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A Kinetic Study of Biogas Produced from Cow and Elephant Dungs Using the Residual Substrate Concentration Approach

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Abstract Kinetic investigations of biogas produced from Cow dung and Elephant dung were carried out. Three samples tagged: 1 (100% Cow dung), 2 (50% Cow dung and 50% Elephant dung) and 3 (100% Elephant dung) were investigated in prototype batch bio-digesters using anaerobic digestion process. In addition, the kinetic studies of the three samples investigated were carried out. Results obtained revealed that Sample '2', the co-digestion of Cow and Elephant dung gave the best cumulative biogas production of $3.92*10^{-4}$ g/cm^3 and average yield of 0.084 5 over a period of 33 days. The kinetic of the process followed a shifting order (0-1); the kinetic parameters obtained can be used to size bio-digester and also monitor the rate of biogas produced. Therefore, the co-digestion of Elephant and Cow dung in equal proportion can be used to increase yield of biogas.

Keywords: *anaerobic, co-digestion, yield, cumulative concentration, prototype, batch, biogas, kinetic*

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1. Introduction

The need for energy to carry out our day to day activities both at our homes and in the industries cannot be overlooked. The demand for energy is increasing with increasing growth in technology and urbanization. Our main sources of energy (i.e. oil, natural gas and coal) are threatened by fear of depletion if new reserves are not found within the next thirty years [1]. In addition, the hydro-power are affected during the dry season when level of water in our hydro stations are low. As a result, it is important to research into other sources of energy preferably from renewable sources to compliment those of fossil fuels and hydro-power sources.

Energy are needed for cooking, lighting, heating, power our electronics and machines at home, schools, industries and other varieties of applications to better our standard of living on earth. In addition, the use of fossil fuels and biomass (such as fuel wood and agricultural wastes) as means of energy are accompanied by environmental pollution and a shift to environmentally friendly energy sources (from renewable sources) will curtail the rate of depletion of the Oxon layer.

Biogas energy is one out of the many sources of renewable energy. It is produced from many raw materials such as sewage, liquid manure of hens, animal dung, organic wastes and other forms of biodegradable wastes most especially from the food industry [2,3]. Digesters are used for the production of biogas and anaerobic digestion is widely employed as it leads to methane and carbon dioxide rich biogas suitable for energy production [4]. In addition, bio-gas energy is smokeless, more environmental friendly and more convenient to use than solid fuels. Anaerobic digestion of biogas production involves three processes namely; hydrolysis, acidogenesis/acetogenesis and methanogenesis [5]. These processes can be represented as follows;

$$\left(C_6H_{10}O_5\right)_n + nH_2O \rightarrow n\left(C_6H_{10}O_6\right) - hydrolysis \quad 1$$

$$n\left(C_6H_{10}O_5\right)_n \rightarrow nCH_3COOH - acetogenesis / acidogenesis \quad 2$$

$$3nCH_3COOH \rightarrow nCH_4 + CO_2 - hydrolysis \quad 3$$

A lot of work has been carried out on kinetic of biogas production but mainly such study were based on the volume of biogas produced [6], [7]-[8]. Based on literatures at my disposal no such study has been carried out on residual substrate concentration. In this study, kinetics of biogas produced from cow and elephant dung were carried out. The kinetic models obtained provided useful parameters that can be used to develop or size a small scale plant for the production of biogas for the urban and rural dwellers.

2. Materials and Methods

Cow dung was obtained from the abattoir, Muda Lawal market, Bauchi and the elephant dung was obtained from the Yankari Game Resort, Bauchi State. These materials were sun dried at ambient temperature (25 – 28 ^{o}C) for three days and after which each waste material (dung) was thoroughly homogenized. Analyses of the homogenized animal wastes were carried out using standard methods. Parameters carried out include; moisture content [9], organic carbon (calorimetric method), nitrogen (Kjeldahl method), volatile and fixed solids.

