Hyacinth

Properties	Elephant grass	Water hyacinth
Moisture content (%)	0.197	0.2
Volatile matter (%)	5.28	5.20
pH	5.71-6.92	5.96-6.96
Particle size	<106 µm	<106 µm
Aliphatic	0.7381	0.5519
Copper (ppm)	<0.001	<0.001
Cadmium (ppm)	0.101	0.2
Temperature (°C)	24 – 30	24 – 30
Zinc (ppm)	<0.05	<0.05
Lead (ppm)	<0.001	<0.001
Arsenic (ppm)	<0.05	<0.05
Nikel (ppm)	<0.01	<0.001
Polycyclic Aromatic Hydrocarbon content (mg/kg)	0.0108	0.0095
Total Aliphatic Hydrocarbon (mg/kg)	0.7489	0.5614

6. Fourier Transform Infrared (Ftir) Analysis

6.1. Water Hyacinth

It is seen in Figure 2 that the broad band with frequency (3251.402 – 3519.133 cm^{-1}) exhibited RO – H (Alcohol) wide branded band while the broad band (2655.519 – 2792.539 cm^{-1}) exhibited aldehyde (C – H) bending. C = O huge band was shown in broad band (1626.748 – 1845.781 cm-1). Alkene (RC = CH2) was revealed at broad band 923.3814 cm^{-1} [12]. Methyne C – H stretch was seen in broad band (2792.539 cm^{-1}) while methylene C – H band was shown in broad band (1462.563cm^{-1}). The highest peak with frequency 2655.519 cm-1 suggests that C – H bending is the main functional group in the water hyacinth.

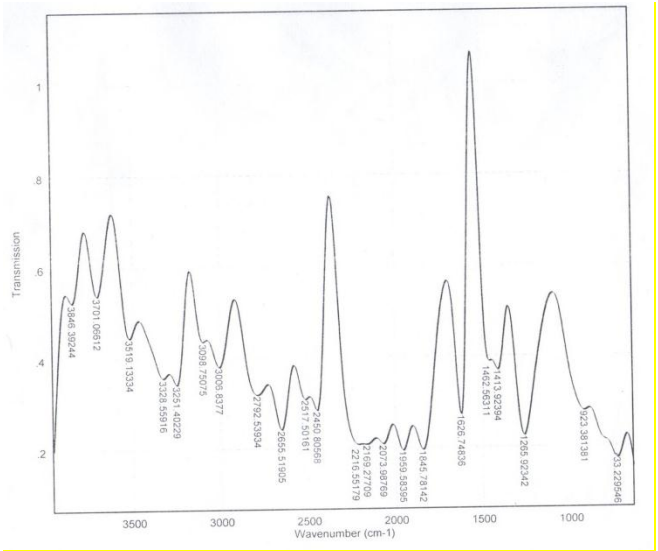

Figure 2: FTIR Spectra of Water Hyacinth

6.2. Elephant Grass

As shown in Figure 3 that the RO – H (Alcohol) wide branded band was shown with frequency (3337.265 – 3579.631 cm^{-1}). COO – H (carboxylic acid) group very wide band was shown with frequency (2538.129 Cm^{-1} and 2746.307 cm^{-1}) while 1622.158 cm^{-1} and 900.037 cm^{-1} frequency corresponds to C = C (alkene) group. The methyl functional group (- CH3) was exhibited by broad band 2285.852 cm^{-1} and 900.037 cm^{-1} while SP3, C – H band was shown in 3020 cm^{-1} frequency. 2877.503 cm^{-1} shows alkanes CH3 bands [16]. The presence of the alkanes and methyl group makes the elephant grass to produce more biogas than water hyacinth.

