INTERNATIONAL JOURNAL OF ELECTRICAL AND POWER ENGINEERING

MEDWELL PUBLICATIONS

Production, Kinetics and Purification of Biogas from Cow-Dung and Cassava Peels

[1, 2]Ekele Dinneya-Onuoha and [1]Kechinyere B. Oyoh
[1]*Department of Chemical Engineering, Federal University of Technology, Owerri, Nigeria*
[2]*Department of Industrial Chemistry, University of Nigeria, Nsukka, Nigeria*

Key words: Cow dung, cassava peels, anaerobic, co-digestion, regression, model, biogas

Corresponding Author:
Ekele Dinneya-Onuoha
Department of Chemical Engineering, Federal University of Technology, Owerri, Nigeria

Page No.: 1-10
Volume: 15, Issue 1, 2021
ISSN: 1990-7958
International Journal of Electrical and Power Engineering

Abstract: The aim of this work is to predict the effect of temperature, pH and retention time on biogas production using some regression models while investigating other parameters such as the chemical oxygen demand and total viable count. A slurry mixture of cassava peels and cow-dung was co-digested in a metallic fixed-dome anaerobic digester in a ratio of 1:1 and then monitored for a 30-day period. The experiment was carried out at ambient temperatures which also fall into the mesophilic temperature range, (25-40°C). Daily physicochemical data demonstrated that the pH and slurry temperature ranged from 5.8-7 and 25.8-34.7°C, respectively. Biogas production began on the second day with a peak production of 6.2-L on the 15th day. The work recorded a cumulative volume of 103.3-L for the 30-day span. Kinetic studies reveal significant biogas production with Modified Gompertz Model giving the better prediction with an R^2 value of 0.9949 as compared to the Logistic Growth Model used. The explicit polynomial regression model was clearly seen to be the best predictor with R^2 = 0.79, showing retention time as a primary factor while pH and temperature are secondary factors. This tool is thus, useful in the optimization of biogas production as it considers the interactions of these core factors affecting biogas production. There is further need for improvement and refinement.

INTRODUCTION

In recent times, a good number of researchers have explored biogas production, since, it is a greener and better substitute to fossil fuels, especially in the hike in energy prices, treatment and management of waste and creating sustainable development in the world at large. It is not unclear that rapid growth in world population and urban concentration has led to an awfully tremendous increase of waste generation. Under-developed and developing countries have the great challenge of properly managing solid wastes to minimize the risk to human health and pollution problems. In fact, it has become a global concern. But these problems of energy and environment could be simultaneously handled by biogas production from waste, since, biogas can be generated from a wide range of solid or liquid wastes[1].

Biogas is produced by a set of complex biochemical reactions that occur under the action of pH sensitive bacteria in the presence of little or no oxygen. There are three major groups of bacteria namely; hydrolytic bacteria, acidogens/acetogens and methanogens. At anaerobic conditions, these bacteria break down the complex organic substrates to form the biogas[2]. Biogas is a gaseous mixture of methane, carbon dioxide, hydrogen sulphide and several other gases, produced by anaerobic digestion.

The anaerobic digestion process in bio-digesters transform organic substrates comprising of carbon into carbon dioxide and methane. The growth of most pathogenic organisms is inhibited by the anaerobic environment and extended digestion time. Thus, the biological parameters of wastes will be improved upon passage through bio-digesters[3].

Anaerobic digestion, as a treatment technique for wastewater and biodegradables is not a new technology. It has been used since, the nineteenth century. In rural areas of China and India, simple reactors have been used for a long time to treat agricultural and livestock wastes in order to get energy for cooking and lighting. However, it was only in the 70s that this technique has attracted the attention of many scientists in terms of research and technological development. This interest has increased after being conscious of climate change and the degradation of the environment. Furthermore, in the late 80s, the technique of co-digestion, that was used to treat mixtures of different types of wastes including livestock waste, agriculture waste and household organic waste, was widespread in several countries[4].

Agricultural wastes used in bioconversion range from animal manure to crop residues. Due to the high nitrogen content of cow-dung, an animal manure, it is one of the most suitable substrates for high yield biogas production, because of pre-fermentation in the stomach of the ruminants and presence of micro-organisms that aid in the bio-digestion process[5]. Cassava is among the fastest growing staple foods in the world. West Africa accounts for 57.8% of the total Africa cassava production with Nigeria as the highest producer[6]. In many West African countries, cassava peels, in enormous quantities, are abandoned, dumped in landfills or burnt. A small fraction is washed and sun-dried to feed pigs, sheep and goats. Due to their high cyanide content, cassava peels are highly polluting bio-materials which can affect the environment[7]. However, these highly polluting bio-materials have been investigated to produce biogas on digestion, although, in small quantities. Further research has proven that various mixtures of manure with lignocellulose materials such as cassava peels, increase the efficiency of bioconversion of complex substrates to methane[7].

