LAUTECH Journal of Engineering and Technology 19 (2) 2025: 10-20
10.36108/laujet/5202.91.0220

Evaluation Of Biogas Yield from Co-Digestion of Varying Particle Sizes of Corncob with Poultry Manure and Process Parameters Optimization Study

[1*]Oladejo, O. S., [2]Ogunbunmi, S. I., [3]Sanni, K. A., [4]Olanrewaju, O. F., [5]Azeez, Y. O.

[1, 2, 3, 4, 5,] Department of Civil Engineering, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Oyo State, Nigeria.

[1]osoladejo@lautech.edu.ng

Article Info

Article history:

Received: Mar 13, 2025
Revised: April 28, 2025
Accepted: April 30, 2025

Keywords:

Anaerobic digestion,
Biogas, Corncob,
Inoculum, Optimization,
Poultry manure

Corresponding Author:
osoladejo@lautech.edu.ng

ABSTRACT

The need to improve renewable energy generation, advance sustainable waste management techniques, and uncover beneficial agriculture methods, necessitated anaerobic co-digestion of grounded corncob (GC) biologically pretreated with cattle rumen (inoculum) and poultry poos (PP) for biogas generation, as discussed in this study, Corncob biomass (CB) and PP (substrates) were obtained at the teaching and research laboratory in LAUTECH Ogbomoso. CB was pretreated using mechanical grinding and sieving methods and then divided into two portions labelled A and B, using sieve sets of 0.30mm and 0.45mm. The ratio of the combination of substrates: GC: PP: inoculum is 1:0.5:0.5. Standard procedures were used to assess the physicochemical parameters of the substrates and digestates. Central Composite Design (CCD) was used to batch the experimental design of pretreated samples A and B with PP and inoculum to produce biogas which was analysed for methane content using a gas chromatograph mass spectrometer. Response Surface Methodology (RSM) was used to optimize data generated for temperature, pH, retention time, total solids, and volatile solids (VS) using the 'Design-Expert Application' version 11. The biogas yields for experiments A and B were 1.368L/kg VS and 1.221L/kg VS while Methane compositions were 60.44% and 57.58% respectively. The optimized data for A and B were; temperature (40 ^{o} C, 40 ^{o} C); pH (8.0, 6.0); retention time (30, 30 days); total solids (12, 4 g/kg); and volatile solids (12, 12 g/kg) respectively. The model's coefficient of determination (R^2) was high (0.9267) for A, indicating strong modelling and prediction accuracy, thus, recommending the usage of corncob for bioenergy generation.

INTRODUCTION

The world's over-reliance on fossil fuels is taking its toll on humanity in terms of environmental degradation, disease spread, and climate change/global warming via GHG emissions (Anjum et al., 2016; Guenther-Lübbers et al., 2016; Priebe et al., 2016). For this purpose, it is necessary to integrate cleaner production technology and appropriate policy implementation to address the world's myriad environmental difficulties, particularly those related to energy generation and consumption (Klemes et al., 2012; Kalbar et al., 2016). Fossil fuels account for about 88 percent of worldwide energy use, which is often accompanied by environmental challenges such as GHG emissions and contamination of soil, air, and water (Gonzalez-Garca et al., 2016).

Anaerobic digestion is a proven technological method of converting organic matter, thereby producing biogas and nutrient-rich digestate (Leite et al., 2016). It has been globally applied in the treatment of diverse wastes, agricultural residues, and energy crops and is a veritable means of abating environmental pollution. The organic fraction of poultry dropping is biodegradable and thus fitting for anaerobic digestion for methane yield (Dalkilic and Ugurlu, 2015). However, the digestion of poultry dropping is usually slowed down due to its low C/N ratio, richness in nitrogen, and high total ammonia levels. Therefore, co-digestion with other carbon-rich substrates is often recommended to guarantee the success of anaerobic digestion and subsequent improvement in biogas yield. Co-digestion of substrates has been carried out by various researchers utilizing different biomass and waste materials and this enhanced the biodegradability and high biomethane yield from such materials (Dahunsi et al., 2017).