2.1. Volatile and Fixed Solids

Haven determined the moisture contents of the animal dung in a method described in [9], the dried samples were ignited in an oven at 550°C for three hours. These samples were cooled in desiccators to constant weight. The difference in weights in each case gave the volatile solids whereas; the residue after ignition was the fixed solids. All analyses conducted in this study were in triplicate.

2.2. Procedure

Three identical batch units (bio-digesters) were used as experimental unit (Figure 1). These digesters were cylindrical closed vessels made of metallic steel, each of 37 cm in diameter and 30 cm in height. All the bio-digesters were painted back to increase their heat absorption. In addition, the gas holder was 26 cm in diameter and 30 cm height.

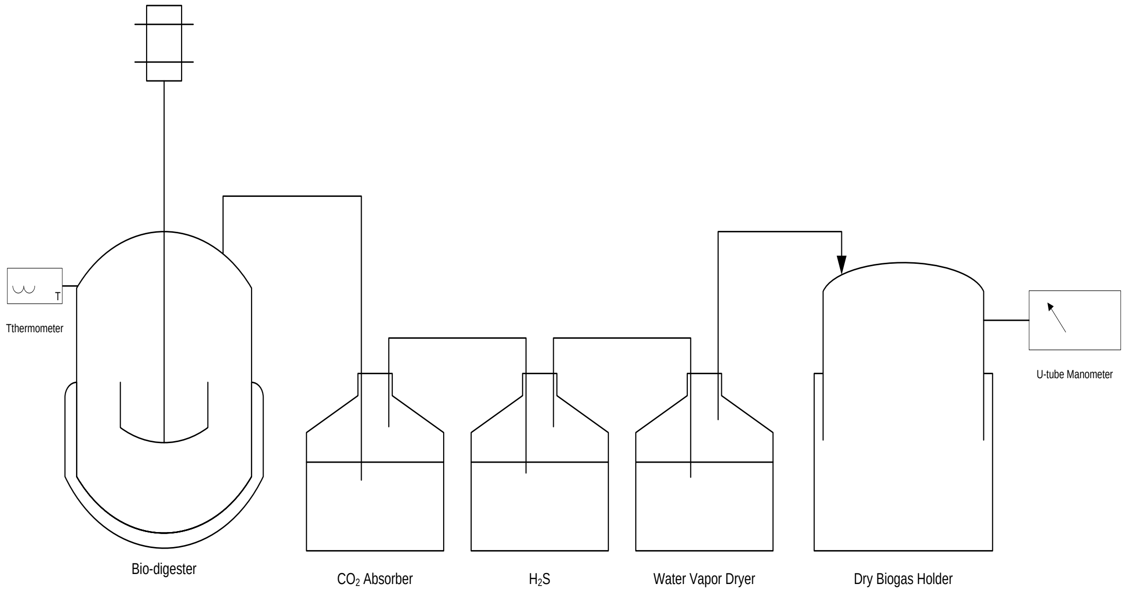

Figure 1. Flow diagram of the biogas production unit

Six liters of 1 g/cm^3 cow dung slurry was prepared (Sample "1") by adding 3 kg of ground cow dung to 3 kg of distilled water to form a 1:1 mixture as reported in [3] and charged into the bio-digester. This slurry was heated on a steam bath at 50^{o}C in order to evacuate air bubbles with constant stirring. The pH of the slurry was adjusted to 7.6±1 and overlying air removed by aspiration. The digester outlet was then closed to prevent re-entry of air. Delivery tube was connected through three 1 000 ml conical flasks connected in series as depicted in Figure 1; the first conical flask contain 300 ml KOH solution for CO_2 absorption, the second conical flask contain 300 ml of $KMnO_4$ solution for the absorption of H_2S and the third was used as the $CaCl_2$ bag to trap the water vapor in the biogas stream. The bio-digester was maintained at room temperature and its content shake on daily basis.

