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Comparison of the First Order and Modified First-Order Model for Biogas Production from Chicken Manure in Maiduguri, Borno State of Nigeria

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ABSTRACT

Maiduguri in North-Eastern Nigeria can boost of considerable amount of biogas generated from chicken manure (CM) if the organic waste is exploited for such purposes. The objective of this work is to determine the most accurate model for predicting biogas kinetic parameters by analyzing the CM empirical data obtained in Maiduguri. Biogas potential (BP) estimates using NLREG 6.6 software from the First Order and the Modified First-Order models gives BP = 10252217.1g and 83861.2925g respectively. The First Order model is the most correct kinetic model based on a careful assessment of statistical results gotten from both the ORIGIN and NLREG softwares. However, constant parameters estimated from the models, which would have helped significantly in optimizing future biogas production from CM are ambiguous and might be ascribed to errors in the biogas yield measurements or the inability of the selected models to effectively predict the constant parameters

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INTRODUCTION

In Turkey, Onay (2020), reported that 30 kilo tons of chicken manure (CM) is produced daily, with potential for renewable energy recovery. Deqingyuan chicken farm (in China), reckons as the chief egg farm plant in Asia and reap CMs from the farm for biogas production (Yilmaz & Sahan, 2020). Annually, China alone outputs about 15 million tons of CM (Wang et al., 2021). Estimates of CM global production stood at 457 million tonnes per year (Ksheem, 2015; Zahedi et al., 2020). Number of poultry birds in a certain location could also signal its potential for manure recovery and subsequent utilization for anaerobic digestion (AD). Relevant studies shows that a chicken farm with about 100,000 chickens is capable of producing up to 10 tonnes of CM daily (Wang et al., 2021). In Indonesia, for instance, Yusof et al. (2019), has it that, there are 523 million birds in that country. Estimates puts the population of chickens in Bangladesh at 123 million with potentials for 1.56 million metric tons of manure (Miah et al., 2016). Brazil sat on the top global ranking of chicken exports and occupies the second position in chicken production in the world (Barreto et al., 2019; Silva et al., 2021). In Europe, $\cong 1.886 \times 10^9$ poultry heads produced 10^7 tonnes of poultry manure according to Rubežius et al. (2020). Per year, Morocco, in North Africa, produces > 519,000 tons of broiler droppings, mostly used as fertilizer (Elasri & Afilal, 2016).

Chicken population in Nigeria is 150.682 million (second in Africa) of which 15% are semi-commercially farmed, 25% commercially and 68% in backyards, based on a report by Francis et al. (2016). One year after (in 2017), a higher population of 180 million chickens were estimated to exist in Nigeria, of which only 21% are intensively reared. Specifically, 83 million chickens are raised in extensive systems and 60 million in semi-intensive systems, most of which are indigenous chickens, contributing substantially to the nation's gross domestic product (GDP) (Lasagna et al., 2017). In the North Eastern part of Nigeria, specifically Yobe State, it was reported that, there are 3.4 million chickens reared domestically (Annuar et al., 2008). Currently, the populations are sure to surpassed the previously reported figures by Annuar et al. (2008), Francis et al. (2016) and Lasagna et al. (2017). Maiduguri, an area in the same region, employed mostly, the deep litter rearing system; although facing challenges including, bad housing, poor management practices, inadequate vaccination, and diseases resulting in high mortality rate. Common diseases identified by Francis et al. (2016), faced by poultry farmers in Maiduguri metropolis are newcastle, fowl pox, gumboro, fowl typhoid, fowl cholera, chronic respiratory disease, helminthiasis, ectoparasitism and, coccidiosis.

THEORETICAL REVIEW

In Borno State, biogas production doesn't go beyond the laboratories of learning institutions there, and there has been limited research or move to develop a large scale biogas plant for commercial use; somewhat tied to non-availability of information on the chicken inventory in the state (Dunya et al., 2015). One notable move was the construction of a biogas plant at Kasuwan Shanu, Maiduguri, which is capable of producing 40,000 litres of biogas in 3 days in 2021. During religious festivities, many chickens are slaughtered at strategic slaughter points in Maiduguri, generating wastewaters with high oxygen demand, which can also serve as biogas feedstock (Ardestani & Abbasi, 2019). The First Order and the Modified First-Order models are among the several model equations developed to analyse biogas production. UlukardeŞler & Atalay (2018) studied the kinetics of microorganisms enhancing biogas production from CM. Kinetic parameters of the First Order model had been determined by Arifan et al. (2021) using CM and other feedstock, but in codigestion of poultry litter and cow dung, it is clear that the process followed the First Order kinetics, as concluded by Miah et al. (2016). Other works are those carried out by Pecar et al. (2020), Deepanraj et al. (2016) and Wei et al. (2018), where the utilization of multiple feedstock mixed with CM was witnessed. Reaction kinetics of biogas production (both first and second order rate equations) using codigested CM and banana peel feedstock had also been studied by Nwosu-obieogu et al. (2020). This work, therefore entails the utilization of biogas data obtained from AD of CM in Maiduguri to estimate optimization parameters in First Order and Modified First Order biogas models.