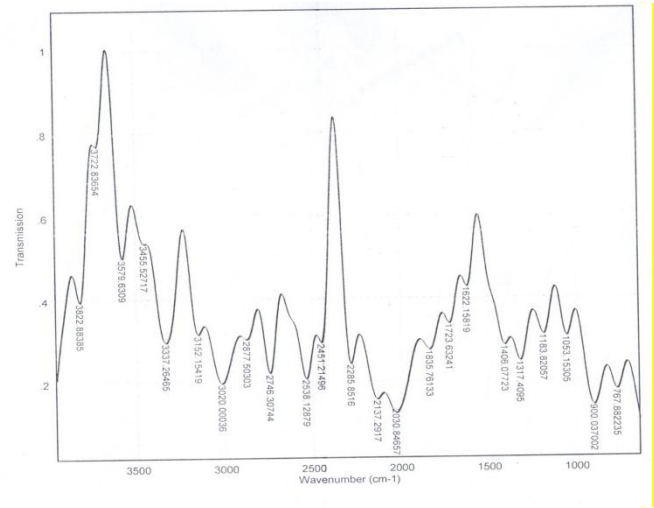

Figure 3: FTIR Spectra of Elephant grass

Ezeonu et al [3] reported that the mixture of the gases is combustible if the methane content is more than 50%. It is seen in Table 2 that the biogas produced is combustible with the methane (CH_4) concentration above 50% for all the digesters. Figure 4 showed the biogas produced from the three digesters for 60 days of fermentation.

Table 2: Gas Chromatography Analysis of the Biogas produced

Compositions (%)	**Digester 1**	**Digester 2**	**Digester 3**
CH_4	62.00	57.09	54.0
CO_2	30.50	35.00	37.00
NH_3	1.50	1.00	1.80
H_2S	2.20	2.10	2.70
O_2	0.30	0.40	0.10
N_2	2.40	3.27	2.10
H_2O	1.10	1.14	2.30

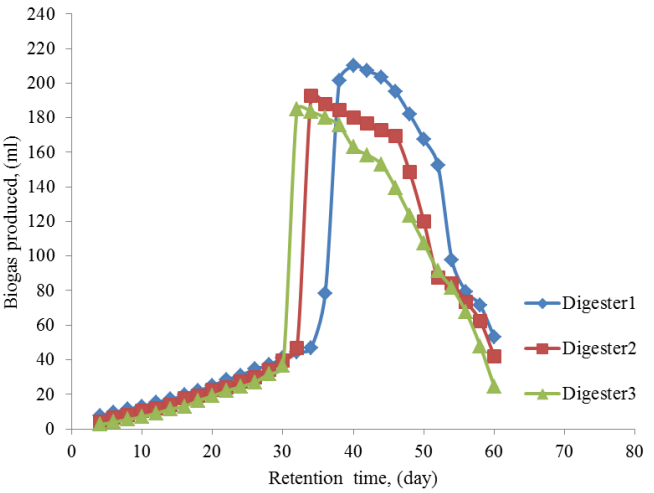

Figure 4: Biogas produced with retention time

There was no production in the three digesters for the first three days of fermentation this can be explained as a result of the inoculum is either in the lag phase or methanogens undergoing a metamorphic growth process by consuming methane precursors produced from the initial activity as reported by [17]. Production started on the 4th day for all the three digesters with a volume of 7.5 ml, 4 ml, and 22.5 ml for digesters 1, 2, and 3 respectively. There was a steady increase in biogas production till there was a sudden increase in biogas production for all the three digesters within a

retention time of 32 – 40 days. Digester 1 had a maximum volume of gas on the 40th day which was 210 ml, digester 2 produced a maximum volume of 192.5 ml on the 34th day and digester 3 produced 185 ml on the 32nd day. This sudden increase is as a result of an exponential increase in micro – organism which leads to an increase in fermentation rate and corresponding increase in biogas production. Thereafter, the volume of production decreased due to the variation of fermentative bacteria counts methanogen bacteria with pH and temperature until the 60th day when production finally stopped. This reduction is as result of the decreased in the fermentable micro – organisms in the digesters. The initial pH for the slurry in the digesters is 6.8, 6.92, and 6.96 for digester 1, 2, and 3 respectively. The value of the pH decreased for all the three digesters throughout the period of biogas production. This can be explained as a result of the volatile fatty acid (VFA) that is produced by the acid forming bacteria resulting in declining pH and reducing the methanogens produced from the methanogenic bacteria during the methanogenesis stage of production. It is suggested that a low pH value in activated micro – organisms are responsible for biogas production. The net performance of digesters in terms of biogas yield is digester 1 > digester 2 > digester 3.

