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Reducing the Hydraulic Retention and Lag Times for the Degradation of Simulated Organic Fraction of Municipal Solid Wastes Using Carbon to Nitrogen Ratio Proportioning

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ABSTRACT

The hydraulic retention time (HRT) and the lag time for the complete degradation of manually sorted, size reduced simulated organic fraction of municipal solid wastes (OFMSW) was dramatically reduced to 15 days and 17 hours respectively via the anaerobic co-digestion of the simulated OFMSW with cow dung (CD) and poultry droppings (PD) via mixing of the two substrates to achieve literature reported optimum carbon to nitrogen ratio (C/N).
The process was conducted under ambient conditions and was achieved at a mesophilic digestion temperature range of 33.09 to 35.06^{o}C and a pH in the range of 7.37 to 7.57.
The Modified Gompertz equation was used to determine the gas evolution parameters by non-linear regression analysis and showed that 38% and 22% CD and PD respectively mixed with OFMSW to achieve a (C/N) of 30:1 improved gas production by 17% and 25% under ambient conditions.

Keywords *:* Carbon to nitrogen ratio, Co-digestion, Cow dung, Hydraulic retention time, Lag time, Municipal wastes, Poultry droppings.

1 INTRODUCTION

Municipal solid waste (MSW) management especially in cities is an enormous challenge confronting governments in many developed and developing countries consequent to increasing populations brought about by the mass migration of people from rural to urban areas, increase in economic activities, industrialisation as well as changing lifestyles of the people.

Environment Canada [1] and [2] reported that solid wastes create health problems which include pollution, global warming and climate change due to release of green house gases, increased disease incidence such as malaria, cholera, diarrhoea, dysentery, respiratory tract infection and other filth–related diseases. Other problems associated with solid waste accumulation include blockage of roads and drainage systems, flooding, automobile accidents, and are not pleasant to the eye, production of malodorous smells, block drainages and direct impairment of human health as explained by [3]. Similarly, [4] added breeding of flies and attraction of rodents which may cause zoonotic infections and loss of environmental aesthetics to the list above.

Thus, to prevent the negative impacts posed by municipal wastes and counter the ever increasing mountain of wastes especially in the cities of low and middle income countries, there is the need to find a commensurate, fast, safe and cost-effective waste disposal and treatment method.

The effective degradation of organic fraction of municipal solid wastes (OFMSW) ensures the conversion of a sizeable proportion of MSWs to useful products such as biogas and biofertilizer which are very useful since perhaps next to the challenge of waste accumulation and treatment comes the need for countries and governments to find an alternative energy source and food to cater for the ever growing populations and since as observed by [5], renewable energy is one of the most important factors to global prosperity as relying on fossil fuels as the main source of energy had lead to global climate change, environmental degradation and human health problems.

Biogas is an excellent alternative source of energy which according to [6] contains 50-75% CH_4, 25-48% CO_2 and other gases in small amounts and which is can be produced by the anaerobic co-digestion of biodegradable material such as manure, sewage, plant materials, and crop residues amongst others. Hartman [7] defined co-digestion as the anaerobic treatment of a mixture of at least two different waste types.

Kigozi *et al.,* [8] had listed a number of advantages of using OFMSW as a substrate for biogas production including its availability at little or no cost, as a means of environmental conservation, high total and volatile solid content as well as good quality of produced biogas, the co-digestion of OFMSW with other wastes offers several advantages in relation a balance of nutrients and adjusting the buffer capacity of the OFMSW.

Francesco *et al.*, [9] stated that temperature, pH, electrical conductivity, total organic carbon, total nitrogen, and carbon to nitrogen ratio (C/N) ratio are common factors that affect the biodegradation process. While [10] stated that the primary and controllable factors that affect the size of a biogas digester are the temperature, the Volatile Solids (VS) and the Hydraulic retention time (HRT).

For a batch anaerobic digester, [11] defined the retention time (RT) as the length of time volatile solids (VS) remain in the reactor while the solids retention time (SRT) is the average time microorganisms spend in the digester. Thus, essentially, hydraulic retention time (HRT) is the period slurry of the waste spends in the anaerobic digester and it is crucial because if the feed does not stay in the reactor long enough for the entire digestion process to take place, biogas will not be produced as reported by [12]. Notably, the SRT is the same as the hydraulic HRT for a completely mixed batch anaerobic digester.

Agulanna [13] reported that the lag time is the minimum time taken to produce biogas from a given waste sample or, time taken for bacteria to acclimatize to the waste degradation environment.