Maize cob waste is available worldwide in high amounts, as maize is the most produced cereal in the world (FAO, 2023). Maize cob is generally left in the crop fields, but due to its low biodegradability, it has a negligible impact on soil fertility. Moreover, maize cob can be used as the substrate to balance the C/N ratio during the anaerobic co-digestion with other biodegradable substrates (Agric4profits, 2024)

Corn cobs are currently being used for heat in some parts of Europe; while in the United States, there is a notable level of cobs milled as base products for various industries (feed filler–additive, oil-drilling adsorbent, desiccant, and as a bio-abrasive). This feedstock is rapidly being developed as a feedstock for cellulosic ethanol and gasification projects (Agric4profits, 2024).

Corn cobs are dense and relatively uniform, and they have a high heat value, generally low N, and can be collected during corn grain harvest. Harvesting cobs has little potential impact on soil residue, soil carbon, or the nutrient requirements of subsequent crops. Corn cobs appear to be a relatively sustainable, but relatively low-yielding feedstock. Being a lignocellulosic biomass, it has a high potential for biodegradation during hydrolysis and fermentation by hydrolytic and acidogenic microorganisms.

Lignocelluloses are frequently employed for the generation of renewable and alternative energy due to their abundance/availability and key roles in GHG emissions reduction when properly exploited, globally (Auburger et al., 2016; Shane et al., 2016). However, the high lignin content of these biomasses has remained a key barrier to their commercial use (Carrere et al., 2016). Several pretreatment approaches, such as biological, mechanical, thermal, and chemical, have been studied to enhance the biodegradability of lignocellulosic biomasses to overcome this major obstacle (Caiet al., 2016; Lalak et al., 2016; Li et al., 2016a, b).

These pretreatments often improve digestion efficiency, sludge reduction, digestate dewatering, and microbial diversity, all of which lead to increased methane output. Alkaline pretreatment has proven to be more suited for lignocelluloses than other treatments, particularly in terms of cost and increased methane output (Dongyan et al. 2014). Livestock waste such as cow dung, and poultry waste generated in large volumes is on the increase with little or no proper disposal treatment thereby resulting in environmental problems which are also applicable to plant weeds and household wastes (Alia et al., 2017).

The digestate obtained at the end of the digestion period can be utilized as a soil improvement to increase soil fertility for agricultural produce output (Oladejo et al., 2020). The optimization of bioprocess parameters is an important step for the success of the anaerobic digestion process (Emeko et al., 2015). The aim of this research therefore was to evaluate the biogas- producing potentials of corncob in co-digestion with poultry droppings. The process parameter optimization of the study was equally carried out using the Response Surface Methodology (RSM).

MATERIALS AND METHODS

Sample Collection and Preparation

Corncob biomass and fresh poultry droppings were collected from the Ladoke Akintola University of Technology (LAUTECH) Teaching and Research

Farms and transported to the site of the experiment. Fresh cattle's rumen content was also obtained from the Atenda slaughterhouse (abattoir) in Ogbomoso, Oyo State, and used as inoculum for digestion. The use of rumen content as inoculum has been reported in many studies (Alfa et al., 2014a, b). Being a lignocellulosic material, corncob biomass was pre-treated using a modification of already described mechanical, thermal, and biological pretreatment methods (Oladejo and Akeredolu, 2024; Oladejo et al., 2025). A mechanical approach, using a hammer mill was used to crush the corncob biomass into particle sizes 0.3mm and 0.45mm, with the aid of particle size distribution standard sieves set, and was then labeled 'A.' and 'B' respectively, as previously described in (Oladejo et al., 2020). The crushed corncob biomass was then heated for one hour at 80 C in the CLIFTON, 88579 water bath (NICKEL ELECTRO Ltd., ENGLAND), as greater temperatures have been documented to have an unfavorable effect on the AD system (Liu et al., 2012).