As shown in Figure 5 the slurry temperature range of 24ºC – 30ºC was observed during the process of fermentation. The highest volume of biogas was observed for all the three digesters at temperature of 24ºC.

Ukpai et al [18] reported that ambient temperature affects the rate of digestion due to the outside walls of the digesters surface making direct contact with the atmosphere. The digester walls absorb or loose heat depending on the temperature gradient between the digester and its immediate environment. This indicated that seasons affect the rate of heat loss or gain from the digester which in turn affects the microbial activities in the slurry at each stage of fermentation.

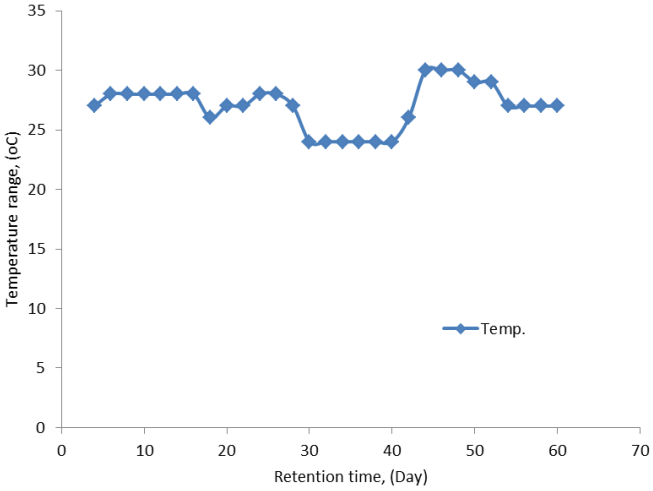

Figure 5: Temperature variation with retention time

The pH of values for all the three digesters decreased as retention time increases as depicted by Figure 6. It shows that at the beginning of the biogas production, acid forming bacteria during acidogenesis produces the volatile fatty acids that results in declining of pH and thereby diminishes the growth of methanogenic bacteria (methanogenesis) and methanogens corroborating the work of [19]. It shows that a low pH value inactivated microorganisms were responsible for the biogas production as observed in three digesters.

7. Conclusion

Anaerobic digestion of elephant grass, and water hyacinth inoculated with cow dung for biogas production was established in this work. The co-digestion of water hyacinth and elephant grass gave a higher yield in biogas production. The highest methane content of 62% was obtained in digester 1. It was shown that the variation in temperature, pH, and retention time had effect on the yield in volume of biogas production. The presence of alkanes and methyl group in elephant grass makes the elephant grass to be a good substrate for biogas production compared to water hyacinth. The net performance of the digesters are digester1 > ddigester2 digester3. The residue of this anaerobic digestion retains a rich fertilizer value of the initial plant waste products.

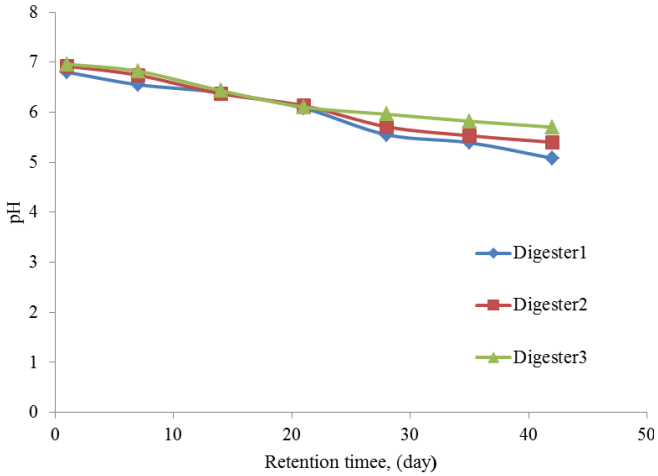

Figure 6: pH variation with retention time

References

[1] M. O. Aremu, S. E. Agarry: Comparison of Biogas Production from Cow Dung and Pig Dung under Mesophilic Condition, International Refereed Journal of Engineering and Science, 1(4), 16 – 21, 2012.

[2] L. G. Holm, D. L. Plucknett, J. V. Pancho, J. P. Herberger: The World's Worst Weeds: Distribution and Biology, Honolulu, University press of Hawaii, 609, 1977.