A lot of work has been done and published on anaerobic digestion treating different mixture of organic wastes in the quest to optimize biogas yield in anaerobic digestion. This technique has proven to give a higher amount of biogas yield than that obtained when organic wastes are treated individually[8]. In fact, Kashi *et al*.[9] posited that the mixture of two or more wastes increases the rate of biogas production, especially within the early days of reaction and final biogas yield is a sum of the yields of the individual wastes. Other works that agree include: "Co-digestion of solid wastes: a review of its uses and perspective including modeling" by Mata-Alvarez *et al*.[8], "Anaerobic co-digestion of kitchen waste and pig manure with different mixing ratios" by Tian *et al*.[10], "Anaerobic digestion of canteen wastes for biogas production, process optimization" by Nand *et al*.[11], "Production of biogas from market waste" by Ranade *et al*.[12], "Kinetic and performance study of batch two phase anaerobic digestion of fruit and vegetable wastes" by Mata-Alvarez *et al*.[13], different studies on animal wastes by Yono *et al*.[14], Ofoefule *et al*.[15] and Yusuf *et al*.[16], etc.

A number of operating parameters, however, affect biogas yield in anaerobic digestion. They include temperature, pH, retention time, COD etc. Jayaraj *et al*.[17] considered the effect of pH (5, 6, 7, 8) on the production of biogas from food wastes by the anaerobic digestion method. They found out that biogas yield and degradation efficiency were substantially higher for substrate with pH 7 compared to other pH values with a methane composition of 60.8% (v/v). Sebola *et al*.[18] found out from their research on 'methane production from anaerobic co-digestion of cow dung, chicken manure, pig manure and sewage waste' that the optimum temperature for anaerobic digestion was 40°C with 62% methane yield on the sixth day of production time. Researchers have done a great deal in finding out how these various parameters affect the digestion process and biogas yield.

This work aims at mathematically establishing the best regression model that will predict daily biogas production based on the interactions and effects of only retention time, pH and temperature in the anaerobic co-digestion of cow-dung and cassava peels obtained from from cassava processing plants, houses and abattoir located in Nsukka, Enugu State, Nigeria. This will help in process optimization for further studies and better biogas yield. Other objectives include investigating biogas yield from the co-digested substrate under ambient temperature conditions and analyzing operational parameters such as pH, temperature, etc.

MATERIALS AND METHODS

Raw anaerobic digestion materials: Fresh cow dung used was obtained from an abattoir in Nsukka.

The Cassava peelings were gotten from a local Cassava processing plant in Nsukka, Enugu State.

Experimental set-up: The study was carried out for 30-days from 5th August to 4th September 2017 in a 32-L metallic fixed-dome digester. The 4 kg of cow-dung was weighed and thoroughly mixed with 4 kg of chopped cassava peels, (ratio 1:1), making 8 kg. The ratio was chosen based on the research by Adelekan and Bamgboye[19] and preliminary works by the authors of this study.

The measured size of the chopped cassava peels was about 15±5 mm. The 16 L of water was measured out and mixed with the co-substrate thoroughly, then, fed into the digester. The slurry occupied three-quarter of the digester leaving the remaining one-quarter for gas production and occupancy. No other inoculum was introduced into the system.

The physicochemical parameters (pH, temperature, moisture, %TS, %VS, COD) of undigested slurry were determined before the digester was sealed completely. pH, temperature and volume of gas produced were monitored daily for the 30-day period. Jenway 3510 pH meter was used to measure the daily pH while a thermometer was used to measure the ambient and slurry temperatures. The water displacement method was used to determine the daily biogas volume. The measurement of the total solids was carried out according to the standard method for the examination of water and wastewater described by APHA[20]. The 50 g of each of the biomass with pre-weighed porcelain boxes were taken using a weighing balance. The samples were pre-heated at 60°C for 6 h and then at 105°C for 3 h using a hot oven. The final weights or dried sample weights were recorded. The percentage total solids content of the samples was then calculated using the formula:

$$TS = \frac{m_3-m_1}{m_2-m_1}\times 100 \quad (1)$$

Where:

TS = The Total solids in percentage (%)
m_1 = Mass in grams of the empty dish
m_2 = Mass in grams of sample plus the empty dish before drying
m_3 = Mass in grams of sample plus empty dish after drying

The moisture content was determined using the method described by APHA[20], samples were weighed in a dish pre-heated and then dried in an oven at 105°C for about 3 h. The weight of the dried sample plus dish was noted and the percentage moisture content was calculated by Eq. 2:

$$\%\ \text{moisture content} = \frac{(m_2-m_1)-(m_3-m_1)}{m_2-m_1}\times 100 \quad (2)$$

Where:

m_1 = Mass in grams of the empty dish
m_2 = Mass in grams of sample plus the empty dish before drying
m_3 = Mass in grams of sample plus empty dish after drying

The volatile solids and non-solids content of feed materials were determined as per the standard method by the APHA[20]. After determining the total solids and moisture content, the oven dried samples were further dried at 550±50°C temperature for 1 h in a muffle furnace and allowed to ignite completely. The dishes were then transferred to desiccators for final cooling. The weights of the cooled porcelain dishes with ash were taken. The volatile solids content and non-volatile solids content of the samples were calculated using Eq. 3:

$$VS = \frac{(m_3-m_1)-(m_4-m_1)}{m_3-m_1}\times 100 \quad (3)$$

Where:

VS = The volatile solids in dry sample (%)
m_4 = The mass of dry ash plus empty dish
(m_3-m_1) = The mass of oven dried sample in grams
(m_4-m_1) = The mass of dry ash left after igniting the sample in a muffle furnace

The measurement of the Chemical Oxygen Demand (COD) was carried out according to the standard method for the examination of water and wastewater described by APHA[20]. The 0.1 g of the samples were oxidized with potassium dichromate then titrated with ferrous ammonium sulphate using ferro in indicator. The COD of the slurry was carried out every 6 days to monitor its reduction efficiency.