Analytical Procedure

Before and after the digestion, the physicochemical parameters of the inoculum and the fermenting materials were evaluated in the Environmental Engineering Laboratory of Landmark University using standard methods (APHA, 2012). Parameters evaluated include Total Solids (TS), Volatile Solids (VS), pH, Total Carbon, Total Nitrogen (TN), Total Phosphorus (TP), Phosphates (PO_4^{2-}), Sulphates (SO_4^{2-}) Potassium (K), Sodium (Na), Magnesium (Mg), Calcium (Ca), Nitrates (NO_3^-), Ammonium (NH_4^-), Iron (Fe), Copper (Cu), Zinc (Zn), Aluminium (Al) and Manganese (Mn) using the Palintest(R) Photometer 7100 (PHOT.1.1.AUTO.71) and Photometer 7500 (PHOT.1.1.AUTO.75) advanced digital-readout colorimeter (England). The photometer was operated at an absorbance of 0.5 and a wavelength of 450 nm in triplicates for all samples.

Design of Experiment via central composite rotatable design (CCRD)

Central Composite Rotatable Design (CCRD) experimental design was employed to design the bioconversion of the biomass to biogas because of its success in improving bioprocessing systems (Emeko et al., 2015). Five-level-five factors design was applied, which generated 50 experimental runs including 42 non-centre points and 8 centre points to provide information regarding the interior of the experimental region thus making it possible to evaluate the curvature effect. The alpha value used was 2.37841. Selected factors for biogas optimization were Temperature (^{o} C): A, pH: B, Retention time (days): C, Total solids (g/kg): D, and Volatile solids (g/kg): E. These factors were selected based on their importance in biogas generation and the chosen ranges are based on reports of earlier research. The optimal temperature for most mesophilic digestions has been reported to vary between 30 and 40 ^{0}C (McKennedy and Sherlock, 2015), pH of 6.5–8 has been reported to be best for methanogenesis (Olanipekun and Oladejo, 2022a, b; Oladejo et al., 2020; Oladejo and Akeredolu, 2024; Oladejo et al., 2025), while the optimal retention time for mesophilic digestion has equally been reported to be within 20–30 days depending on the ambient temperature. For total and volatile solids, it has been documented that for efficient operation of a liquid anaerobic system, the solids content must be less than 15% but not lower than 4% to avoid total failure (Jain et al., 2015).

The various ranges for optimization used in this study were therefore chosen based on the above submissions in order to arrive at the very optimal condition for the most efficient anaerobic digestion of grounded corncob, poultry poos and inoculum.

Experimental procedures for samples A and B

1500g each of mechanically pretreated corncob of particle sizes 0.3mm and 0.45mm (samples A and B) were mixed with 1500g of fresh cow dung and poultry waste in a predetermined ratio of 1:1, to form the feedstock, and were further diluted with water in the ratio of 1:1 w/v to form a slurry thus making a total of 6000cm^3. Hence, the ratio of the combination of substrates: corncob: poultry dropping: and inoculum is 1:0.5:0.5. A portion of 574cm^3 of the slurry was taken for physiochemical analysis. The capacity of the biodigester was 6000 cm^3 (6 L) and hence a total slurry of 4226 cm^3 which occupied four-fifths of the biodigester while one-fifth was left for the collection of the gas.

Several metrics were assessed at various points throughout the AD to determine treatment efficiency. Daily measurements of generated biogas, as well as physicochemical parameters of feedstock and digestates, are recorded. The average temperature readings and pH values were taken from the daily readings twice and the average was recorded. The daily gas collection used the water displacement method previously described (Dahunsi et al., 2017). A Gas Chromatography-Mass Spectrometry/Electron Ionization (GC-MS/EI) model with a flame ionization detector (FID) was used to characterize produced biogas to measure methane and other compounds.