[3] S. O. Ezeonu, I. J. Dioha, A. N. Eboatu: Daily Biogas Production from different wastes and identification of methanogenic bacteria Involved, Nigerian Journal of Solar Energy, 15, 80 – 85, 2005.

[4] V. C. Kalia, V. Sonakya, N. Raizada: Anaerobic Digestion of Banana Stems Waste, Bio-resource Technology, 73, 191 – 193, 2000.

[5] E. T. Iyagba, I. A. Mangibo, Y. S. Mohammad: The Study of Cow Dung as Co-substrate with Rice Husk in Biogas Production, Scientific Research and Essay, 4(9), 861 – 866, 2009.

[6] J. C. Agunwamba (2001): Waste Engineering and Management Tool, Immaculate Publication Limited, Enugu, Nigeria.

[7] A. Lehtomaki, S. Huttunen, J. A. Rintala: Laboratory Investigations on Co-digestion of Energy Crops and Crop Residues with Cattle Manure for Methane Production: Effect of Crop to Manure Ratio, Resources, Conservation and Recycling, 51, 591–609, 2007.

[8] E. Neczaj, J. Bien, A. Grosser, M. Worwag, M. Kacprzac: Anaerobic Treatment of Sewage Sludge and Grease Trap Sludge in Continuous Co-digestion, Global Nest Journal, 14 (2), 141-148, 2012.

[9] M. M. Ekwenchi, B. U. Akunwanne, N. R. Okeke, Ekpenyong K. I. Ekpenyong: Gaseous Fuel Production by Fungal Degradation of Elephant-grass, Fuel, 69, 1569-1572, 1989.

[10] K. I. Ekpenyong, Arawo, J. D. E. Arawo, A. Melaiye, M. M. Ekwenchi, H. A. Abdullahi: Biogas Production Potential of Unextracted, Nutrient–rich Elephant-grass Lignocellulose, Fuel, 74 (7), 1080-1082, 1995.

[11] W. Parawira, M. Murto, R. Zvauya, B. Mattiasson: Anaerobic digestion of solid potato waste alone and in combination with sugar beet leaves: Renewable Energy, 29:1811 – 1823, 2004.

[12] A. M. Mshandete, W. Parawira: Biogas Technology Research in Selected Sub-Saharan African Countries A Review, African Journal of Biotechnology, 8,116 – 125, 2009.

[13] H. M. El – Mashad, Zhang, R. Zhang: Co-digestion of Food Waste and Dairy Manure for Biogas Production, Transaction, ASABE 50, 1815 – 1822, 2007.

[14] P. A. Philadelphia: American Society for Testing and Materials: Annual Book of ASTM Standard, Volume 15.01, Refractories, Carbon and Graphic Products, Activated Carbon, ASTM, 1996.

[15] P. A. Philadelphia: American Society for Testing and Materials: Standard Test Methods for Moisture in Activated Carbon,: ASTM Committee on Standards, 1991.

[16] J. Coates: Interpretation of Infrared Spectra: A Practical Approach, in Encyclopedia of Analytical Chemistry, Meyers, R. A., (Ed.), John Wiley and Sons Ltd., Chichester, 10815 – 10837, 2000.
[17] K. Lalitha, K. R. Swaminathan, R. P. Bai: Kinetics of Biomethanation of Solid Tannery Waste and the Concept of Interactive Metabolic Control, Applied Biochemical Biotechnology, 47:73 – 87, 1994.
[18] P. A. Ukpai, M. M. Nnabuchi: Comparative Study of Biogas Production from Cow Dung, Cow Pea, and Cassava Peeling Using 45 Litres Biogas Digester, Advances in Applied Science Research 3(3), 1864 – 1869, 2012.
[19] M. Vicenta, G. Pacheco, M. L. A. Alamis, P. G. Anglo, B. V., Tan, C. M. Silverio: A Study of some Factors Affecting Biogas Production from Pineapple Peelings, In: Bidin., R., Chong, C. N., Wang, C. W., (Eds), Proceedings of the second ASEAN Workshop on Biogas Production Applied to the Management and Utilization of Food Waste Materials, Kaula Terengganu, Malaysia, 189 – 202, 1984.