Lu and Ahring [14] observed that HRT is not only an easily controlled operational parameter, it is also a macro-conceptual time for the organic material to stay in the reactor for which if bigger than the growth rate of microbial cells in the reactor, the microbe will be washed out, and otherwise the microbe will be accumulated in the reactor. In the same vein, [8] reported that very short retention times lead to a condition where the active biogas bacteria are flushed out of the digester rendering the bacterial population unstable and most likely, inactive while a longer retention time implies larger digester and consequently, increased cost of the process and the possibility of malfunctions.

Also, [15] as well as [12] observed that HRT is the ratio of digester volume to the amount of manure added per batch. Hence, longer retention time requires large volume of the digester and hence more capital. [8]

Kigozi et al., [8] reported that in countries with colder climates, the HRT may go up to 100 days as compared to warmer climates where the values lie between 30-50 days. Mattocks [16] reported that the HRT has a range of 20 to 25 days while [11] reported that Hydraulic retention time usually varies from 10 to 30 days depending on the temperature. FAO [17] had reported that up to 35°C, a linear relationship exist between retention time and the digester temperature with higher temperatures resulting in lower retention times and vice versa.

National Engineering Handbook [18] reported that to obtain a mixture with a desired C/N ratio from two component parts X and Y, the equations to use are:

$$X_C a + Y_C b = C \qquad (1)$$

$$X_N a + Y_N b = N \qquad (2)$$

Where X_C is the carbon content of component X; *a* the mix proportion of component X;Y_C the carbon content of component Y;C the carbon content of mixture; X_N the nitrogen content of component X, Y_N the nitrogen content of component Y; *b* the mix proportion of component Y and, N the nitrogen content of mixture

Syaichurrozi and Sumardiono [19] reported that the modified Gompertz equation was developed by [20] to predict bacterial growth. Lo *et al.,* [21] found that for biogas evolution and accumulation simulations, the modified Gompertz plots showed better (higher R^2) correlation.

The modified Gompertz equation is usually applied on the assumption that the rate of biogas production in batch biodigesters is directly proportional to the specific growth rate of the methanogenic bacteria in the biodigester as reported by [20], [21], [22], [23], [24], [25] and [26].

Yusuf *et al.,* [27] and [13] presented the modified Gompertz equation in the following form:

$$B_t = B_{\max} \exp[-\exp\{\frac{R_b}{B_{\max}} e.(\lambda - t) + 1\}] \qquad (3)$$

Where B_t is cumulative of biogas produced (ml) at any time (t); Bmax, biogas production potential (ml); Rb = maximum biogas production rate (ml/day); λ is the lag time. That is the minimum time taken to produce biogas or time taken for bacteria to acclimatize to the environment (days) and t is the time of biogas production (days)

The constants B, R_b and λ can be determined using the non-linear regression approach with the aid of regression tools such as the SigmaPlot® [21], solver function in the Microsoft office Excel® ToolPak [27],the polymath software [28], the curve fitting tool in MATLAB® [13] and so on.

2 MATERIAL AND METHODS

2.1 Substrate collection and preparation

Substrates that were utilized in this research work included manually sorted, size reduced OFMSW collected and sorted from municipal Solid Wastes (MSW) which was collected from central dumpsites located in communities around the Ahmadu Bello University, Zaria, Nigeria using the stratified random sampling method as recommended by [29] following the guidelines of sampling methodology given by [30]. The sorted MSW was reconstituted to form the simulated OFMSW. The CD and PD used were collected from the National Animal Production Research Institute (NAPRI), Shika, Kaduna state, Nigeria. The OFMSW was prepared for the purposes of the experiment, proximate, ultimate and microbial analyses in accordance with the criterion outlined by [13].

2.2 Substrate analyses

Waste composition, moisture content, waste particle size, waste density, temperature and pH which are important factors that affect the extent and rate of degradation of wastes, were determined on the mixed components of the solid wastes using the procedure outlined in [31] and was carried out at the Chemistry Department, Ahmadu Bello University (ABU), Zaria, Nigeria and the Institute of Agricultural Research (IAR), ABU. Standard spread-plate dilution method described by [32] was adopted to identify the microbial contents of the simulated OFMSW, cattle dung and poultry droppings.
Each sample was mixed, and a suspension of one gram (dry weight equivalent) in ten millimetres of sterile water was prepared. One ml of the suspension was then diluted serially (tenfold) Identification of isolates was based on cultural, microscopic, and biochemical characteristics based on the procedure outlined in [33] with reference to [34].

2.3 Experimental design

The experiment for the anaerobic co-digestion of OFMSW with CD and PD was carried out at room temperature by mixing the substrates in proportions as obtained from the ultimate analysis and then the use of equations (1) and (2) to achieve literature reported optimum carbon to nitrogen ratio (C/N) of 30:1 as recommended by [35] , [36] and [37] making a digestion slurry via the addition and vigorous mixing of total solid with an equivalent amount of water needed for maximum production according to the method of [38] , [39] and as described by [40] as well [41]. The experiments were performed in three sets of laboratory scale, 4 litre slurry biodigesters in triplicates labeled A, B and C with compositions as shown in Table 1.