METHODOLOGY

Materials and Biogas Production

CM from Maiduguri, North-Eastern Nigeria was slurrified at a ratio of 1:1 to water mixture to cover 75% of the digester and was digested for 40 days. Bacteria or fungi (such as *Saccharomyces cerevisiae*) need not to be added as done with Tofu wastewater by Syaichurrozi et al. (2020), but are presumed present in CM to facilitate gas production through feedstock decomposition. Biogas yield was recorded in grams by weighing the gas storage tube on daily basis for 40 days so as to generate values of the cumulative amounts over the period using a digital weighing balance.

Estimation of Kinetic Parameters

Using cumulative biogas yield (CBY) from empirical records of biogas production from CM, the First order and the Modified First order models given by Equation 1 and 2 (Abubakar et al., 2022), were used to estimate vital parameters of biogas production,

$$\mathrm{CBY} = \mathrm{BP}\left(1 - e^{-kt}\right) \qquad (1)$$

$$\mathrm{CBY} = \mathrm{BP}\left[(1 - \beta) - (1 - \beta)e^{-kt}\right] \qquad (2)$$

where, BP = maximum biogas potential of the CM feedstock (g), k = specific biogas generation rate (/day), t = retention time (day) and β = non-degradable fraction of the substrate. Using NLREG 6.6, developed by Phillip H. Sherrod (1992), separate programs were written declaring the initial values of the unknown parameters as shown in Figure 1.