Total viable count: Total viable count was carried out by the method adopted from Munshi *et al*.[21] on the undigested sample and samples collected from the digester every 5 days during the digestion period. Each sample was carefully collected in sterile tubes. 1ml from each sample was serially diluted in 9 mL sterile normal saline and diluted up to 10^{-7}, then spread on starch agar. Each plate was duplicated and incubated for 26 h at a temperature of 35°C. Afterwards, emergent colonies on the plates were numbered by counting and the average value was recorded.

Analysis of data

Regression analysis: The use of statistical analysis involving data collection approach that leads to

Table 1: Existing regression model adopted from Nnabuchi *et al*.[22]

Models name	Equation	Source
Linear	$y = a+bz$	Angstrom in 1924
Quadratic	$y = a+bz+cz^2$	Akinoglu and Ecevit in 1990
Polynomial	$y = a+bz+cz^2+dz^3$	Samuel in 1991
Logarithmic	$y = a+b.logz$	Ampratwum and Dorvlo in 1999
Linear-logarithmic	$y = a+bz+c.logz$	Newland in 1988
Power	$y = e^a z^b$	Coppolino in 1994

Table 2: Regression model for data analysis for present work

Models	Regression equation
Linear	$Y = a+b(t)+c(T)+d(pH)$
Quadratic	$Y = a + b(t)+c(T)+d(pH)+e(t)^2+f(T)^2+g(pH)^2$
Polynomial	$Y = a+b(t) +c(T)+d(pH)+e(t)^2+f(T)^2+g(pH)^2+h(t)(T)+i(t)(pH) +j(T)(pH)$
Logarithmic	$Y = a+b.log(t)+c.log(T)+d.log(pH)$
Linear-logarithmic	$Y = a+b(t) +c(T)+d(pH)+e.log(t)+f.log(T)+g.log(pH)$
Power	$Y = e^a.t^b.T^c.pH^d$

determining patterns or trends is not new in scientific research. One of such statistical tools which was implemented in this work was regression analysis. Regression permits us to understand the relationship that exist between variables, independent and dependent and helps us into further investigation of these relations[23]. In this study, the relationship/effects of temperatures, pH and retention time on biogas production were analyzed using multiple linear regression through determination of correlation coefficients, R^2 values.

Table 1 shows some existing regression models which were modified for use in this present work. The different works focused on the relationship between biogas yield and retention time where y represents the biogas yield and z represents the retention time. This work has thus, incorporated temperature and pH factors. Table 2 presents the regression models adopted in analyzing the data generated from the experiment. Y represent daily biogas yield, t represents retention time, T represents temperature and then pH. It is a well-established fact that pH, time and temperature play substantial role in biogas production, this is thus, the reason these parameters have been used for the present study. The analysis was composed of regression analysis of biogas production against the varying temperatures and pH on retention time.

RESULTS AND DISCUSSION

Feedstock characterization: Table 3 shows the preliminary characterization of the co-substrate used while Table 4 presents the daily and cumulative biogas production. The daily and cumulative biogas volumes have been plotted in Fig. 1a and b, respectively.

Biogas production began on the first day with an observed 0.8 L. Although, production was slightly slow, it continued to increase until it got to a peak of 6.2-L on the 15th day of digestion. This agrees with Ukpai and Nnabuchi[5] where he showed that the rate of

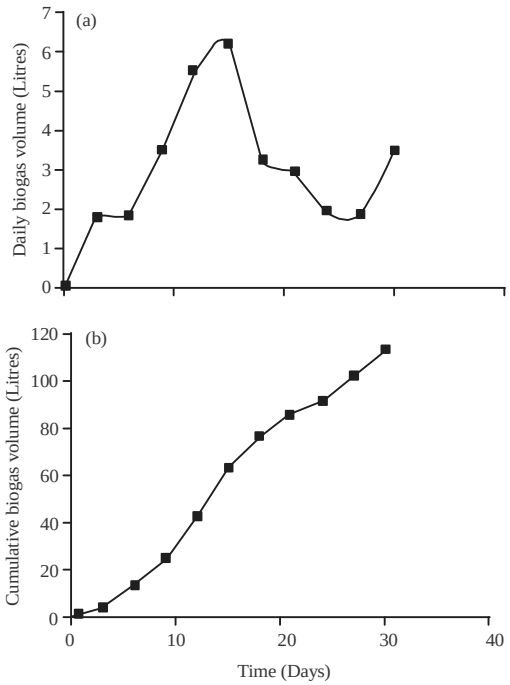

Fig. 1(a, b): Daily and cumulative biogas production for the 30-day period

biogas production in batch condition is directly proportional to the specific growth rate of methanogenic bacteria in the bio-digester. During the first 7 days of the experimental exercise, production was found to be low as a result of the microbial growth lag phase. After about 10 days, there was a significant increase in gas production because of the high-level growth of microorganisms in the digester. Biogas production started declining from the 16th-27th day due to receding microbial growth. The sudden rise after the 27th day is uncertain but not uncommon since biogas production studies beyond 30 days have shown trends of rising and falling of daily yield. The rises do not exceed that of the peak production[24].