Statistical Data Analysis

The data obtained from biogas generation from each of the digestion regimes was analyzed statistically using response surface methodology, to fit the quadratic polynomial equation generated by the Design-Expert software version 9.0.3.1 (Stat-Ease Inc., Minneapolis, USA). To correlate the response variable to the independent variables, multiple regressions were used to fit the coefficient of the polynomial model of the response. The quality of the fit of the model was evaluated using a test of significance and analysis of variance (ANOVA). The fitted quadratic response model is described by:

$$Y = \beta_O + \sum \beta_i X_i + \sum \beta_{ii} X_i^2 + \sum \beta_{ij} X_i X_j \ldots\ldots\ldots(1)$$

where Y is the response variable, bo is the intercept, bi (i = 1, 2, k) is the first-order model coefficient, bij is the interaction effect, bii = the quadratic coefficients of Xi, and e is the random error. The model was validated with the same digesters using conditions predicted by the software. The deviations of actual values from the observed values were then plotted.

DISCUSSION

Physicochemical analysis and biogas production

The result of the physical and chemical analysis of the substrate (before and after digestion) and that of the inoculum is shown in Table 1. The pH of the substrates in all digesters was slightly alkaline, and the temperature of the digesters also remained within the mesophilic range (30–40 ^{0}C), throughout the digestion process and falling within the experimental design range by Response Surface Methodology (RSM). All the temperature readings throughout the digestion fluctuated between 34.9 and 35 ^{0}C which was within the experimental design. The results of all physical and chemical analyses showed an increase in values only for Manganese, while there were reductions in the values of other parameters after the digestion. This has been previously observed by Olanipekun and Oladejo (2022b). In all the two experiments, biogas production commenced between the 2nd day and the 29th day after which a fall was observed and remained diminishing till the end of the experiments (Fig. 1). The biogas yields from samples A and B were 1.36752 and 1.221 (L/kg VS), respectively (Fig. 1), with Gas chromatography analysis revealing 60.44% methane and 24.14% carbon dioxide for sample A and 57.58% methane and 21.72% carbon dioxide for sample B as presented in Figure 2. Overall, sample A outperformed B, hence, further statistical analysis and optimization were carried out on experiment A because of the high methane yield.

Table 1: Physiochemical Analysis of Substrate and Digestate

S/N	Parameters	Corncobs	Fine substrate 0.3mm	Coarse substrate 0.45mm	Fine digestate	Coarse digestate
1	pH	5.92	7.03	7.05	7.08	7.11
2	T.N	23.1	26.2	26.4	24.1	24.7
3	Total Carbon	197.9	395	392	296.2	301.8
4	Potassium	2.9	4.6	4.2	4.4	3.9
5	Phosphate	1.41	2.61	2.36	2.48	2.32
6	Sulphate	22	78	65	67	62
7	Calcium	12	48	40	42	36
8	Magnesium	34	86	68	81	67
9	Manganese	0.014	0.023	0.016	0.024	0.012
10	Iron	3.20	6.84	5.96	6.72	5.92
11	Zinc	13.0	26.2	24.8	24.9	23.9
12	Aluminum	0.47	1.06	0.96	1.00	0.94
13	Copper	2.00	3.84	3.60	3.73	3.54
14	Nitrate	1.80	3.30	3.24	3.26	3.12
15	Total Alkalinity	270	460	436	450	420
16	C/N	8:1	15:1	15:1	12:1	12:1
17	BOD	165	340	315	324	292
18	COD	482	1948	1860	1930	1820
19	% T.S	29.86	17.4	19.11	21.84	24.93
20	% F.S	24.64	13.74	15.81	18.60	20.78
21	% V.S	68.95	83.74	81.42	76.89	73.92
22	Moisture content	59.62	65.41	63.80	60.68	60.15
23	Volume of sample	1490	4480	4480	4379	4416

