INVESTIGATION OF THE EFFECTS OF STARTING pH, MASS AND RETENTION TIME ON BIOGAS PRODUCTION USING POULTRY DROPPINGS AS FEEDSTOCK

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ABSTRACT

The effect of starting pH, mass and retention time on biogas production was studied using poultry droppings as the feedstock. A full factorial experiment was designed and performed with starting pH set at 5, 6, 7, 8 & 9 for feedstock mass of 100g and 200g at specific retention times. The results presented an optimal biogas yield at pH=7 with a volume of 722 and 1046cm³ while pH=5 had the least with 255 and 481 cm³ at 100g and 200g mass respectively. The starting pH, mass and retention time and the interaction of starting pH and mass had significant effect on biogas yield at 5% significance level. The R-Square value obtained from the analysis was 92.1%. Thereafter, a log-linear regression model for predicting biogas yield was generated and was found to provide adequate prediction given its MAPE value of 19.97.

Keywords: Biogas Production, Mass, Poultry Droppings, Retention Time, Starting pH.

1. INTRODUCTION

Increasing energy need, population growth, declining fossil fuels and the environmental issues that surround the use of fossil fuels has led to an increasing interest in clean alternative sources of energy. According to Weiland [1], fossil fuel usage has significantly contributed to the level of Carbon (IV) Oxide (CO_2) emissions and greenhouse gases (GHGs). In order to curb the numerous problems associated with the use of fossil fuels, research is tilting towards renewable energy sources such as, solar, wind and biomass [2-3]. Also, renewable energy sources are affordable and environment-friendly [4-6].

Among the renewable energy sources, biogas energy has received much interest in recent times [7]. This is as a result of its applicability in small and large scale energy generation [8]. Also, its beneficial waste management and environmental preservation characteristics has further encouraged its adoption [9-10].

Biogas can be generated from wastes, energy crops and animal faeces. Biogas constituents are primarily methane and CO_2 and are suitable for heat and power production [11-12]. According to Bharathiraja *et al.*; Haryanto *et al.* [13-14], agricultural residues such as, livestock faeces, residues and wastes from food industries are the most suitable substrates for biogas production. They are readily available, environment friendly and have economic values. However, other technical parameters that are vital to biogas production exists. Such include, concentration, temperature, pH, hydraulic retention time and reactor configuration [15-16].

The production of biogas, involves a biological conversion of biomass into biogas by microorganisms in the absence of oxygen [17]. This is a proven method and is referred to as Anaerobic Digestion (AD) [13]. It is an efficient and a beneficial method for biodegradation, biofuel production and sustainable waste management of waste [13;18-20]. However, the operation performance of AD which is measured based on the biogas yield is dependent on factors such as the concentration, temperature, mass etc. Thus, to achieve maximum biogas yield from a substrate, it is necessary to know the appropriate settings and the

point at which these technical parameters aid optimal biogas yield.

Previous research has considered the influence of various feedstock on biogas yield. Such as, agricultural wastes, food wastes and spoilt milk [21-23]. In Belostotskiy *et al.* [24], the effect of anaerobic digestion of chicken manure as a single substrate in biogas production was investigated with the organic loading rate as the main factor considered. The loading was done alongside the use controlled ammonia concentration to reduce the amount of inhibiting ammonia in the process. The results gave an insight into the potential of chicken manure as a suitable substrate. Kim [25] investigated the influence of temperature and hydraulic retention time on anaerobic digestion of food waste. It was concluded that more biogas yield is obtained at increased thermophilic temperature than at mesophilic. Budiyono [26] studied the effect of substrate concentration on biogas production using cattle manure with rumen fluid as inoculum. Dennis [17], also performed similar experiment and introduced inoculums into cattle manure to observe the effect on biogas yield. The result showed that increase inoculums resulted into increase in biogas production. Raheman and Mondal [27] investigated the solid concentration of a Jatropha in biogas production. Kafle *et al.* [28] studied the effects of co-digestion using waste silage and swine waste at mesophilic temperatures. Jayaraj *et al.*; Deepanraj *et al.* [29-30] studied the effect of pH and temperature respectively on biogas production with food waste as the substrate. However, the review showed that there are limited works on the effects of starting pH, the mass of substrate, retention time and their contributory effects in biogas yield. These three technical parameters are yet to be dealt with exhaustively. Thus, this has become the aim of this research. The research is to investigate the individual and contributory effects of the three technical parameters on biogas production from poultry droppings.