Table 1: Composition of biodigesters

Digester composition	OFMSW (kgVS)	CD (kgVS)	PD (kgVS)	Water (kg)
A				
62%OFMSW + 38% CD	0.992	0.608	-	1.6
B				
80% OFMSW + 20% PD	1.28	-	0.32	1.6
C				
100% OFMSW)	1.6	-	-	1.6

OFMSW; Organic fraction of municipal wastes, CD; cow dung, PD; poultry dung, VS; volatile solids

2.4 Experimental Set-Up

A total of nine digesters each of 4 litres working volume was employed as adopted and modified from [42] and [43] as shown in fig. 1 below.

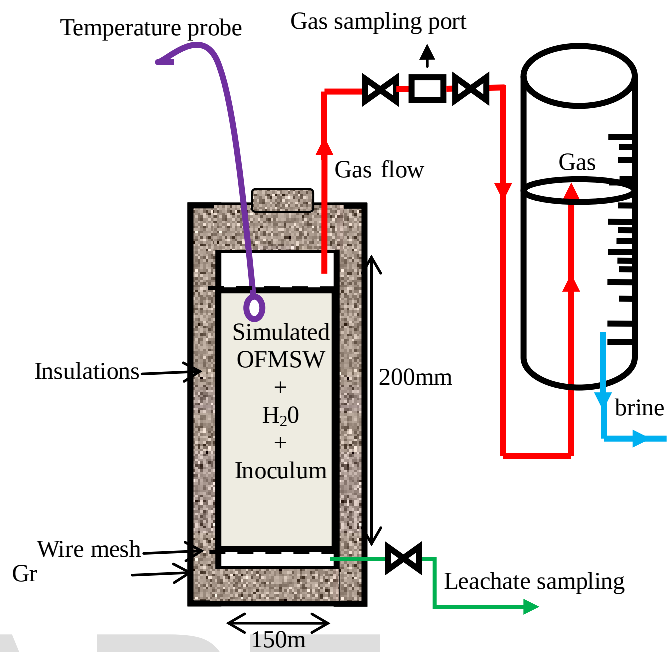

Figure 1: Experimental Set-Up
Adopted and modified from West *et al.*, (1998)

The digester was constructed using an acrylic column 150mm in diameter, 200mm in height, with a wall thickness of 5 millimetres.

Three layers of heat-insulating materials were employed to prevent loss of conductible heat. A heavy-duty aluminium foil was placed on the inner and outer layers for reflecting heat. Polyurethane foam insulation material was then used to fill the spaces between the heavy-duty aluminium foil as adopted and modified from [44]. A tap was placed at the bottom of the reactor to collect the leachates

The digesters were also equipped with a layer of gravel and a wire mesh at the bottom for leachate collection and to prevent waste saturation and a layer of wire mesh at the top of the digester for the homogenous escape of the gases from the top as adopted from [42]. Two perforations were made on the cover of the digester through which the gas hose and thermometer were tightly fixed. The thermometer was fixed tightly in one of the holes, while the other hole was placed the gas delivery tubing to pass the evolved gas from the digester into an inverted 250 ml graduated gas jar cylinder filled with saline water. The gas cylinder was held in position in a trough of the saline water by a clamp mounted on a retort stand.

2.5 Analytical methods

Daily variations in Leachate pH was measured using a digital pH probe (JENWAY 3510), the ambient temperature was monitored with a Maximum and Minimum thermometer (ZL-101) and the digestion temperature with a mercury-in-glass Thermometer (B60810, 0-100°C). While the measurement of the volume of evolved gases was carried out using the method described by [45] as well as [46] and modified by [27] and [47] using the water displacement method in which the amount of saline water (20% NaCl (w/v), pH 4) displaced was proportional to the volume of biogas produced. Quantitative and qualitative analyses of biogas were conducted with a portable biogas analyser (BIOGAS 5000).

3 RESULTS AND DISCUSSIONS

3.1 Daily changes in digestion temperature

The initial average temperature of the digesters was equivalent to the ambient temperature of about 32°C but rose steadily to about 37°C after the fifth day of biodegradation. The temperature continued to remain above the ambient in all the digesters (Fig. 4.2) and within a narrow range of 33.9-35.06°C. The temperature increase is due to the energy released from the biochemical reactions of the microorganisms on the substrates in the digesters.