24	Weight of sample	1711	5146	5234	4835	4921

RSM optimization of biogas data

Table 2 shows the experimental design matrix by central composite design (CCD) for a five-level-five-factors response surface study for biogas yield for experiment A: fine corncobs (0.3 mm) + cow + poultry poos + inoculum. The experimentally observed and predicted yields as well as the residual values are shown in the table. From the results obtained, as shown in Table 3, the Model F-value of 60.65 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Furthermore, P-values less than 0.0500 indicate model terms are significant. In this case, C, D, E, AB, AC, AD, AE, BC, BE, CD, CE, DE, A^2, B^2, C^2, D^2, E^2 are significant model terms. This is because values greater than 0.1000 indicate the model terms are not significant. The following is a description of the fit model statistics and the values obtained. The predicted R^2 of 0.9267 was very close to the adjusted R^2 of 0.9762 as normally expected because the difference is not more than 0.2. This therefore indicated that there was not a large block effect with the model and/or data. Also, adequate precision is used to measure the signal-to-noise ratio and usually, a ratio greater than 4 is always desirable. Therefore, the ratio of 29.8158 of this study indicated that the signal is adequate and this means the model is fit enough for the navigation of the design space.

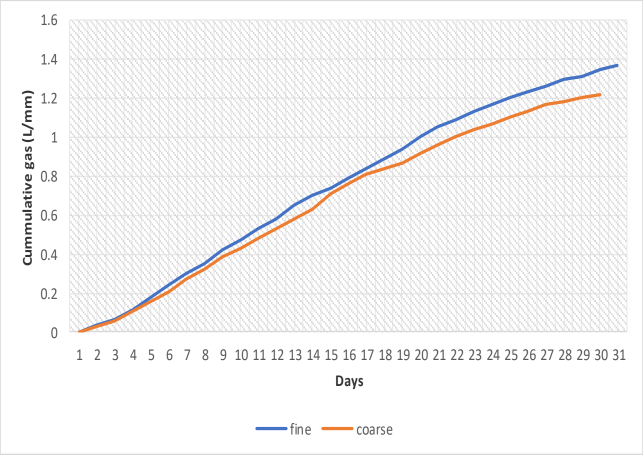

Figure 1: Cumulative gas production against the number of days

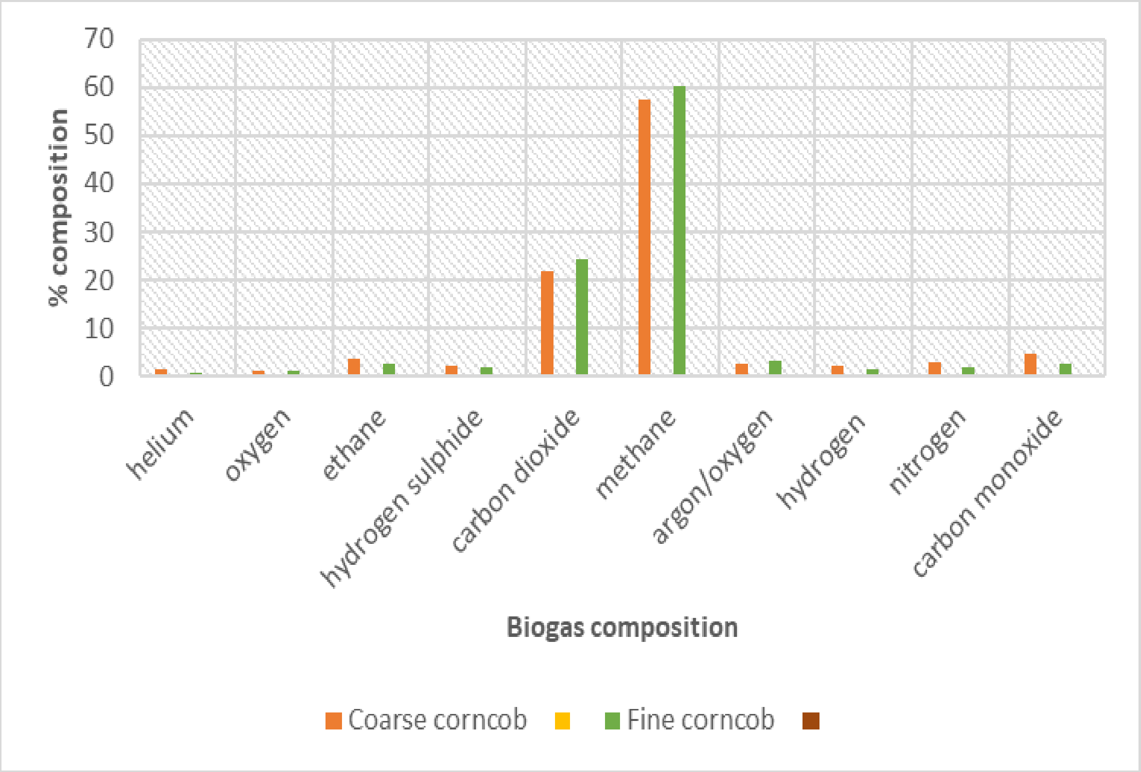

Figure 2: Graph showing the percentage composition of biogas produced