Table 3: Feedstock characterization

Composition	Co-digested
Moisture content (%)	89.4
Total solids (%)	10.6
Volatile solids (%)	88.3
pH	6.6
Chemical oxygen demand (mg L^{-1})	66.8
Total viable count (CFU m L^{-1})	1.2*106

Table 4: Daily and cumulative biogas production

Time	Biogas produced (L)	Cumulative volume (L)
0	0	0
3	1.8	3.3
6	1.9	11.9
9	3.5	22.9
12	5.5	38.7
15	6.2	57.5
18	3.3	69.9
21	3	78.2
24	2	83.9
27	1.9	93.5
30	3.5	103.3

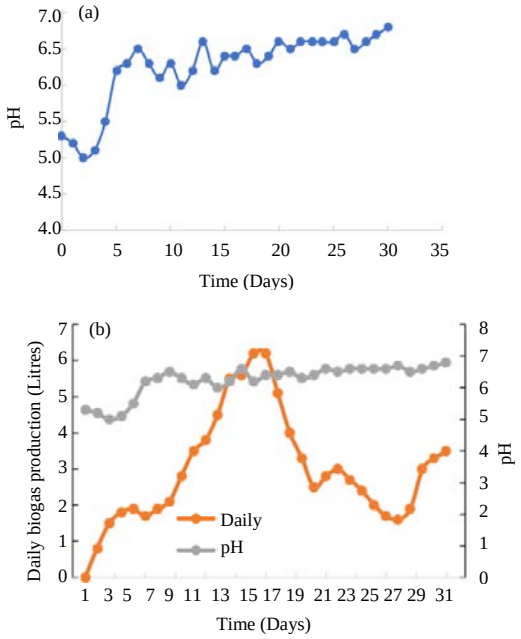

Fig. 2(a, b): pH variations for the 30-day period in relation with the daily biogas production

It was also observed that the cumulative yield of biogas follows a slightly S-curved or sigmoid pattern as shown in Fig. 1b. It is generally the case for batch growth curve[25].

Effect of pH on gas production: pH is a major factor that affects anaerobic digestion. Figure 2 shows the pH variations for the study period in comparison with the daily gas produced. In the first few days of the digestion, a decrease in the pH was observed. This could be as a result of the high-level volatile solids in the substrate which were converted into Volatile Fatty Acids (VFAs) and other acidic substances by acid forming bacteria which were then acted upon by methanogenic bacteria to produce the gas[14]. Yono *et al*.[14] also reported that the corresponding increase in pH immediately after the observed sharp decrease could be due to the generation of NH_{4+} during protein degradation as ammonia which was a base combine with carbon dioxide and water to form ammonium bicarbonate (a natural pH buffer). It thus implies that the rate of hydrolysis and acetogenesis was high. From the study, it is clear that pH fluctuated between 5.8 and 7.5 after which there was considerable stability at neutral pH, 7 which is within the range of optimum pH level, (6.0-7.0)[5].

Temperature variation: The average ambient temperature observed during the study was 27.9°C while the average digester temperature was gotten as 31.5°C.

The ambient and slurry temperature values were closely monitored in determining the rate of digestion since temperature is another important factor. The ambient temperature affected the slurry temperature and thus, rate of digestion. This is because the exterior of the digester surface made direct contact with the atmosphere. The relationship trend between the ambient and slurry temperature is seen in Fig. 3. The temperature gradient that exist between the digester and the surrounding environment determines whether the digester walls loose or absorb heat. The temperature distribution was within the mesophilic temperature range (24-37°C) for optimal biogas production.

Cod reduction efficiency and total viable count changes: The reduction of COD value means the reduction of organic load from the substrate by digestion or other treatment method. The COD of the slurry considerably reduced by the anaerobic process as seen in Fig. 4. This reduction confirms the presence of anaerobic bacteria responsible for the conversion of COD into methane and carbon dioxide[26]. Percentage of COD reduction achieved was 55.5% for the co-digested substrate. Percentage reductions for days 0-6, 6-12, 12-18, 18-24, 24-30 are 9.8, 16.4, 27.8, 9.4 and 9.7%, respectively. Peak gas production was observed within the 12-18 days range where we also observed higher reduction in COD and higher total viable count. This means that the higher the anaerobic activities, the higher the reduction in COD levels which in turn gives higher biogas yield. Table 5 shows the total viable count and COD values.

Figure 5 shows the variations in total viable count over the 30-day period of study. It was observed that there was a decrease in total viable count during the first three days of the digestion. This could be the reduction in the

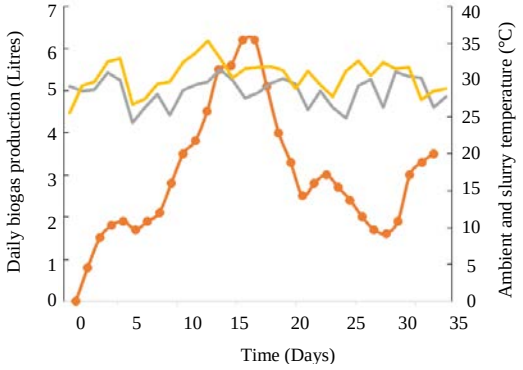

Fig. 3: Variations of daily biogas production, ambient and slurry temperatures with time