2. METHODOLOGY
2.1. Substrate Sourcing, Collection and Design of Experiment

Poultry droppings were sourced from the teaching and research farm of a University located in the south-west of Nigeria. Following this, the experiment was designed using three factors namely; starting pH, mass and retention time at a mixed level of 5, 2, and 10 respectively. A full factorial experimental design

was created. The experiments were thereafter carried out within the laboratory using the necessary equipment and a feedstock size.

The designed experiments were carried out on the basis of the following Null (H_{0i}) and alternative (H_{1i}) hypotheses:

1. H_{o1}: There is no significant main effect of the starting pH on biogas yield
2. H_{11}: There is a significant main effect of the starting pH on biogas yield.
3. H_{o2}: There is no significant main effect of the mass of substrate on the biogas yield
4. H_{12}: There is a significant main effect of the mass of substrate on the biogas yield
5. H_{o3}: There is no significant main effect of retention time on the biogas yield
6. H_{13}: There is a significant main effect of retention time on the biogas yield
7. H_{o4}: There is no effect of the interaction between pH and mass on the yield of biogas
8. H_{14}: There is an effect of the interaction between pH and mass on the yield of biogas
9. H_{o5}: There is no effect of the interaction between pH and retention time on the yield of biogas
10. H_{15}: There is an effect of the interaction between pH and retention time on the yield of biogas
11. H_{o6}: There is no effect of the interaction between mass and retention time on the yield of biogas
12. H_{16}: There is an effect of the interaction between mass and retention time on the yield of biogas
13. H_{o7}: There is no effect of the interaction between pH, mass and retention time on the yield of biogas
14. H_{17}: There is an effect of the interaction between pH, mass and retention time on the yield of biogas

At a p-value of less than 0.05, H_{0i} was rejected and H_{1i} accepted, otherwise H_{0i} was accepted.

2.2. Experimental setup
2.2.1. Apparatus

The following apparatus were used for the experiment: measuring cylinders, mini-sized airtight digesters fabricated from plastic materials fitted with rubber tubes to avoid biogas leakage, thermometer, weighing balance, pH meter, tetraoxosulphate (VI)

acid (H_2SO_4) and Sodium Hydroxide (NaOH) solutions of 0.1 Molar concentration, retort stands and clamps.

2.2.2. Experimental Procedure

Firstly, a sample of the sourced poultry droppings was analysed to establish its Dry matter (DM) content. This was achieved by oven-drying a dry sample of the substrate at $105^o C$ for 15 hours. The DM content of the substrate was subsequently determined by weighing and checking the substrate weight before and after the drying process. This was done to ensure that the DM content of the substrate did not exceed the maximum recommended amount [31].

Ten runs of the experiment made up of one hundred observation windows were carried out in two replicates. In each run, the poultry droppings was measured into 100g and 200g using weighing balance. The droppings were then converted into its substrate form by dilution in water ($100g$ and $200g$ were diluted with $100cm^3$ and $200cm^3$ respectively) and fed into a digester. A tube from the fitted digester was inserted into clamped water filled inverted cylinders and placed in the water bath. The pH meter was subsequently used to measure the initial pH of the sample. Using the H_2SO_4 or NaOH solutions, the sample was then conditioned to various starting pH levels (5, 6, 7, 8 and 9) substrate pH level. The runs of the experiment were observed on a 24-hour window of increasing retention time. The mesophilic temperature range ($26^0 C - 32^0 C$) was employed for carrying out the experiment. Each run of the experiment was terminated at the tenth period from the first observation window. Once the desired retention time for a run was attained, the experiment was terminated for that run. The cumulative volume of biogas yield was measured and recorded for each observation window one day after the substrate had been charged. The method of biogas collection used was the downward displacement of water technique. The retention time during each observation window was also recorded. At the maximum retention time for each run, the terminating pH was also measured and recorded.