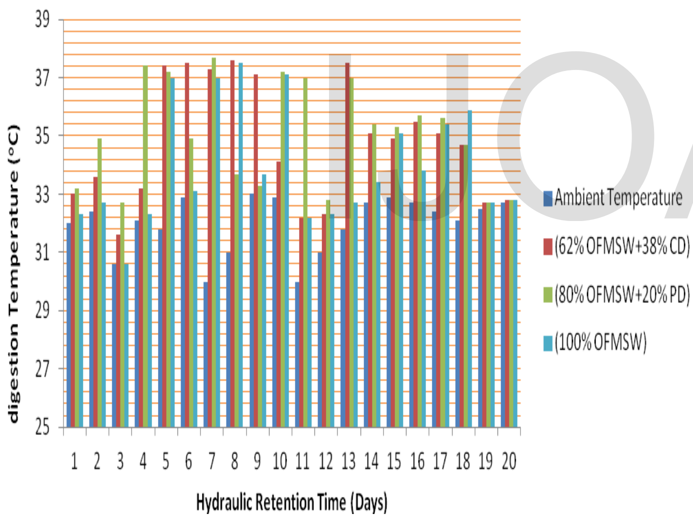

Figure 2: Comparing Daily Biomass and Ambient Temperatures

The biodegradation temperature stabilising at about 34°C was in close agreement with findings by [48] who got 37°C and with [49] that got 35°C.

3.2 Daily **changes in leachate Ph**

As depicted in Fig. 3, below the pH in all the digesters declined at the beginning of the digestion period and continued declining up to the third day of the enhanced co-digestion process. This may be due to the formation of acids by acidogenic bacteria during the lag and incubation periods. Thus, there was a shift in pH from the initial conditions of near neutral towards alkaline conditions. This occurrence may be attributed to the bioconversion of the organic material into various intermediate types of organic acids and higher mineralization of the nitrogen and phosphorous into nitrites and/or nitrates.

However, the pH stabilised at about the neutral region (7.37-7.59) after the sixth day and increased on the eleventh day. This surge in pH may be due to the production of ammonium as a result of the ammonification process. The fluctuations in pH conformed closely with the pattern obtained by [49] as well as [19].

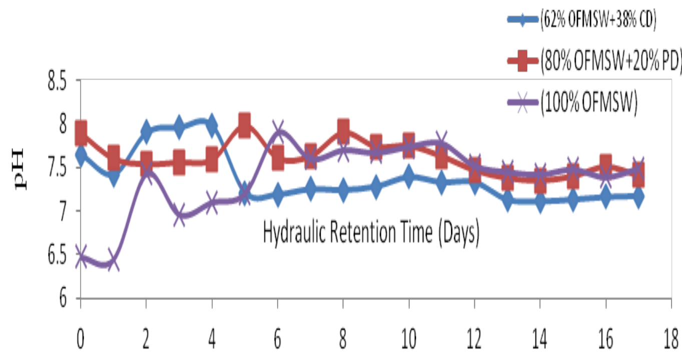

Figure 3: Daily Variations of leachate pH

3.3 Modified Gompertz Plots for Cumulative Volume of Evolved Biogas

The daily biogas production from the biodigesters is as shown in fig. below while the daily cumulative biogas production is as shown in fig. and was found to be best described (highest R^2 values) using third order polynomial equations. The HRT was determined when gas evolution had ceased completely after several thorough agitations of the digester for 48 hours.