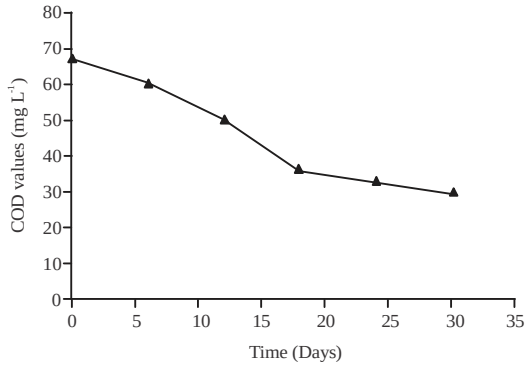

Fig. 4: COD reduction

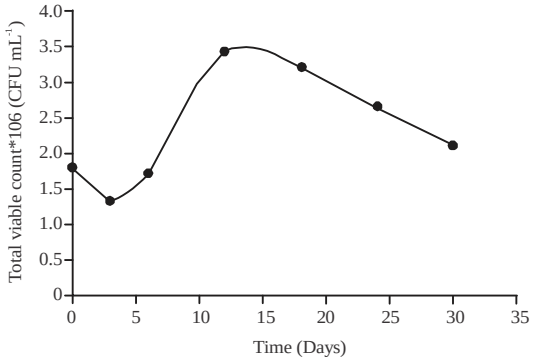

Fig. 5: Variations in total viable count

Table 5: Total viable count and COD values

Days	Total viable count	COD (mg L^{-1})
0	$1.8*10^6$	66.8
3	$1.34*10^6$	-
6	$1.72*10^6$	60.2
12	$3.4*10^6$	50.3
18	$3.2*10^6$	36.3
24	$2.65*10^6$	32.9
30	$2.1*10^6$	29.7

total aerobic organisms, since, the digester was sealed off completely for the anaerobic process. This is in agreement with Mukhtar *et al.*[27] who studied the total aerobic and total anaerobic bacterial activities in digestion process. This is not however, to say that there was no growth in anaerobic organisms, since, production of gas started on the second day. The corresponding increase in total viable count could be attributed to the massive growth in anaerobic organisms favorable for the production of biogas[3]. Within the period of growth of these anaerobic organisms, we had peak production of biogas until the 18th day where we started observing decreasing total viable count. The trend continued until the 30th day of digestion.

Analysis of the different regression models: The regression models developed were based on the daily produced biogas and their corresponding pH, temperature and retention time. The different models which included linear, quadratic, polynomial, power and exponential were determined statistically using Microsoft Excel 2007 software. Their different coefficients of determination (R^2-values) were determined in order to ascertain the model with the best fit. The equations are presented in Table 6 while their corresponding scatter plots are seen in Fig. 6.

Figure 6 give a graphical view of the experimental and modeled data. The explicit polynomial model was observed to be the best fit with $R^2 = 0.79$ which was followed closely by the Linear-logarithmic regression model with a coefficient of determination of 0.71. The linear model had the least R^2 with a value of 0.24. For the work, the explicit polynomial function seems to be more reliable in predicting gas production in anaerobic co-digestion of cassava peels with cow-dung.

The poor correlation coefficient obtained from the linear model indicates that there is little or no linear relationship between the daily biogas yield and the pH, temperature and time. This is clear, since, increase in pH and temperature did not necessarily give increased volume of biogas and vice-versa. The quadratic relationship gave a higher correlation coefficient though not as high as the explicit polynomial model which suggests that biogas production depends more on the interplay and interactions of pH, temperature and time. Thus, their interactions can either reduce or increase the production of biogas in this kind of system.

It can also be observed that the time factor (t) has positive coefficients in all resulting models making it the primary factor since any increase in time will give a corresponding increase in the yield. This agrees with[5, 28] who assert that hydraulic retention time is a key factor in the design process anaerobic digestion for digestible and hard complex organic pollutants while solid retention time is the control parameter in the design process for readily digestible organic elements. The slurry temperature and pH remain secondary factors. Of course, the slurry

Table 6: Developed regression models from Microsoft Excel 2007 software

Models type	Regression equation	R^2
Linear	Y = 0.9587+0.1302(t)+0.7189(pH)-0.1945(T)	0.24
Quadratic	Y = 25.5023+0.5191(t)-2.0319(T)+1.7499(pH)-0.0152$(t)^2$+0.0335$(T)^2$ – 0.1486$(pH)^2$	0.56
Polynomial	Y = 15.5719+4.7683(t)-1.9856(T)-1.4522(pH)-0.0094$(t)^2$+0.0388$(T)^2$+0.5473$(pH)^2$-0.0115(t)(T)-0.5995(t)(pH)-0.0266(T)(pH)	0.79
Logarithmic	Y = -12.4174+0.9979.log(t)+7.4288.log(T)+4.0759.log(pH)	0.34
Linear-logarithmic	Y = 673.2600+12.3960(t) - 554.3600(T)-191.5100(pH) -0.3993.log(t)+7.5202.log(T)+11.0534.log(pH)	0.71
Power	Y = $e^{-3.1870}.t^{0.1070}.T^{0.9880}.pH^{0.3507}$	0.34