A factorial design worksheet was used for recording the experiment design details and all necessary information obtained in the course of carrying out the experiment. The analysis of the resulting data was subsequently undertaken by the use of the Stat-Regression-Regression tab of the software package; MINITAB 16. The daily and cumulative biogas yield

for behaviour i run Y_i, was theorized to follow a log-linear relationship as expressed in equation (1).

$$Ln(Y_i) = X_{1i} + X_{2i} + X_{3i} + X_{1i}^2 + X_{1i}X_{2i} + X_{1i}X_{3i} + X_{2i}^2 \\ + X_{2i}X_{3i} + X_{3i}^2 + X_{1i}^3 + X_{1i}^2 Xi_2 + X_{1i}^2 X_{3i}$$

$$X_{1i}X_{2i}^2 + X_{1i}X_{3i}^2 + X_{2i}^3 + X_{2i}^2 X_{3i} + X_{3i}^3 + X_{1i}X_{2i}X_{3i} \quad (1)$$

Where: X_{1i}, X_{2i}, X_{3i} the values of pH, mass and retention time for each run i ($i = 1, 2, 3, ..., 100$).

The yield residual plots, as well as the regression analysis results from the software, were employed to determine the factors which exhibited main and interacting effects on the biogas yield. The index of the significance of the effect of the factors (p-value) was set at $p \le 0.05$ such that effects and interactions which fell within this region were accepted and presented as a reduced form of the relation $(Ln\{Y_i\})^R$ while those which fell outside were rejected. In order to obtain a better grasp of the model's prediction precision, the Mean Absolute Percentage Error (MAPE) was subsequently employed in determining the accuracy of the non-logarithmic predictions from Y_i^R using equation (2)

$$\delta = \sum_{i=1}^{i=n} 100 \left\{ \frac{|Y_i^a - Y_i^R|}{Y_i^a} \right\} \quad (2)$$

Where;

$$Y_i^R = Exp(\ln\{Y_i^R\}) \quad (3)$$

Where δ: MAPE of the model prediction, Y_i^a: Experimental value of biogas yield at run i ($i = 1, 2, 3 ... n \{n \le 100\}$)

3. RESULTS AND DISCUSSION

The DM content of the substrate was found to be 39.26%. This indicated that the fresh poultry droppings used was a suitable feedstock for the generation of biogas [31]. Table 1 shows a part of the factorial design worksheet contents including the independent and response factors as well as the terminating pH for each experimental run. The daily biogas yield of the poultry droppings obtained at various pH conditions within the retention time studied is shown in Figures 1 and 2.

Table 1: Biogas yield results based on effective experimental runs carried out

S/N	Mass (g)	Starting pH	Residence time (days)	Cumulative Yield (cm³)	Terminating PH
1*	100	5	1	0	5.6
2	100	5	2	9	
3	100	5	3	63	