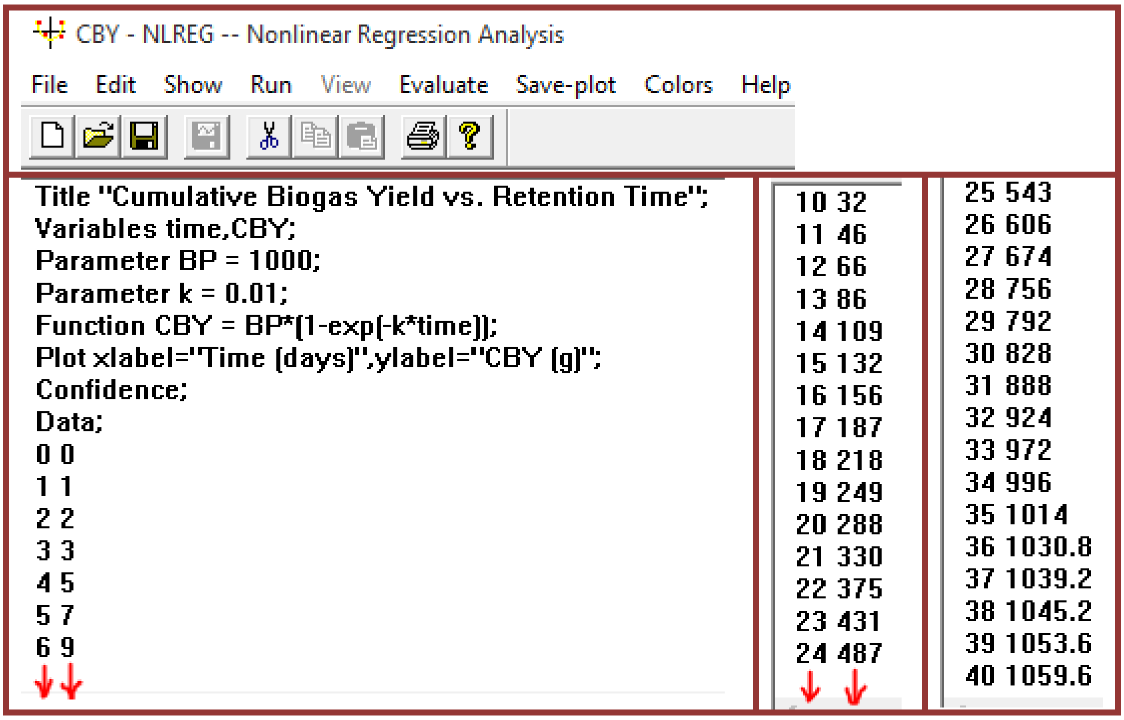

Figure 1. NLREG 6.6 First-Order Version of the Code

Figure 1 was edited to execute for the Modified First order model, with appropriate initial value of β (say '0'). The observations are the same for both models, numbering up to 41 data points. The Origin software was also used to estimate these parameters and also compare the two models. The NLREG software can perform 500 iterations with a convergence tolerance factor equal to 10^{-10}.

Deviation and Correction Factor

The deviation of model-predicted biogas yield from that of the observed/experiment, D_v, was calculated using Equation 3 (Nwoye et al., 2012),

$$D_v = \left(\frac{P_{BY} - E_{BY}}{E_{BY}}\right) \times 100 \qquad (3)$$

$$C_f = -D_v \qquad (4)$$

where, P_{BY} = model-predicted biogas yield (g), E_{BY} = biogas yield from experiment (g), and C_f = correction factor (%).

Biogas Analyser

Biogas obtained, a total of 487g was analysed using gaseous analyser.

RESULTS AND DISCUSSION

Upon running the NLREG program in Figure 1, both the statistical parameters (Table 1) and model equations were estimated together with CBY-time plot.

Table 1. Statistical Estimates for Each Model

Regression Parameters	First Order	Modified First Order
Number of iterations	321	234
Final Sum of squared deviations (SSD)	998214.2	998225.53
Final Sum of Deviations	−2410.9401	−2411.6705
Standard error of estimate	159.985	162.077
Average deviation	141.126	141.124
Maximum deviation for any observation	232.402	232.417
Proportion of variance explained (R^2)	0.8483	0.8483
Adjusted coefficient of multiple determination (R^2 adj.)	0.8444	0.8403
Durbin-Watson test for autocorrelation (DW)	0.019	0.019

Actually, the Durbin-Watson value (DW) indicates autocorrelation of inappropriate function (degree of serial correlation). Fundamentally, the measure of the relationship between a variable's current and past values is termed autocorrelation; where +1 autocorrelation represents a perfect positive correlation while −1 represents a perfect negative correlation. DW value between 1.5-2.5 is considered normal and can be concluded that its residuals are relatively independent with no serial correlation between them. However, DW = 0.019, as obtained in this work, shows that successive error terms are positively correlated. Normally, DW is between 0-4, where DW < 2 implies positive autocorrelation; DW < 1 means successive error terms are positively correlated; DW = 2 points to zero or no autocorrelation; and DW > 2 means successive error terms are negatively correlated. Both First Order and the modified version have close estimates of other statistical parameters as shown in Table 1. NLREG 6.6 software results of BP and k estimates is shown in Figure 2.

---- Calculated Parameter Values ----

Parameter	Initial guess	Final estimate	Standard error	t	Prob(t)
BP	1000	10252217.1	0	1.0E+030	0.00001
k	0.01	2.3678372E-006	0	1.0E+030	0.00001

---- Analysis of Variance ----

Source	DF	Sum of Squares	Mean Square	F value	Prob(F)
Regression	1	5582533	5582533	218.11	0.00001
Error	39	998214.2	25595.24		
Total	40	6580747			

Figure 2. NLREG Results of Calculated Model Parameters and Analysis of Variance (ANOVA) of First Order Biogas Kinetic Model

From Figure 2, BP = 10252217.1g and k = 2.3678×10^{-6} day^{-1} for First Order model biogas equation. Taking biogas density equivalent to 1.2 kg/m^3 (g/L), the biogas volume is 8543514 litres. However, using ORIGIN regression software, BP = 2.66941×10^{6}g while k = $9.09499\times 10^{-6} day^{-1}$, but gives almost an equivalent estimate of R^2 and the residual sum of squares (RSS) obtained using NLREG. These estimates (those from NLREG), when plugged into Equation (1) produces the plot seen in Figure 3.