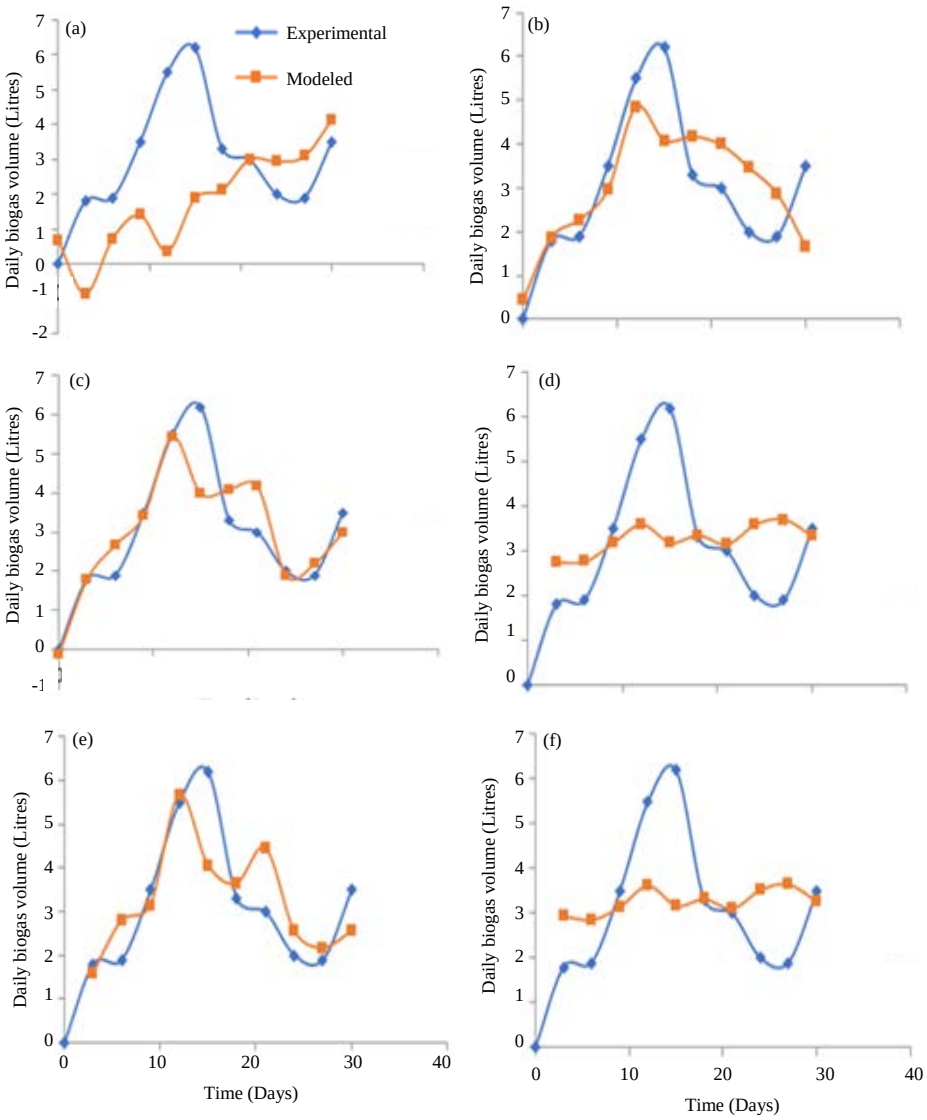

Fig. 6(a-f): Graphs showing comparison between the regression models and experimental data, (a) Linear regression, (b) Quadratic regression, (c) Polynomial regression, (d) Logarithmic regression, (e) Linear-logarithmic regression and (f) Power regression

temperature is affected by the ambient temperature and the microbial activities within the digester while the pH is basically affected by microbial activities as earlier established. It is thus, not strange to have some negative coefficients for pH and temperature in the different models.

Kinetic studies: Existing Kinetic Models were used to carry out the kinetic study for the digestion process. They include:

- Modified Gompertz Model
- Logistics growth model

The modified Gompertz equation is presented as follows[14, 16]:

$$Y(t) = Ym*\exp(-\exp[\frac{U*e}{Ym}(Y-t)+1]) \quad (4)$$

Where:

Y(t) = Cumulative of the specific biogas production (L/kg)
Ym = Biogas production potential (L/kg)
U = Maximum biogas production rate (L/kg/day)
Y = Lag phase period or the minimum time required to produce biogas (day)
t = Hydraulic retention time (day)
e = 2.718

In this study, Microsoft Excel Solver 2007 was used for the non-linear regression analysis of the experimental data while solving for the modified Gompertz model parameters, Ym, U and Y.

Logistic growth model: The equation is as follows:

$$C = \frac{A}{1+B\exp(kt)} \quad (5)$$

Where:

C = Cumulative biogas production (L/kg)
k = Kinetic rate constant (day^{-1})
t = Time (day)
A and B = Model constants

Microsoft Excel solver was also used to determine the model constants, A and B and the kinetic rate constant, k.

The modified Gompertz equation relates cumulative biogas production and the time of digestion through biogas yield potential (Ym), the maximum biogas production rate (U) and the duration of lag phase (Y). To analytically quantify parameters of the batch growth curve, the modified Gompertz equation was fitted to the cumulative biogas production data for the digester. Values of parameters obtained using Microsoft Excel Solver 2007 are listed in Table 5. The best fit to Gompertz equation is compared with experimental data in Fig. 7 and the following observations were made.