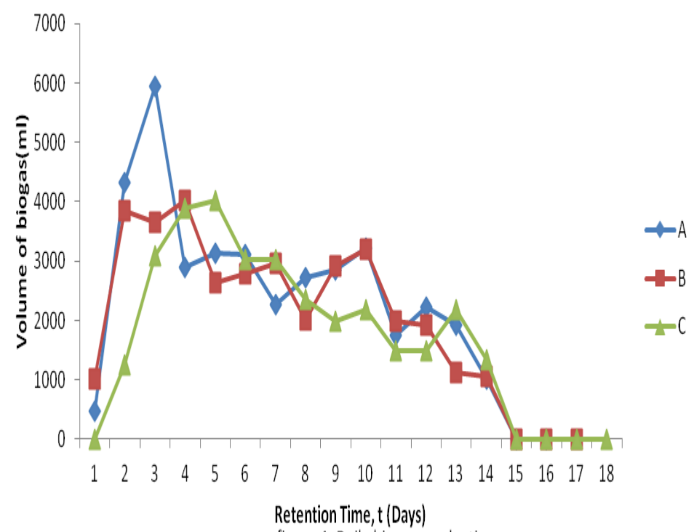

figure 4: Daily biogas production

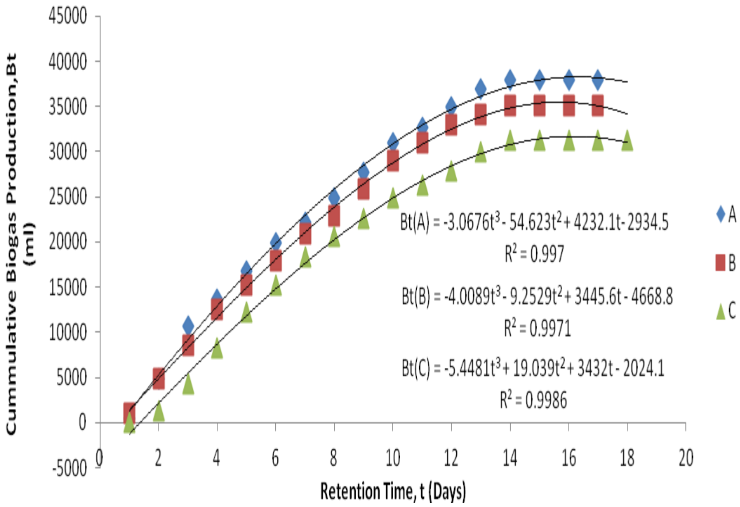

Figure 5: Daily cumulative biogas production

Furthermore, the cumulative volume of the biogas evolved (B_t) from each digester, was evaluated using the modified Gompertz equation as presented in (3):

$$B_t = B_{\max} \exp[-\exp\{\frac{R_b}{B_{\max}} e.(\lambda - t) + 1\}] \quad (3)$$

The values of B_{max}, R_b and λ were determined by the non-linear regression approach using MATLAB® (*R2013a)* software programme at 95% confidence bounds and the resulting kinetic parameters and plots are presented in figs. 6 to 8.