Table 2: Experimental design matrix by central composite design (CCD) for five-level-five-factors response surface study for biogas yield for experiment A: fine corncobs (0.3 mm) + cow + poultry poos + inoculum

Run	A	B	C	D	E	Actual value L/kgVS	Predicted Value L/kgVS	Residual	Leverage
1	30	8	20	4	12	0.01628	0.0140	0.0023	0.857
2	40	8	30	12	12	0.01628	0.0169	-0.0006	0.929
3	30	8	30	12	12	0.03256	0.0302	0.0023	0.857
4	40	8	30	4	4	0.03256	0.0320	0.0006	0.929
5	30	8	20	4	4	0.03256	0.0343	-0.0017	0.857
6	30	8	30	12	4	0.04884	0.0506	-0.0017	0.857
7	35	7	36.9	8	8	0.04884	**0.0488**	**0.0000**	**1.000(2)**
8	30	8	30	4	4	0.04884	0.0477	0.0012	0.714
9	40	6	30	12	12	0.04884	**0.0488**	**0.0000**	**1.000(2)**
10	35	7	25	8	-1.5	0.04884	**0.0488**	**0.0000**	**1.000(2)**
11	35	7	25	8		0.04884	0.0488	0.0000	0.125
12	23.1	7	25	8	8	0.06512	**0.0651**	**0.0000**	**1.000(2)**
13	35	7	25	8	8	0.04884	0.0488	0.0000	0.125
14	35	7	25	8	8	0.04884	0.0488	0.0000	0.125
15	30	6	30	4	4	0.04884	**0.0488**	**0.0000**	**1.000(2)**

16	35	7	25	8	8	0.04884	0.0488	0.0000	0.125
17	35	7	25	8	8	0.04884	0.0488	0.0000	0.125
18	30	8	20	12	12	0.03256	0.0355	-0.0029	0.714
19	40	8	20	12	4	0.03256	0.0331	-0.0006	0.929
20	40	6	20	4	4	0.01628	**0.0163**	**0.0000**	**1.000**(2)
21	40	8	20	4	12	0.01628	0.0169	-0.0006	0.929
22	35	7	25	8	8	0.04884	0.0488	0.0000	0.125
23	30	8	30	4	12	0.01628	0.0180	-0.0017	0.857
24	35	7	25	-1.5	8	0.03256	**0.0326**	**0.0000**	**1.000**(2)
25	35	7	25	8	17.51	0.03256	**0.0326**	**0.0000**	**1.000**(2)
26	30	8	20	12	4	0.04884	0.0465	0.0023	0.857
27	35	7	25	17.5	8	0.04884	**0.0488**	**0.0000**	**1.000**(2)
28	35	7	25	8	8	0.04884	0.0488	0.0000	0.125
29	40	8	20	12	12	0.03256	0.0314	0.0012	0.714
30	35	7	25	8	8	0.04884	0.0488	0.0000	0.125