From Fig. 7 and Table 5, the digestion process had a biogas production rate, (U), of 6.368 L/kg/day and a biogas production potential, (Ym) of 113.3924 L/kg. It is clear that the modified Gompertz equation fits well to the

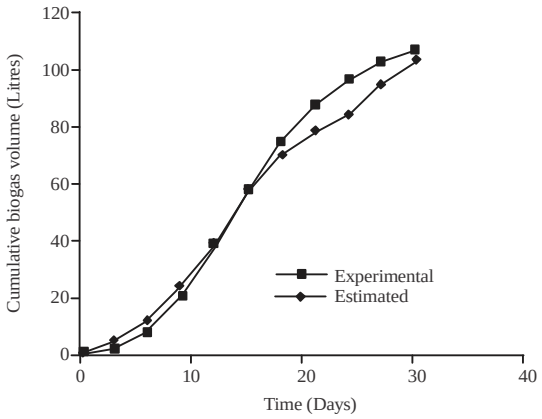

Fig. 7: Comparison of experimental and simulation data using modified Gompertz Model

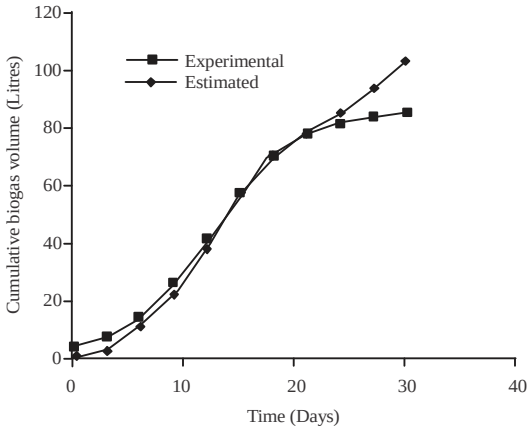

Fig. 8: Comparison of experimental and simulation data using logistic growth model

experimental data with an R^2 value of 0.9949. the estimated biogas yield from the model was also very close to the experimental cumulative yield which showed that the digestion process had commendable results. The difference between the estimated and experimental cumulative biogas produced is 2.48% which agree with the works done by Yone *et al*.[14] and Syaichurrozi[29] who reported 0.96-6.45%. The value of Y, 5.914 days, indicates the time required for the anaerobic bacteria responsible for biogas production to adapt in the cow-dung and cassava peel substrate as defined by Syaichurrozi[29]. This value further indicates a good relationship between the model and the experimental results, since, it is observed in Fig. 1 that from the 6th day, there was continuous rise in the daily production of biogas until the 15th day (Table 7).

For the Logistic Growth model, the kinetic rate constant was found to be 0.2563/day and Table 6 and Fig. 8 shows that the model fits the experimental results very well with an R^2 value of 0.9920.

Table 7: Summary of the modified Gompertz Model variables

			Modified Gompertz Model parameters			
Digester	Experimental yield (L)	Estimated yield (L)	Ym (L)	U (L/kg/day)	Y (days)	R^2
Co-digested	103.3	105.86	113.392	6.368	5.914	0.9949

Table 8: Summary of the logistic Growth Model variables

			Logistic Growth Model			
Digester	Experimental yield (L)	Estimated yield (L)	A	B	K (/day)	R^2
Co-digested	103.3	85.16	86.07	23.23	0.2563	0.9920

Generally, both the Modified Gompertz and Logistic Growth Models are good tools for predicting biogas production from the co-digestion of cow-dung and cassava peels with high R^2 values, nevertheless, the Modified Gompertz Model gave a better prediction (Table 8).

CONCLUSION

Co-digesting cow-dung and cassava peels is one way of addressing biogas production feedstock challenges and world energy demands. The ambient conditions within Nsukka and Nigeria's cities are conducive for the anaerobic digestion of food and animal wastes as a way of managing wastes with gas production, since, these wastes are always in our environment and we had high yield of biogas production. The mathematical models derived using multi-linear regression analysis indicates that biogas production from co-digestion of wastes can be predicted based on the temperature, pH and retention time. The explicit polynomial model, from the analysis, gave the best yield prediction. Kinetics studies show that biogas production from the digestion process was significantly good. Modified Gompertz Model gave a better prediction with an R^2 value of 0.9949 compared to the Logistic Growth Model with R^2 value of 0.9920. This can be of great help in optimizing biogas production rates and yields, however, further refinements are still necessary and required.