The refined biogas was collected in the biogas holder and tested to examine the presence of methane by ignition. A U-tube manometer was connected to the gas holder for the measurement of the gas volume produced (cm^3) and measurement taken on daily basis for the period of 33 days. The concentration of biogas produced was in cm^3/cm^3, it was then converted to g/cm^3 by multiplying with density of methane (6.56*10^{-4} g/cm^3 at 25^{o}C and 1 atm.). In addition, the temperature in the bio-digester was monitored throughout the period of investigation. The procedure above was repeated for samples '2' and '3'. All the three samples were ran simultaneously.

3. Results and Discussion

3.1. Physicochemical parameters

Table 2 presents the physicochemical parameters of Samples '1', '2' and '3'. From this table it can be seen that sample '2' had the highest carbon to nitrogen (C: N) ratio of 30:1, followed by sample '3' with 26:1 and then sample '1' with 18.5:1. The C:N ratio obtained for Sample '1' was in line with the ratio (18:1) reported in [10] but out of the range for optimum biogas production. On the other hand, the C:N ratios for samples '2' and '3' fell within the optimal required for biogas production of 20-30:1 [11] and the 25-30:1 stated as ideal ratio of C: N [12]. Therefore, C:N was not a limiting factor in samples "2" and "3". On the other hand, C:N was a limiting factor to optimal biogas production in sample '1'.

In addition, it can be seen from Table 2 that sample '2' had the highest percentage volatile solid, followed by sample '3', then sample "1". The high percentage volatile solid of sample '2' can be attributed to proper blending of the Cow and Elephant dung, and the high value of volatile solids than in that of sample "1" can be attributed to high biodegradable materials in Elephant dung as a result of high intake of digestible materials [13].

Table 1. Physicochemical parameters for the three samples

Sample	% C	% N	C:N	% MC	%VS	%FS
1	32.30	1.75	18.5:1	42.12	28.40	29.48
2	30.30	0.98	30.0:1	43.38	43.60	12.52
3	27.30	1.05	26.10	51.20	33.60	15.48

Data presented are average values of triplicate determinations; MC: moisture content; VS: volatile solids; FS: fixed solids.

3.2. Temperature and pH in Bio-digesters

The pH values of samples 1, 2 and 3 slurries were 6.6, 6.9 and 6.8 respectively at the initiation of digestion, although these values were adequate and within the limits required for biogas production but for the purpose of comparison, the pH value were adjusted to 7.6±1 which fell within the optimum range of 7-8.5 required for biogas production [14] using KOH solution. The temperature variation for the three samples investigated varies between 26 and 28°C during the period of investigation. This temperature range fell within the limits of 20-45°C [15] required for methane production and thus temperature was not a limiting factor.

3.3 Concentration of Biogas

The dry biogas obtained for each sample was tested to examine the presence of methane by ignition. On ignition, a blue flame was observed indicating the presence of methane gas in the three samples investigated.

Figure 2 shows daily variation in concentrations of biogas produced (g/cm^3) in the bio-digesters within the period of investigation. The cumulative biogas concentrations for samples '1', '2' and '3' were 2.88*10^{-4}; 3.92*10^{-4} and 3.31*10^{-4} g/cm^3 respectively (Figure 3), and their respective average yields were 0.0842, 0.084 6 and 0.083 7. These results showed that the co-digestion of Cow and Elephant dung in equal proportion gave the best result within the range of experimental conditions used. This can be attributed to proper nutrient balance in sample "2" attained via proper mixing of the sample [16]. It can also be seen that the biogas concentration for Elephant dung was more than that of Cow dung, which can be attributed to higher volatile materials in Elephant dung than in the Cow dung. Therefore, Elephant dung is a good and viable raw material for biogas production.