Table 3: Analysis of variance (ANOVA) for Quadratic model and Test of significance and all regression coefficient terms for biogas yield for experiment A: fine corncobs (0.3 mm) + cow + poultry poos

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0051	20	0.0003	60.56	< 0.0001	significant
A-Temperature	1.292E-06	1	1.292E-06	0.3070	0.5930	
B-pH	1.945E-06	1	1.945E-06	0.4623	0.5136	
C-Retention time	0.0001	1	0.0001	30.49	0.0004	
D-Total solids	0.0001	1	0.0001	31.50	0.0003	
E-Volatile solids	0.0001	1	0.0001	31.50	0.0003	
AB	0.0000	1	0.0000	9.31	0.0138	
AC	0.0001	1	0.0001	12.00	0.0071	
AD	0.0000	1	0.0000	6.75	0.0288	
AE	0.0001	1	0.0001	12.00	0.0071	
BC	0.0001	1	0.0001	29.68	0.0004	
BD	4.502E-06	1	4.502E-06	1.07	0.3279	
BE	0.0001	1	0.0001	23.82	0.0009	
CD	0.0001	1	0.0001	12.00	0.0071	
CE	0.0001	1	0.0001	12.00	0.0071	

DE	0.0001	1	0.0001	12.00	0.0071
A^2	0.0001	1	0.0001	14.64	0.0041
B^2	0.0004	1	0.0004	93.64	< 0.0001
C^2	0.0001	1	0.0001	20.29	0.0015
D^2	0.0001	1	0.0001	25.20	0.0007
E^2	0.0001	1	0.0001	25.20	0.0007
Residual	0.0000	9	4.207E-06		
Lack of Fit	0.0000	2	0.0000		
Pure Error	0.0000	7	0.0000		
Cor Total	0.0051	29			
R^2	0.9926				
Adjusted R^2	0.9762				
Predicted R^2	0.9267				
Adeq Precision	29.8158				

Final Equation in Terms of Coded Factors:

$$Y = 0.04884 - 0.000726786 * A - 0.000872143 * B + 0.0071225 * C + 0.00342245 * D -0.00342245 * E + -0.00421536 * AB + -0.00232571 * AC + -0.00174429 * AD + 0.00232571 * AE - 0.00741321 * BC + 0.000938266 * BD - 0.00442684 * BE - 0.00232571 * CD -0.00232571 * CE + 0.00232571 * DE + 0.00257235 * A^2 - 0.0150148 * B^2 - 0.00299464 * C^2 -0.00143896 * D^2 - 0.00143896 * E^2$$

Y = (Biogas Yield, L/kg VS); A = Temperature; B = pH; C = Retention time; D = Total solids: E = Volatile solids.

CONCLUSION

According to this present study, digestion of grounded corncob with poultry poos and inoculum produced biogas of notable values within the expected optimal values. The analysis of the methane gas samples obtained showed that both sample A (60.44%) and B (57.58%) produced enough methane percentage required for a standard biogas sample; however, sample A, finer corncob co-digested with poultry poos and inoculum produced a higher value of methane and ultimately, biogas quality. The study concluded that the selected operating conditions such as pH, temperature, total solids, volatile solids, and retention time had significant cumulative effects on the eventual biogas yield. Moreover, the current study has established that corncob should no longer be viewed as an agricultural residual waste but an energy crop- waste because of its rich energy and biofertilizer-producing potential. Environmentally, it improves renewable energy generation, advances sustainable waste management techniques, and uncovers beneficial agriculture methods.

ACKNOWLEDGMENTS

The efforts of the technical personnel in the Environmental laboratory of Civil Engineering Department, Landmark University, Omu Aran, kwara State is appreciated, for helping out in the course of this work.

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