REFERENCES

01. Iwayemi, A., 2008. Nigeria's dual energy problems: Policy issues and challenges. Int. Assoc. Energy Econ., 53: 17-21.
02. Ilori, M.O., S.A. Adebusoye, A.K. Iawal and O.A. Awotiwon, 2007. Production of biogas from banana and plantain peels. Adv. Environ. Biol., 1: 33-38.
03. Eze, J.I. and K.E. Agbo, 2010. Studies on the microbial spectrum in anaerobic biomethannization of cow dung in 10m3 fixed dome biogas digester. Int. J. Phys. Sci., 5: 1331-1337.
04. Ahring, B.K., 2003. Perspectives for Anaerobic Digestion. In: Biomethanation I. Advances in Biochemical Engineering/Biotechnology, Ahring, B.K., I. Angelidaki, E. Conway de Macrio, H.N.Gavala and J. Hofman-Bang (Eds.). Springer, Berlin, Germany, ISBN:978-3-540-44322-3, pp: 1-30.
05. Ukpai, P.A. and M.N. Nnabuchi, 2012. Comparative study of biogas production from cow dung, cow pea and cassava peeling using 45 litres biogas digester. Adv. Appl. Sci. Res., 3: 1864-1869.
06. FAO., 2012. Statistical yearbook, economic and social development department. Food and Agricultural Organization, Rome, Italy.
07. Bayitse, R., G.N. Laryea, G. Selormey, W.O. Oduro and M. Aggey *et al*., 2014. Anaerobic co-digestion of cassava peels and manure: A technological approach for biogas generation and bio-fertilizer production-feature article. J. Applied Sci. Technol., 19: 10-17.
08. Mata-Alvarez, J., J. Dosta, S. Mace and S. Astals, 2011. Codigestion of solid wastes: A review of its uses and perspectives including modeling. Crit. Rev. Biotechnol., 31: 99-111.
09. Kashi, S., B. Satari, M. Lundin, I.S. Horvath and M. Othman, 2017. Application of a mixture design to identify the effects of substrates ratios and interactions on anaerobic co-digestion of municipal sludge, grease trap waste and meat processing waste. J. Environ. Chem. Eng., 5: 6156-6164.
10. Tian, H., N. Duan, C. Lin, X. Li and M. Zhong, 2015. Anaerobic co-digestion of kitchen waste and pig manure with different mixing ratios. J. Biosci. Bioeng., 120: 51-57.
11. Nand, K., S.S. Devi, P. Viswanath, S. Deepak and R. Sarada, 1991. Anaerobic digestion of canteen wastes for Biogas production: Process optimisation. Process Biochem., 26: 1-5.
12. Ranade, D.R., T.Y. Yeole and S.H. Godbole, 1987. Production of biogas from market waste. Biomass, 13: 147-153.
13. Mata-Alvarez, J., P. Llabres-Luengo and F. Cecchi, 1993. Kinetic and performance study of a batch two-phase anaerobic digestion of fruit and vegetable wastes. Biomass, 5: 481-488.

14. Yono, B., I.N., Widiasa, S. Johari and Sunarso, 2010. The kinetic of biogas production rate from cattle manure in batch mode. Int. J. Chem. Biol. Eng., 3: 39-44.
15. Ofoefule, A.U., E.O. Uzodinma and C.N. Anyanwu, 2010. Studies on the effect of anaerobic digestion on the microbial flora of animal wastes 2: digestion and modelling of process parameters. Trends Applied Sci. Res., 5: 39-47.
16. Yusuf, M.O.L., A. Debora and D.E. Ogheneruona, 2011. Ambient temperature kinetic assessment of biogas production from co-digestion of horse and cow dung. Res. Agric. Eng., 57: 97-104.
17. Jayaraj, S., B. Deepanraj and V. Sivasubramanian, 2014. Study on the effect of pH on biogas production from food waste by anaerobic digestion. Proceedings of the 9th Annual Green Energy Conference, May 25-28, 2014, Tianjin, China, pp: 799-805.
18. Sebola, M.R., H.B. Tesfagiorgis and E. Muzenda, 2015. Methane production from anaerobic co-digestion of cow dung, chicken manure, pig manure and sewage waste. Proceedings of the World Congress on Engineering Vol. 1, July 1-3, 2015, WCE, London, UK., pp: 1-7.
19. Adelekan, B.A. and A.I. Bamgboye, 2009. Comparison of biogas productivity of cassava peels mixed in selected ratios with major livestock waste types. Afr. J. Agric. Res., 4: 571-577.
20. APHA., 1995. Standard Methods for the Examination of Water and Wastewater. 19th Edn., American Public Health Association (APHA), Washington, DC., USA., pp: 9-35.
21. Munshi, S.K., J. Roy and R. Noor, 2018. Microbiological investigation and determination of the antimicrobial potential of cow dung samples. Stamford J. Microbiol., 8: 34-37.
22. Nnabuchi, M.N., F.O Akubuko, C. Augustine and G.Z. Ugwu, 2012. Assessment of the effect of co-digestion of chicken dropping and cow dung on biogas generation. Int. Res. J. Eng. Sci. Technol. Innovation (IRJESTI.), 1: 238-243.
23. Ithnin, N.H.C. and H. Hashim, 2019. Predictive modelling for biogas generation from Palm Oil Mill Effluent (POME). Chem. Eng. Trans., 72: 313-318.
24. Salam, B., S. Biswas and M.S. Rabbi, 2015. Biogas from mesophilic anaerobic digestion of cow dung using silica gel as catalyst. Procedia Eng., 105: 652-657.
25. Patil, J.H., M.A. Raj, P.L. Muralidhara, S.M. Desai and G.K.M. Raju, 2012. Kinetics of anaerobic digestion of water hyacinth using poultry litter as inoculum. Int. J. Environ. Sci. Dev., 3: 94-98.
26. Dinsdale, R., K. Bryne and D. Tucker, 2007. The Anaerobic Digestion of Textile Desizing Wastewater. In: Ecotextiles, Miraftab, M. and A.R. Horrocks (Eds.)., Woodhead Publishing, Cambridge, UK., pp: 163-167.
27. Mukhtar, F., A. Abubakar, U.A. Saulawa and H. Garba, 2018. Biogas production from cow dung for sustainable energy generation. UMYU J. Microbiol. Res., 3: 81-86.
28. Speece, R.E., 1996. Anaerobic Biotechnology for Industrial Wastewaters. Archae Press, Nashville Tennessee, USA., ISBN-13: 978-0965022606, Pages: 416.
29. Syaichurrozi, I., 2018. Biogas production from co-digestion Salvinia molesta and rice straw and kinetics. Renewable Energy, 115: 76-86.