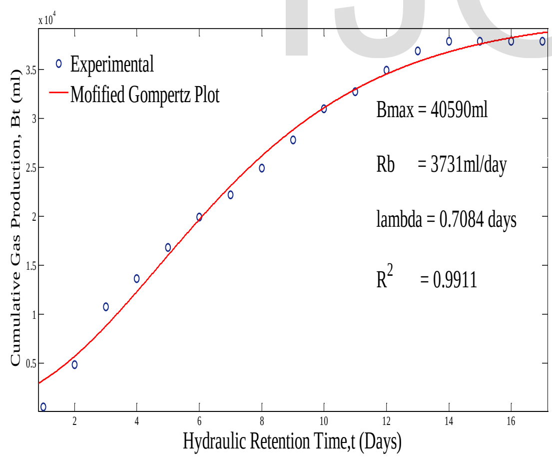

Figure 6: Experimental and Modified Gompertz Plot for 62% OFMSW +38% CD

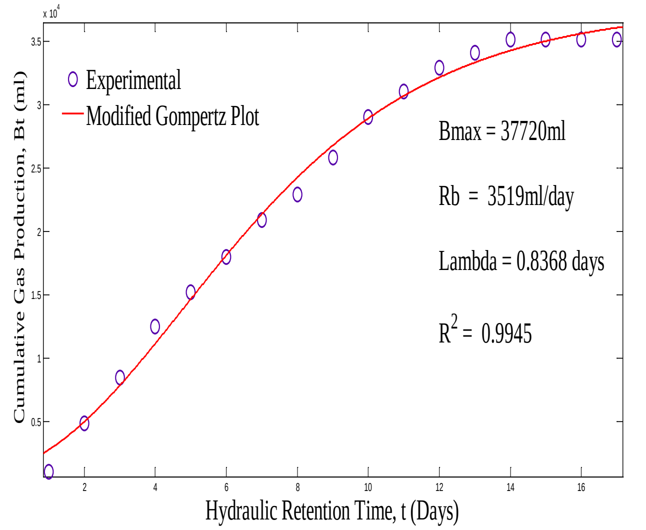

Figure 7: Experimental and Modified Gompertz Plots for 80% OFMSW +20% PD

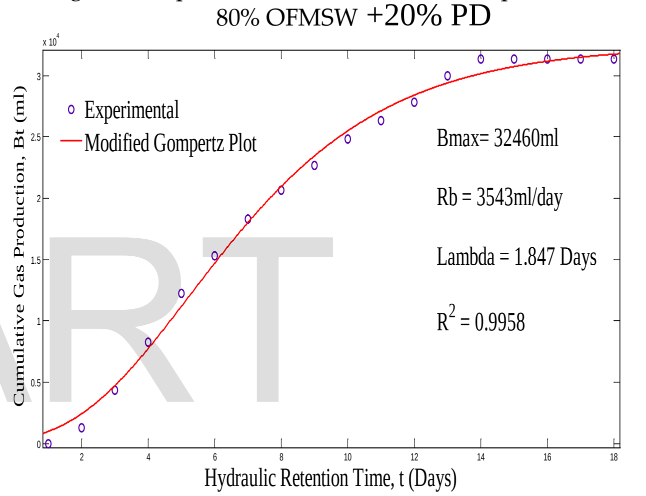

Figure 8: Experimental and Modified Gompertz Plots for 100% OFMSW

The values of maximum volume of cumulative gas evolved per kilogramme of the 3.2kg raw feedstock slurry as obtained using the modified Gompertz equation for digesters A, B and C of 12.68, 11.78 and 10.14L/kg conforms very closely to the experimentally obtained values of 11.84, 10.98 and 9.79 L/kg of raw feedstock respectively. However, it is observed that the values obtained from the modified Gompertz equation were slightly higher than the experimental; this may be attributed to the level of conversion of the feedstock and the dependence of the biodegradation process on several other operative parameters.

The lag time represented by lambda (λ) indicated that the time for the anaerobic biodegradation to begin was as short as 17.0, 20.1, and 44.33 hours for digesters A, B, and C respectively.

4 CONCLUSIONS

The HRT and the lag time (λ) for the complete degradation of manually sorted, size reduced simulated organic fraction of municipal solid wastes (OFMSW) was drastically reduced to 15 and 17 days as well as 17.0 and 20.1 hours by co-digestion with CD and PD respectively mixed to achieve a C/N OF 30:1 at ambient temperature. The feasibility of the process, which was established at a mesophilic temperature range of 33.09 to 35.06°C and a near neutral pH range of 7.37- 7.59, was demonstrated through an improved production of biogas as an environmentally friendly energy source from OFMSW inoculated with animal wastes. furthermore, the biogas yield as obtained using the modified Gompertz equation for digesters A, B and C of 12.68, 11.78L/kgVS conforms very closely to the experimentally obtained values of 11.84, 10.98 and 9.79 L/kgVS of raw feedstock respectively.

References

[1] Environment Canada,. ''Curbing the Effects of Waste on Climate''. http://www.ec.gc.ca/science/sandenovoz/article1_e.html 2002

[2] B.O. Nwankwo .Solid Waste Generation and Management among Traders in Owerri Municipal Markets, Imo State. *The Journal of environmental Health (JEH)* Vol. 5, No.2 pp. 56-63. (2008).

[3] F. E. Uwakwe,''Solid Waste Management in Owerri Municipality and its Immediate Environs''. *Academic Journal of Interdisciplinary Studies. Vol 2 No 5, July 2013.* Doi:10.5901/ajis.2012.v2n5p141.

[4] A.M, Stanley,S.S. Andrew, A.A. Dania and I.F. Sani, ''An Assessment of solid waste disposal practices in Sabon Gari, Zaria''. *Atbu journal of environmental technology, 2012-5.*

[5] R. Budiyono, E Sanchez and P. Weiland, '' Influence of Ammonia Concentration on Thermophilic Anaerobic Digestion of Cattle Manure in Up-flow Anaerobic Sludge Blanket (UASB) Reactors'' *Process Biochemistry, 31(5), pp. 477-483,1996.*

[6] S.B. Karellas,"Development of an Investment Decision Tool for Biogas Production From Agricultural Waste". *Journal of Renewable and Sustainable Energy September 2010.Reviews, 14: 1273-1282.2.*

[7] H. Hartmann, ''Anaerobic Digestion of the Organic Fraction of Municipal Solid Waste with Recirculation of Process Water'' PhD dissertation presented to the University of Denmark. http://vbn.aau.dk/files/14927443/Hartmann_PhD_thesis.pdf.

[8] R. Kigozi, A. Aboyade and E. Muzenda, ''Biogas Production using the organic fraction of municipal solid waste as Feedstock'' *Int'l Journal of Research in Chemical, Metallurgical and Civil Eng. (IJRCMCE) Vol. 1, Issue 1(2014).*

[9] M. Francesco, D. Mariangela, V. Carolina and D. Giambattista, ''Biodegradation of Olive Husk Mixed with other Agricultural Wastes''. *Bioresource Technology 100 (2009) 2969–2974.*

[10] F. Koudache and A.A. Yala, ''A Contribution to the Optimisation of Biogas Digesters with the Design of Experiments Method '' *J. Int. Environmental Application & Science, Vol. 3 (3): 195-200 (2008).*

[11] I. Jenagi, '' Production methane gas from effluent''. Diploma Individual Project. Adelaide University. In: Ezekoye, V.A., Ezekoye, B.A. and Offor P.O. Effect of Retention Time on Biogas Production from Poultry Droppings and Cassava Peels. Nig J. Biotech. Vol. 22 (2011) 53-59 ISSN: 0189 17131 Available online at www.biotechsocietynigeria.org. 53.