S/N	Mass (g)	Starting pH	Residence time (days)	Cumulative Yield (cm³)	Terminating PH	S/N	Mass (g)	Starting pH	Residence time (days)	Cumulative Yield (cm³)	Terminating PH
4	100	5	4	107		54	200	5	4	185	
5	100	5	5	142		55	200	5	5	247	
6	100	5	6	180		56	200	5	6	316	
7	100	5	7	203		57	200	5	7	358	
8	100	5	8	218		58	200	5	8	396	
9	100	5	9	235		59	200	5	9	442	
10	100	5	10	255		60	200	5	10	481	5.8
11*	100	6	1	0	6.2	61*	200	6	1	23	
12	100	6	2	25		62	200	6	2	97	
13	100	6	3	109		63	200	6	3	235	
14	100	6	4	187		64	200	6	4	392	
15	100	6	5	247		65	200	6	5	476	
16	100	6	6	294		66	200	6	6	548	
17	100	6	7	327		67	200	6	7	626	
18	100	6	8	364		68	200	6	8	676	
19	100	6	9	392		69	200	6	9	739	
20	100	6	10	417	5.9	70	200	6	10	792	6.4
21*	100	7	1	8		71*	200	7	1	32	
22	100	7	2	73		72	200	7	2	119	
23	100	7	3	233		73	200	7	3	296	
24	100	7	4	339		74	200	7	4	459	
25	100	7	5	428		75	200	7	5	554	
26	100	7	6	501		76	200	7	6	661	
27	100	7	7	563		77	200	7	7	776	
28	100	7	8	632		78	200	7	8	872	
29	100	7	9	675		79	200	7	9	947	
30	100	7	10	722	6.7	80	200	7	10	1046	7.3
31*	100	8	1	2		81*	200	8	1	25	
32	100	8	2	62		82	200	8	2	97	
33	100	8	3	202		83	200	8	3	231	
34	100	8	4	299		84	200	8	4	395	
35	100	8	5	383		85	200	8	5	494	
36	100	8	6	458		86	200	8	6	575	
37	100	8	7	508		87	200	8	7	666	
38	100	8	8	564		88	200	8	8	768	
39	100	8	9	604		89	200	8	9	846	
40	100	8	10	640	7.5	90	200	8	10	921	7.3
41*	100	9	1	0		91*	200	9	1	5	
42	100	9	2	25		92	200	9	2	87	
43	100	9	3	85		93	200	9	3	189	
44	100	9	4	139		94	200	9	4	285	
45	100	9	5	194		95	200	9	5	350	
46	100	9	6	234		96	200	9	6	422	
47	100	9	7	262		97	200	9	7	516	
48	100	9	8	294		98	200	9	8	576	
49	100	9	9	324		99	200	9	9	629	
50	100	9	10	346	8.2	100	200	9	10	696	7.9
51*	200	5	1	9							
52	200	5	2	46							
53	200	5	3	112							