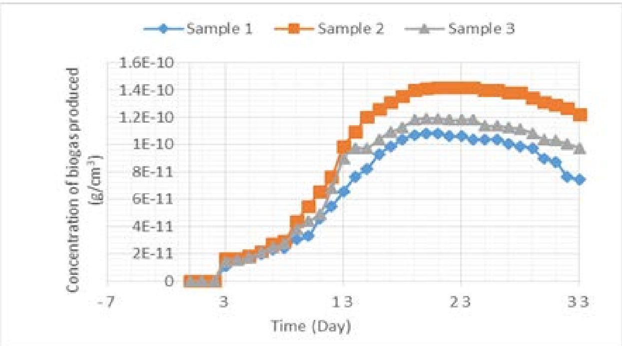

Figure 2. Daily variation of biogas produced over the period of study

The trends of biogas concentrations in the three samples follow similar trend as the C:N, % MS and %VS. The higher the C:N, % MS and % VS of a sample, the higher the concentration of biogas produced. Conversely, the higher the biogas concentration for a particular sample, the lower the % FS.

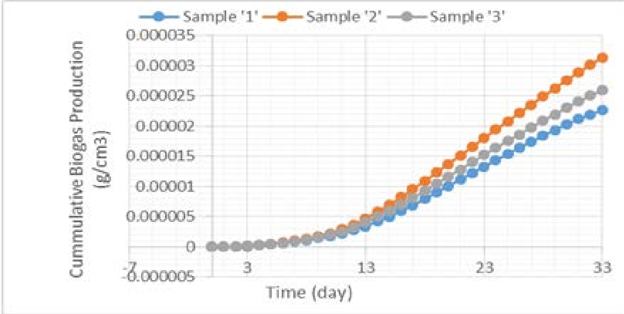

Figure 3. Commutative rate of biogas produced over the period of study

In addition, Figure 4 depicts the residual substrate concentration with time for the three samples, which indicates gradual decreased in substrate concentrations with time. Sample '2' showed the highest decreased, followed by Sample '3' then Sample '1'. The concentrations for the three samples were somewhat constant between day '0' and '5', and thereafter started declining at proportionate form to the end suggesting a shifting order reaction.

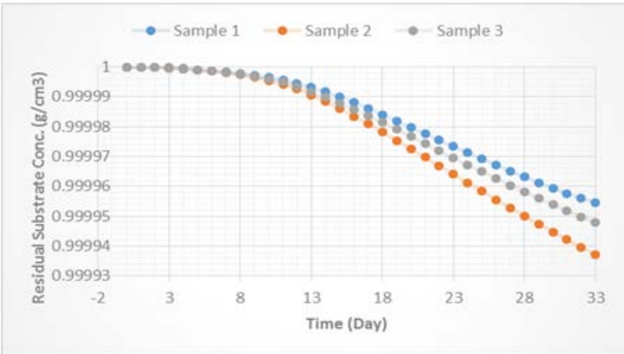

Figure 4. Variation in substrate concentration with time

3.4. Kinetic Study

From Figure 2, it can be seen that the profiles of biogas production followed typical microbial growth pattern depicting the lag, log, stationary and death phases [17]. In addition, Figure 3 and Figure 4 show the shifting order characteristics; while Figure 3 depicts rate of cumulative biogas produced, Figure 4 is the rate of residual substrate. Therefore, the mathematical expression for batch reactor for enzymatic reactions can be used for the kinetic study [18]. This equation is given by;

$$\frac{1}{t}\ln\frac{S_0}{S} = \frac{V_{\max}}{K_m} = \frac{S_0 - S}{K_m.t} \quad (1)$$

where; t=time; S_0=initial substrate concentration; S=substrate concentration at time, t; K_m and V_{max} are Michealis Menten constants.

The yield of biogas produced is given by;

$$Yield\ of\ biogas\ (Y_{P/S}) = \frac{Volume\ of\ biogas\ produced\ in\ cm^3}{Volume\ of\ substrate\ consumed\ in\ cm^3} = \frac{P}{S_0 - S} \quad (2)$$

Assuming that the rate of production of biomass (P) is equal to that of cell mass growth in the bio-digester, then substrate concentration can be expressed as;

$$S = S_0 - 2P \tag{3}$$

Figure 5, Figure 6 and Figure 7 depict the plot of 1/t*ln (S_0/S) against (S_0-S)/t for the three samples, it can be seen that the regression coefficients (R^2) for the three samples is one (1) indicating that data obtained were well described by the chosen equation (Eq. 1). The kinetic parameters evaluated from Figure 5, Figure 6 and Figure 7 were summarized in Table 2.