[12] S.J. Ojolo and S.A. Oke, ''Design of an Anaerobic Waste Digester'' *The Pacific Journal of Science and Technology , Volume 8. Number 2. November 2007–220. http://www.akamaiuniversity.us/PJST.htm.*

[13] C.N. Agulanna, G.N. Onuoha, E.E. Anyanwu, N.O.E. Ejike and N.V. Ogueke, ''Experimental Studies of Anaerobic Digestion of Organic Fraction of Municipal Solid Waste Using a Bioreactor with Integral Flow Features''. *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 3(3):461-469 (ISSN: 2141-7016.*

[14] J. Lu and B.K. Ahring,''Effects of Temperature and Hydraulic Retention Time on Thermophilic Anaerobic Pretreatment of Sewage Sludge''. *ADSW 2005 Conference Proceedings – Volume 1 – Session 3a: Collection & pre-treatment.*

[15] A.B. Karki, J.N. Shrestha and S. Bajgain, '' Biogas as Renewable Source of Energy in NepalTheory and Development''. BSP-Nepal, Kathmandu. Nepal.

[16] R. Mattocks, 'Understanding Biogas Generation''. Volunteers in Technical Assistance (VITA), Arlington, Virginia, USA. pdf.usaid.gov/pdf.docs/PNABC935.pdf.

[17] FAO, (1996). Biogas Technology: A Training Manual for Extension. Consolidated Management Services Nepal (P) Ltd., Nepal, India.

[18] National Engineering Handbook: Environmental Engineering (2000). ftp.wcc.nrcs.usda.gov/../neh637c2.pdf

[19] B.I. Syaichurrozi and S. Sumardiono,''Kinetic Model of Biogas Yield Production from Vinasse at Various Initial pH: Comparison between Modified Gompertz Model and First Order Kinetic Model''. *Research Journal of Applied Sciences, Engineering and Technology 7(13): 2798-2805, 2014 ISSN: 2040-7459; e-ISSN: 2040-7467.*

[20] M.H. Zwietering, I. Jongenburger, F.M. Rombouts, and K. Van'tRiet,''Modelling the Bacterial Growth Curve''. *Appl. Environ. Microb. 56(6): 1875-1881.*

[21] H.M. Lo, T.A. Kurniawan, M.E.T. Sillanpää, T.Y. Pai, C.F. Chiang, K.P. Chao and H.Y. Wua, ''Modeling Biogas Production from Organic Fraction Of MSW Co-Digested With MSWI Ashes In Anaerobic Bioreactors''.*BioresourTechnol.,101:6329-6335.* doi:10.1016/j.biortech.2010.03.048.

[22] J. Lay, Y. Li and T. Noike,''Development of Bacteria Population and Methanogenic Activity and a Laboratory-Scale Landfill Bioreactor'' *Water research, Vol. 32, issue 12, pages 3675 -3679.*

[23] M. Momirlan and T. Veziroglu,''Recent Direction of World Hydrogen Production Renew''. Sust. *Energy Review 3:219-231.*

[24] Y. Mu, H.Q. Yu and G. Wang,''A Kinetic Approach to Anaerobic Hydrogen Producing Process''. *Water Res. 41, 1152–1160.*

[25] C.Y. Lin and S.H. Shei, ''Heavy Metal Effects on Fermentative Hydrogen Production using Natural Mixed Microflora''. *Int. J. Hydrogen Energy 33, 587–593.*

[26] L. Altas, ''Inhibitory Effect of Heavy Metals on Methane-Producing Anaerobic Granular Sludge''. *J. Hazard. Mater. 162, 1551–1556.*

[27] M.O.L. Yusuf, A. Debora and D.E. Ogheneruona,''Ambient Temperature Kinetic Assessment of Biogas Production from Co-Digestion of Horse and Cow Dung''. *Res. Agr. Eng. Vol. 57, 2011, No. 3: 97–104.*

[28] S.Adiga, R. Ramya, B.B. Shankar, J.H. Patil and C.R. Geetha, ''Kinetics of Anaerobic Digestion of Water Hyacinth, Poultry Litter, Cow Manure and Primary Sludge: A Comparative Study''. *Proceeding of the 2nd International Conference on Biotechnology and Environment Management, 14: 73-78.*

[29] European Commission (2004). Methodology for the Analysis of Solid Waste (SWA-Tool). www.wastesolutions.org.

[30] ASTM International. (2011). *"Annual book of ASTM standards: Waste Management", vol. 04.11, 2011.*

[31] APHA (1998). Standard Methods for the Examination of Water and Wastewater. 20th Edition. APHA, AWNA, Washington D.C.