* Number of unused experiment runs

The residual plots (Normal probability plot, Residuals versus fitted values, Residuals vs observed order of fitted values and the histogram of the frequency of the residuals) obtained from the analysis is displayed in Figure 3 while the corresponding estimated regression coefficients are deferred in Table 2. The equations obtained from log-linear regression analysis which show the influence of pH, mass, retention time on the yield and is corresponding reduced form are presented in equations (3) and (4). It should be noted that yield values for the first day (Day 1) were not employed in the development of the model. This action was necessary so as to allow for consistent biogas yield from the experiments.
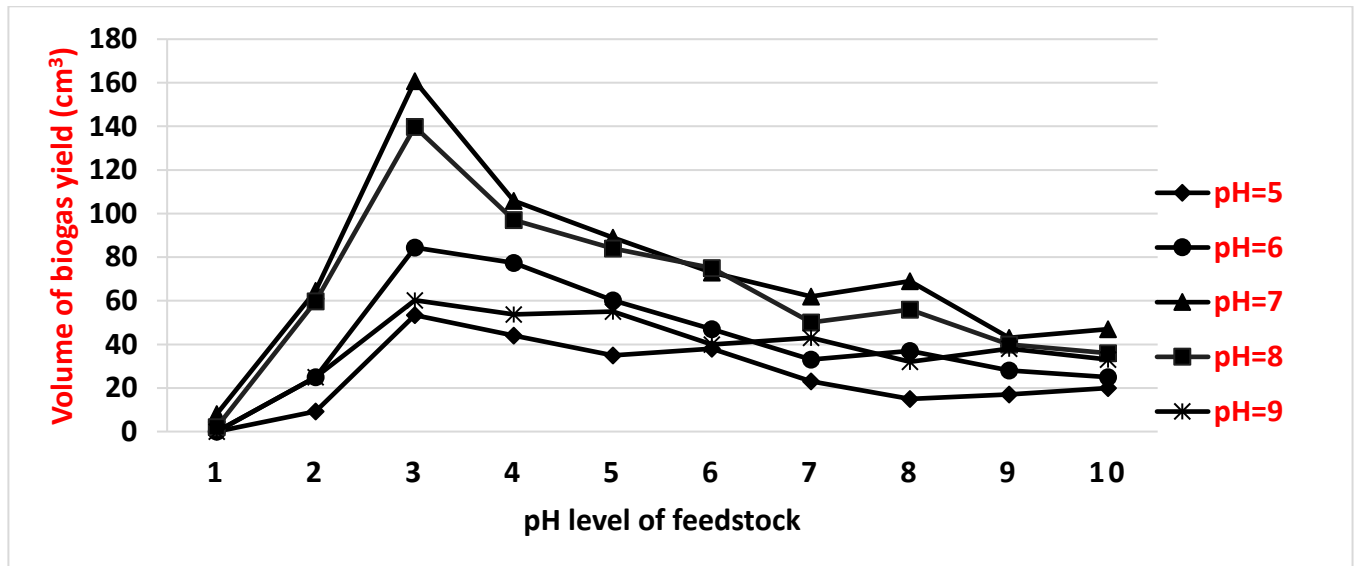
Fig. 1: Daily biogas yield from 100g of poultry droppings for digesters at different pH conditions
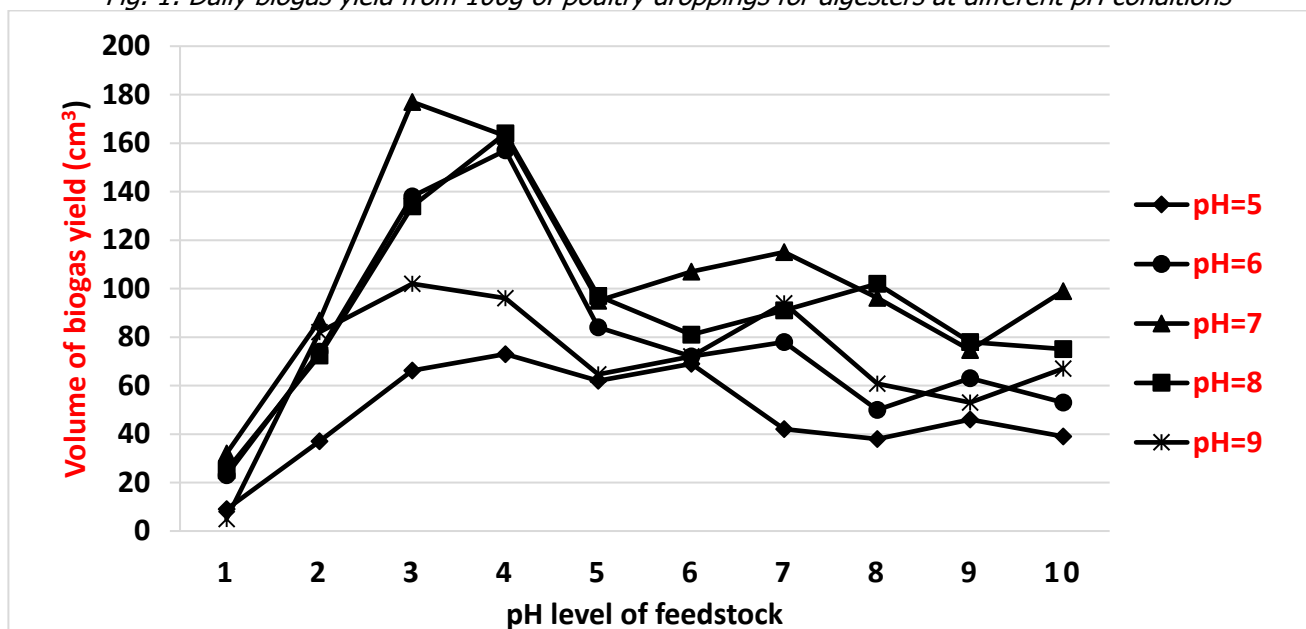