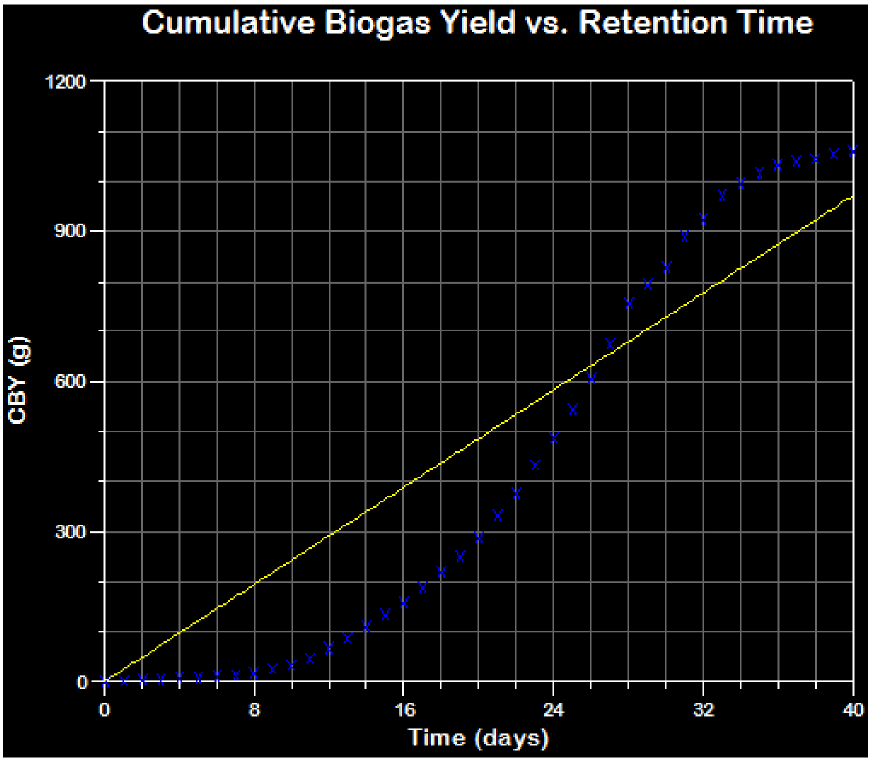

Figure 3. Observed and Correlated First Order CBY versus Time Plot

Furthermore, when the same procedure was replicated for Modified First-Order model, statistical estimates from NLREG 6.6 where as shown in Figure 4.

---- Calculated Parameter Values ----

Parameter	Initial guess	Final estimate	Standard error	t	Prob(t)
BP	1000	83861.2925	0	1.0E+030	0.00001
k	0.01	2.82076953E-006	0	1.0E+030	0.00001
beta	0	-101.626394	0	1.0E+030	0.00001

---- Analysis of Variance ----

Source	DF	Sum of Squares	Mean Square	F value	Prob(F)
Regression	2	5582521	2791261	106.26	0.00001
Error	38	998225.5	26269.09		
Total	40	6580747			

Figure 4. NLREG Results of Calculated Model Parameters and Analysis of Variance (ANOVA) of Modified First Order Biogas Kinetic Model

Figure 4 gives BP = 83861.2925g, k = 2.8208×10^{-6} day^{-1} and $\beta = -101.6264$ from Modified First-Order model NLREG regression program result, producing a similar plot with the original CBY-time relationship of the First Order kinetic model as shown in Figure 5. Applying the density-volume relationship, the equivalence of BP in volume is 69884.41 litres, which is more than 120 times the amount obtained in First Order. But from ORIGIN software, BP, k and β estimates are 62452.01255g, $6.2246 \times 10^{-6}\text{day}^{-1}$ and -61.45201 respectively. It is obvious that where NLREG program reports higher/lower predictions of BP, β and k in the models, the ORIGIN software does the same, though at longest iteration of up to 400; which makes ORIGIN software to present more reliable estimates of the kinetic constants.

In addition, statistical parameters used to compare models, such as the Bayesian Information Criterion (BIC), Akaike's Information Criterion (AIC) and F-test are not domicile in NLREG programming software, but lower values of both AIC (420.76177) and BIC (425.25383) of the First Order model compared to AIC = 423.22127 and BIC = 428.96445 of the Modified First Order alternative makes the First Order biogas kinetic model for this particular data 3.4 times more likely to be correct, according to ORIGIN software. While F-test results assumed that the two models are nested, but at 0.05 significance level, the First Order model is more likely to be correct. Another statistical parameter that can be used to select the best model is the RSS or the SSD. NLREG gives RSS = 998214.2 for First Order and 998225.5 for the Modified version of the model – of which going by the assumption that model with higher RSS value is the most accurate, makes Modified First Order model the best. However, this conclusion is countered by ORIGIN software results, where RSS = 998382.8 (for First) and RSS = 998310.8 (for Modified), dethroning the Modified version because it has lower RSS. Because the ORIGIN software calculations stops after 400 iterations against 321 (First) and 234 (Modified), proves its results as more reliable and favour the First

Order model over the Modified model for the CM empirical data analysed. These comparisons are not based on fits shown in Figure 3 and 5 as both biogas yield predictions from the models are straight lines and did not fit the experimental results.