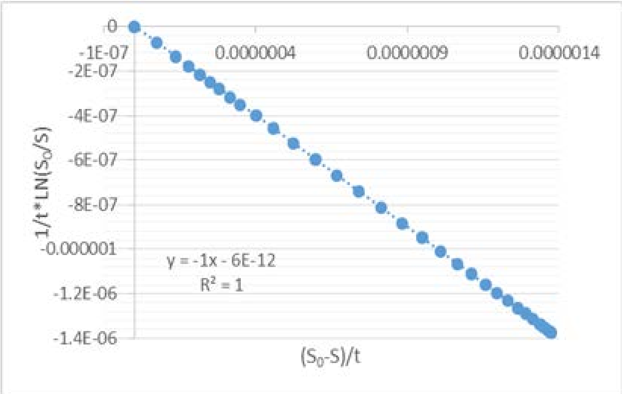

Figure 5. $\frac{1}{t}\ln\frac{S_0}{S}$ against $\frac{S_0 - S}{K_m.t}$ for Sample '1'

The kinetic parameters in Table 2 can be used to design a bio-digester and to monitor the substrate concentration as reaction progresses.

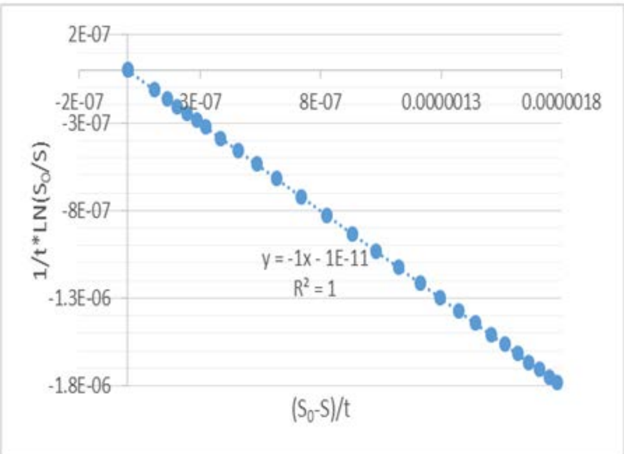

Figure 6. $\frac{1}{t}\ln\frac{S_0}{S}$ against $\frac{S_0 - S}{K_m.t}$ for Sample '2'

Table 2. Summary of Kinetic Parameters for Biogas from Cow and Elephant Dung

Sample	Ave. yield*	V_{max}	K_m	R^2
1	**0.084 2**	**$-6*10^{-12}$**	**1**	**1**
2	**0.084 6**	**$-1*10^{-11}$**	**1**	**1**
3	**0.083 7**	**$-7*10^{-12}$**	**1**	**1**

Ave. yield*=Average Biogas Yield.

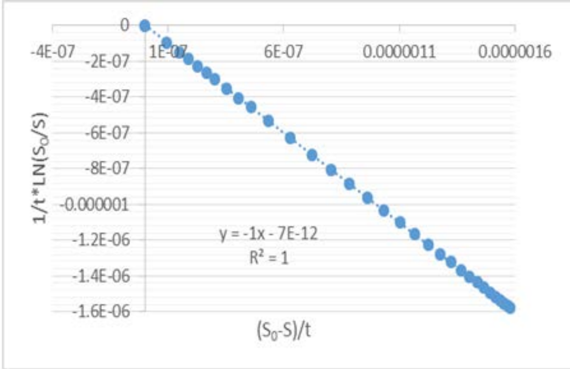

Figure 7. $\frac{1}{t}\ln\frac{S_0}{S}$ against $\frac{S_0 - S}{K_m.t}$ for Sample '3'

4. Conclusion

The biogas processing rig improvised was effective for the production of biogas from Cow and Elephant dungs. Sample "B" (the co-digestion of Cow and Elephant dung) gave the best result with cumulative biogas concentration of $3.92*10^{-4}$ g/cm^3 and average yield of 0.084 5 over a period of 33 days. The concentration of biogas produced for elephant dung was higher than that of cow dung. Therefore, elephant dung is a good source of raw material for biogas production. The rate of biogas produced followed a shifting order pattern (0-1) and equation adopted for kinetic investigation adequately represented the process judging from 100% regression coefficients for the three Samples.