Fig. 2: Daily biogas yield from 200g of poultry droppings for digesters at different pH conditions.
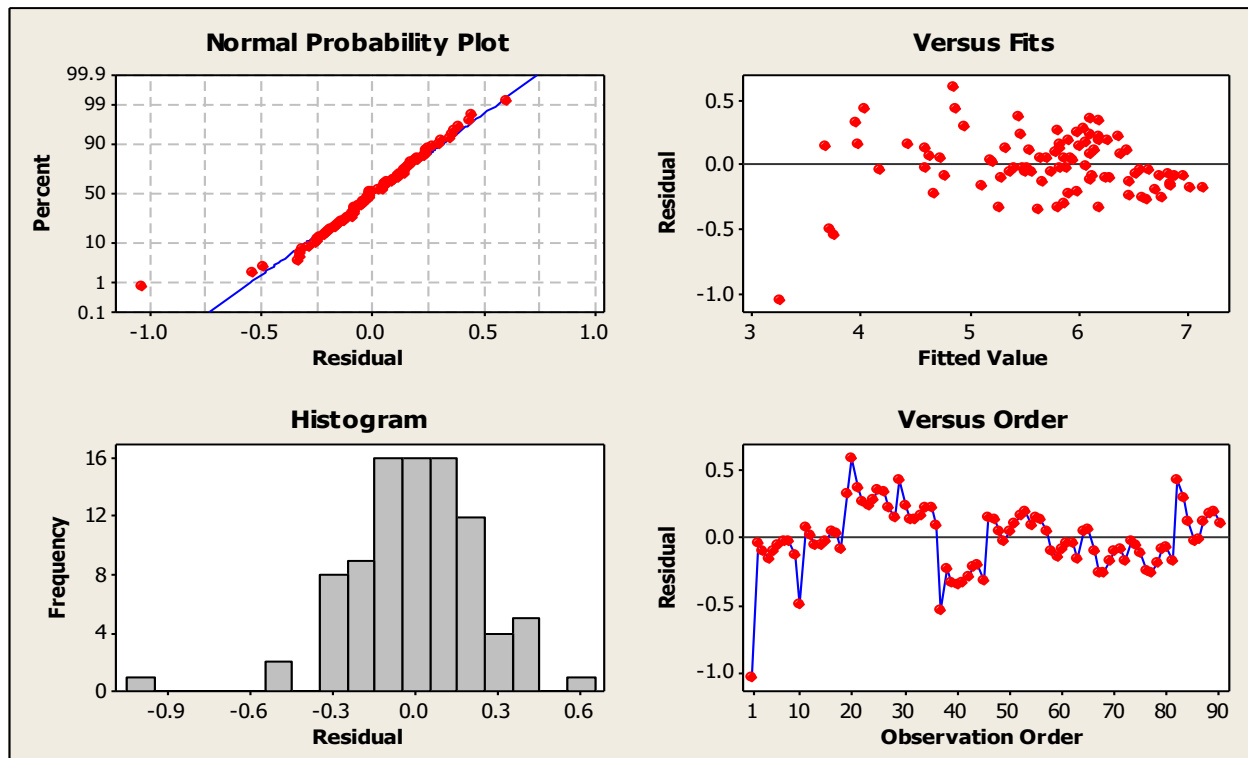
Fig. 3: Residual plots for the biogas yield obtained from poultry droppings at different pH values

Table 2: Regression coefficients for the reduced biogas yield analysis

	Predictor	Coefficient	Coefficient of Squared Effects	Students T-Test Value	P Value
1	Constant	-1.0025	0.5347	-1.87	0.064
2	X_1	0.1626	0.0584	2.78	0.007
3	X_2	-0.0428	0.0053	-8.02	0.000
4	X_3	1.9945	0.2071	9.63	0.000
5	$X_1 X_2$	0.0148	0.0014	10.36	0.000
6	X_3^2	-0.2623	0.0376	-6.97	0.000
7	$X_1^2 X_2$	-0.0011	-9.8770×10^{-5}	-10.99	0.000
8	X_3^3	0.0117	0.0021	5.65	0.000

Prediction Precision Parameters

S = 0.247919,　R-Sq = 92.8%,　R-Sq(adj) = 92.1%, MAPE=19.97

$$ln(Y_i) = -15.9 + 3.50\,X_{1i} + 0.0544\,X_{2i} + 2.98\,X_{3i} - 0.056\,X_{1i}^2$$
$$- 0.0129\,X_{1i}X_{2i} - 0.198\,X_{1i}X_{3i} - 0.001\,X_{2i}X_{3i} - 0.292\,X_{3i}^2$$
$$- 0.0153\,X_{1i}^3 + 0.0009\,X_{1i}^2 X_{2i} + 0.0001\,X_{1i}X_{2i}X_{3i} + 0.0089\,X_{1i}^2 X_{3i}$$
$$+ 0.0042\,X_{1i}X_{3i}^2 + 0.0117\,X_{3i}^3 \qquad (4)$$

$$ln(Y_i) = -1.00 + 0.163\,X_{1i} - 0.0428\,X_{2i} + 1.99\,X_{3i} + 0.0148\,X_{1i}X_{2i}$$
$$- 0.262\,X_{3i}^2 - 0.00109\,X_{1i}^2 X_{2i} + 0.0117\,X_{3i}^3 \qquad (5)$$