[32] I.N. Ogunmwonyi, O.E. Igbinosa, O.A. Aiyegoro, and E.E. Odjadjare,''Microbial Analysis of Different Top Soil Samples of Selected Site in Obafemi Awolowo University, Nigeria''. *Scientific Research and Essay Vol. 3 (3), pp. 120-124, March, 2008.*

[33] Manual of Environmental Microbiology, 3rd Ed. (2012). Hurst C.J. Editor. John Wiley Books Ltd.

[34] Bergey's Manual of Systematic Bacteriology (1989). Sterley, J.T. (Ed). Vol. 3 Williams and Eilkins, Baltimore.

[35] T. Manios,''The Composting Potential of Different Organic Solid Wastes: Experience From the Island of Crete''. *Environment International 29 (2004) 1079– 1089.*

[36] G.D. Rai,''Non-Conventional Energy Resources''. 2nd ed., Khpu Khanna, India. pp 331-337,369,2004

[37] K.M. Kangle, S.V. Kore, V.S. Kore and G.S. Kulkarni,''Recent Trends In Anaerobic Co-Digestion'' *A Review Universal Journal of Environmental Research and Technology Volume 2, Issue 4: 210-219.*

[38] E.E. Ituen, M.M. John, and B.E. Bassey, "Biogas Production from Organic Waste in Akwa Ibom State of Nigeria. Appropriate Technologies for Environmental Protection in the Developing World'' Selected Papers from ERTEP 2007, July 17 -19, Ghana.

[39] F.I. Al- Imam, M.Z.H. Khan, M. A.R. Sarkar and S.M. Ali,''Development of Biogas Processing from Cow dung, Poultry Waste, and Water Hyacinth'' *International Journal of Natural and Applied Science 2013; 2(1): 13-17*. http://www.urpjournals.com.

[40] M.O. Aremu, and S.E Agarry, ''Comparison of Biogas Production from Cow Dung and Pig Dung under Mesophilic Condition'' *International Refereed Journal of Engineering and Science (IRJES)* 2319-1821 *Volume 1, Issue 4(December 2012), PP.16-21.*

[41] C.E. Chibundo,'' Comparative Study of Biogas Yield from Different Animal Waste Mixtures. M. Eng Thesis Submitted to The Department Of Agricultural And Bioresources Engineering, Nnamdi Azikiwe University, Awka, Nigeria, 2012. http://naulibrary.org/dglibrary/admin/book_directory/Thesis/11050.pdf.

[42] J.R.Bayard, C. Gachet, F. Achour, C. de Brauer, C. and R. Gourdon, ''Effect of Leachate Recirculation on the Stabilisation of Organic Matter in Municipal Solid Waste'' *International Workshop « Hydro-Physico-Mechanics of Landfills" LIRIGM, Grenoble 1 University, France , 21-22 March 2005.*

[43] M.E.West, K.W. Brown, J.C. and Thomas, 'Methane Production of Raw and Composted Solid Wastes in Simulated Cells''. *Waste Manage. Res., 16, pp. 430-436*.

[44] Y. Li, J. Liu, G. Huang, H. Yu, K. An, B. and Zhang, ''Application of a Maturity-accelerating Reagent (MAR) to Food Wastes'' *Chem. Biochem. Eng. Q. 23 (3) 359–365.*

[45] S.B. Adeyemo and A.A. Adeyanju, '' Improving Biogas Yield Using Media Materials''. *Journal of engineering and applied sciences. 3(2):207-210, 2008.*

[46] C.A. Bareither, S.J. Fong, G.L. Wolfe and K.D. McMahon, '' Microbial Population Dynamics And Diversity In Municipal Solid Waste Anaerobic Laboratory Reactors'' The University of Wisconsin System. Solid Waste Research Program, August 5, 2009. www.nvbi.nlm.nih.gov/pubmed/23318155.

[47] D.Y. Tsunatu, I.C. Azuaga and J. Agabison,''Evaluation of the Effect of Total Solids Concentration on Biogas Yields of Agricultural Wastes''. *International Research Journal of Environment Sciences. Vol. 3(2), 70-75, February (2014) Int. Res. J. Environment Sci.*

[48] I.O. Akpabio and S.E. Etuk, '' Relationship between Solar radiation and sunshine duration for one onne Nigeria'' *Turkish Journal of Physics, vol. 27, Pp. 161-167.*

[49] P.A. Ukpai , G.F. Ibeh, P.E. Agbo and C.A. Elekwa, '' Effect Of pH on the Volume of Gas Produced from Cowpea, Cassava Peelings'' *Journal of Physical Sciences and Innovation. Volume 3, December 2011.*