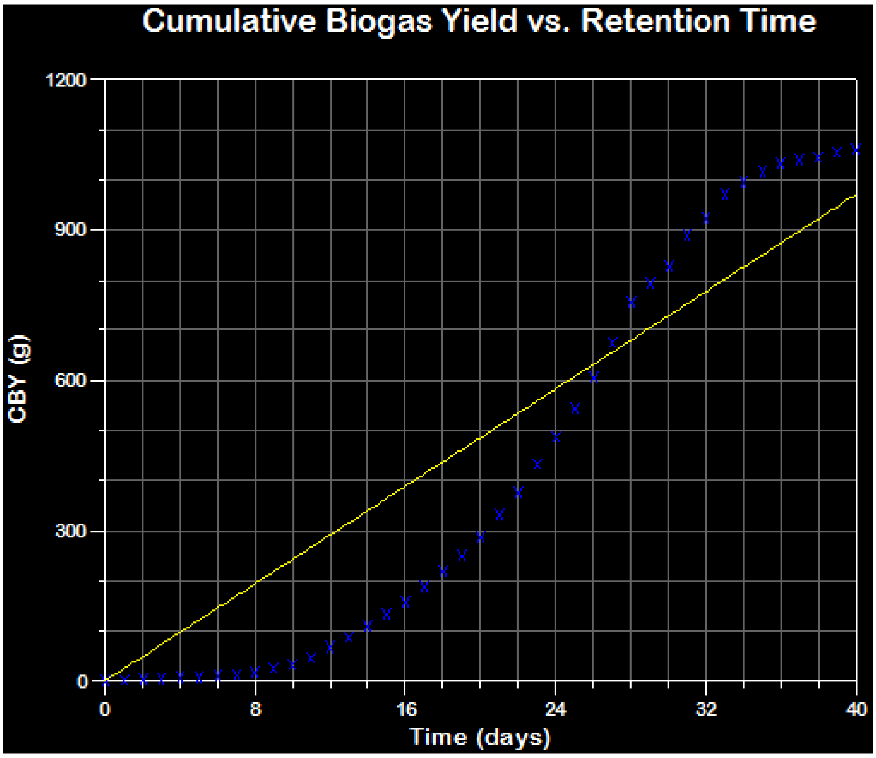

Figure 5. Observed and Correlated Modified First Order CBY versus Time Plot

Table 2 presents the cumulative gas mass (CBY) as E_{BY} (empirical results) and P_{BY} (predicted results) based on NLREG output results, as well as their % differences and correction factors.

Table 2. Deviation and Correction Factors of First and Modified Models' Data

First Order				Modified First-Order			
E_{BY} (g)	P_{BY} (g)	D_v	C_f (%)	E_{BY} (g)	P_{BY} (g)	D_v	C_f (%)
0	0	-	-	0	0	-	-
1	24.27517	23.27517	-23.27517	1	24.27685	23.27685	23.27685
2	48.55028	23.27514	-23.27514	2	48.55363	23.27682	-23.27682
3	72.82534	23.27511	-23.27511	3	72.83034	23.27678	-23.27678
5	97.10034	18.42007	-18.42007	5	97.10699	18.4214	-18.4214
7	121.3753	16.33933	-16.33933	7	121.3836	16.34051	-16.34051
9	145.6502	15.18335	-15.18335	9	145.6601	15.18445	-15.18445
11	169.925	14.44773	-14.44773	11	169.9365	14.44877	-14.44877
18	194.1998	9.788875	-9.788875	18	194.2129	9.789604	-9.789604
25	218.4745	7.738979	-7.738979	25	218.4892	7.739567	-7.739567
32	242.7491	6.58591	-6.58591	32	242.7654	6.586419	-6.586419
46	267.0237	4.804863	-4.804863	46	267.0416	4.805252	-4.805252
66	291.2983	3.41361	-3.41361	66	291.3177	3.413904	-3.413904
86	315.5727	2.66945	-2.66945	86	315.5937	2.669694	-2.669694
109	339.8472	2.117864	-2.117864	109	339.8697	2.11807	-2.11807
132	364.1215	1.758496	-1.758496	132	364.1456	1.758678	-1.758678
156	388.3958	1.489717	-1.489717	156	388.4214	1.489881	-1.489881
187	412.6701	1.206792	-1.206792	187	412.6971	1.206937	-1.206937
218	436.9443	1.004332	-1.004332	218	436.9728	1.004462	-1.004462
249	461.2184	0.852283	-0.852283	249	461.2484	0.852403	-0.852403