It was generally observed from the outcome of each run of the experiment that the terminating pH generally inclined or declined (as the case may be) from their respective starting pH to terminating pH

range between 6.0 and 8.0. This observation is similar to the finding in Kheiredine *et al.* [9] and indicates that in situations of uncontrolled anaerobic digestions, the pH tends to swing towards neutrality

after substrate incubation. The effect of this is that for biogas reactions that have starting pH values far away from 7.0, there is likelihood that there may be a delay in favourable biogas yield even in the face of longer retention times until pH that is positive to digestion is attained. The effect of different values of starting pH can also be observed in Figures 1 and 2, which clearly shows that substrates with initial pH 7, 8, 6, 9, 5 performed better in terms of the order of increasing biogas yield especially between the retention ranges of day 2 to day 8. Clearly, this indicates that starting pH that tends towards neutral possess the potential to produce better biogas yield. With respect to the cumulative biogas yield for 100g and 200g of substrate obtained at the end of day 10 (Table 1), pH=7 produced the highest (722 and 1046cm^3), followed by pH=8 (640 and 921 cm^3), pH=6 (417 and 792 cm^3), pH=9 (346 and 696 cm^3) and pH=5 (255 and 481 cm^3). Given that the starting masses and AD conditions of the substrates were the same, the implication of the result is that pH=7 is the ideal condition for starting AD processes for poultry droppings substrate.

In further investigating the influence of pH alongside mass and retention time independent factors, the outcome of the full regression analysis using the log-linear relation {Equation (3)} indicated that the pH, mass and retention time exhibited main effects on biogas yield. In addition, multiple effects of interactions among the independent factors were also observed. Such interactions included quadratic and cubic level interactions of pH with mass ($X_{1i}X_{2i}$, $X_{1i}^2X_{2i}$), pH with and retention time ($X_{1i}X_{3i}, X_{1i}^2X_{3i}, X_{1i}X_{3i}^2$) as well as with both mass and retention time ($X_{1i}X_{2i}X_{3i}$). However, some of the interactions were observed to be non-significant as their p values existed above the expected threshold of 0.05. Consequently, the rerun of the significant predictor variables yielded equation (4). As can be observed in Table 2, all the predictor variables of the biogas yield obtained from the reduced equation were significant. pH exhibited linear effect, as well as quadratic and cubic interaction effect with mass in influencing biogas yield.

Furthermore, the value of 92.8% obtained for the R-Square precision parameter implies a strong relationship between the biogas yield and its linear, quadratic and cubic predictor variables. Also, the adjusted R-square value of 92.1% obtained (Table 2), indicates that a high degree of variability in the response was captured and explained by the reduced

model. In addition, the standard error of regression (S) of about 0.25 indicates a high precision accuracy of the prediction model as this value indicate that the predicted values lie within the desired 95% prediction interval. From the residual plot (Figure 3) it can be observed that the probability plot of the predictions exhibits approximately normal distribution characteristics and the residuals versus fits plot demonstrate a random residual distribution. However, the residual versus order plot seems to indicate cyclic influences in the model. The cause for this behaviour was not investigated as the study was primarily focused on the effect of pH, mass and retention time on the biogas yield.

The MAPE of the reversed logarithmic values of the predicted biogas values was obtained as 19.97 (Table 2). This result indicates that the model showed a good prediction of the biogas yield. This result is in line with the MAPE evaluation measure proposed by [32].

4. CONCLUSION

An investigation to determine effect of pH on biogas yield obtained from poultry droppings using an experimental design approach has been undertaken. From the results, it was concluded that pH, mass of substrate and retention time exhibit statistically significant main effect as well as quadratic and cubic interaction effects on biogas yield. Also, the maximum yield of gas generated using 100g and 200g occurred when the pH was set to 7. Furthermore, it was concluded, that factorial design can be employed in estimation of biogas yield from poultry droppings.

5. CORRESPONDENCE

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