References

[1] John, W. and Twidell, A. (1987), *Renewable energy resources*, D Weirs ELBS/E and F. N. Spain Ltd., pp. 310-320.

[2] Pound, B., Done, F. and Preston, T. R. (1981), Biogas production from mixtures of cattle slurry and pressed sugar cane stalk, with and without urea, *Trop Anim Prod*, 6:1, pp. 11-21.

[3] Adelekan, B. A. and Bamgboye, A. I. (2009), Comparison of biogas productivity of cassava peels mixed in selected ratios with major livestock waste types, *African Journal of Agricultural Research*, Vol. 4 (7), pp. 571-577.

[4] Bolte, J. P. and Hill, D. T. (1990), A Mond-based model of attached growth anaerobic fermenters, *Biol. Wastes 31* pp. 275-289.

[5] Ofoefule, A. U., Nwankwo, J. I. and Ibeto, C. N. (2010), Biogas Production from paper waste and its blend with cow dung, *Advances in Applied Science Research*, 1 (2): 1-8.

[6] Mahnert, P. and Linke, B. (2009), Kinetic Study of Biogas Production for Energy Crops and Animal Waste Slurry: Effect of Organic Loading Rate and Reactor Size, *Environmental Technology*, Vol. 30, Issue 1, pp. 93-99.

[7] Wanasolo, W., Manyele, S. V. and Makunza J. (2013), A Kinetic Study of Anaerobic Biodegradation of Food and Fruit Residues during Biogas Generation Using Initial Rate Method, *Scientific Research*, pp. 577-586.

[8] Ehiri, R. C., Ikelle, I. I., Mgbabor, C. and Ogbuanu, C. C. (2014), Kinetics of Biogas Production from a Mixture of Water Hyacinth and Fresh Rumen Residue, *IOSR Journal of Applied Chemistry*, Vol. 7, Issue 7 Ver. III, pp. 36-39.

[9] ASTM (1982), *Standard test method for laboratory determination of water content of soil, rock and soil aggregate mixtures*. American Society for Testing and Materials: D 2216.

[10] National Academy of Sciences (1977), Methane generation from human, animal and agricultural wastes, *National Academy of Sciences* Washington D C U S A.

[11] Marchaim, U. (1992), Biogas processes for sustainable development *FAO Agricultural Services Bull*, pp. 95.

[12] Ding, W., Wu, Y., Wang, X. and Gao, Y. (2010), Family-size Biogas Plant using Manure and Urine Mixture at Ambient Temperature in Semi-arid Regions of Northwestern China, *World Academy of Science, Engineering and Technology*, 65, pp. 33-41.

[13] Hobson, P. N. and Bousfield, S. (1981), *Methane production from agricultural and domestic wastes*, Applied science publication.

[14] Buren, V. (1983), *A Chinese biogas manual*. *Popularizing Technology*, Country side. Intermediate Technology Publications Ltd.

[15] Cruazon, B. (2007), History of anaerobic digestion. Available online at http://www.b.pdx.edu. Accessed on 17th August, 2007.

[16] Fulford, D. (1988), *Running a biogas program*, hand book, Intermediate Technology Publication, London.

[17] Bailey, J. E. and Ollis, D. F. (1977), *Biochemical Engineering Fundamentals*, International Student Edition, McGraw-Hill Kogakusha, Ltd, New Delhi, pp. 337-343.

[18] Fogler, H. S. (2001), *Element of Chemical Reaction Engineering*, 2nd edition, Prentice-Hall of India Private Limited, New Delhi, pp. 363-366.