288	485.4925	0.685738	-0.685738	288	485.524	0.685847	-0.685847
330	509.7665	0.544747	-0.544747	330	509.7995	0.544847	-0.544847
375	534.0405	0.424108	-0.424108	375	534.0749	0.4242	-0.4242
431	558.3144	0.295393	-0.295393	431	558.3502	0.295476	-0.295476
487	582.5882	0.19628	-0.19628	487	582.6255	0.196356	-0.196356
543	606.862	0.11761	-0.11761	543	606.9007	0.117681	-0.117681
606	631.1358	0.041478	-0.041478	606	631.1758	0.041544	-0.041544
674	655.4094	-0.02758	0.02758	674	655.4509	-0.02752	0.02752
756	679.6831	-0.10095	0.10095	756	679.7259	-0.10089	0.10089
792	703.9566	-0.11117	0.11117	792	704.0008	-0.11111	0.11111
828	728.2301	-0.1205	0.1205	828	728.2757	-0.12044	0.12044
888	752.5036	-0.15259	0.15259	888	752.5505	-0.15253	0.15253
924	776.777	-0.15933	0.15933	924	776.8252	-0.15928	0.15928
972	801.0503	-0.17587	0.17587	972	801.0999	-0.17582	0.17582
996	825.3236	-0.17136	0.17136	996	825.3745	-0.17131	0.17131
1014	849.5968	-0.16213	0.16213	1014	849.649	-0.16208	0.16208
1030.8	873.8699	-0.15224	0.15224	1030.8	873.9234	-0.15219	0.15219
1039.2	898.143	-0.13574	0.13574	1039.2	898.1978	-0.13568	0.13568
1045.2	922.4161	-0.11747	0.11747	1045.2	922.4721	-0.11742	0.11742
1053.6	946.6891	-0.10147	0.10147	1053.6	946.7464	-0.10142	0.10142
1059.6	970.962	-0.08365	0.08365	1059.6	971.0206	-0.0836	0.0836

The gas analyser relates the percent transmittance with the wavelength of the spectra as shown in the Appendix. However, percent components in the gas are not related to BP of the CM. A similar feedstock could have different gaseous components compositions in biogas.

CONCLUSIONS AND RECOMMENDATIONS

Results shows that the First Order model is the most correct for biogas yield data obtained using CM sourced in Maiduguri, giving BP = 10252 kg from 7kg of CM from estimates reported by NLREG. However, this potential is not altogether satisfiable, as the two models analysed did not fit the measured biogas yield. Origin 2018 statistical tools gives a much lesser BP at higher number of iterations despite not fitting any of the models. In general, the First Order model and its extension fails to give a reliable prediction of the BP of CM using NLREG 6.6 application. It is presumed that the probable potential, and the abundance of the substrate in Borno State as mentioned in the literature, especially during festivities when the rate at which chickens are slaughtered is high, the state can boost of high volume of biogas to meet both its domestic and industrial energy needs. Subjecting the empirical CM biogas yield results to trial with other models in order to correctly predict its potential is therefore suggested. Currently, an electric mini bus and tricycle developed with solar technology and batteries to store power in 2021 by Mr. Mustapha Abubakar Gajibo in Maiduguri are operational, with ability to travel up to 200km after charging them for 35 minutes. Biogas as alternative driving force for vehicles operated electrically, has been suggested in Bangladesh by Ghosh & Mandal (2018), but such vehicles haven't find their way into Maiduguri or the country at large due to non-development in the biowaste-to-biogas sector.

FURTHER STUDY

Researchers in Borno State and the whole North Eastern region of Nigeria might be interested in harnessing waste from her huge livestock market to generate a clean and efficient energy in the process. Especially, a facility to treat the biogas from Kasuwan Shanu, in Maiduguri must be made available to kick-start its utilization. Also, the models failed to effectively analyse the biogas yield from CM and could be further studied using a better empirically measured gas yields from the feedstock.

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APPENDIX

Electronic Analysis of the Biogas Generated