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Biogas Production Potential of Co-Digestion of Pig Droppings with Cow Dung Under Tropical Conditions

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Authors' contributions

This work was carried out in collaboration between both authors. Author GOC *designed the study, wrote the protocol, while author* ECC *wrote the first draft of the manuscript, managed the analyses of the study, and managed the literature review. Both authors read and approved the final manuscript.*

Original Research Article

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ABSTRACT

The biogas production potential of animal wastes offers sustainable biogas production, cleaner environment and economic benefits. This work is an investigation into the best blend leading to higher biogas production from two major animal wastes for improved biogas production. The study of biogas production potentials was conducted for pig droppings (PGD) with cow dung (CD) in different mixture ratios of 100: 00, 75: 25, 50: 50, 25:75 and 00:100 to determine the optimum mixture ratio in a 30 litres digesters. The results revealed that 50%PGD + 50%CD is the optimum mixture ratio for the selected animal waste. The first order kinetic model used in the study adequately fitted the experimental data for the digesters.

Keywords: Biogas; cow dung; pig droppings; co-digestion.

1. INTRODUCTION

Manure constitutes an unavoidable by-product of all livestock production system [1]. Bio-wastes, such as nutrients and organic matter, are normal components of natural ecosystem

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processes but can reach harmful levels due to human activities. Inputs of these materials may exceed natural recycling capacity, consequently; the ecosystem functions are modified or impaired. Nutrients and organic matter, when applied at appropriate rates and locations, are an important resource for the improvement of agricultural soils. The costs of trying to reverse damages to waste-degraded ecosystems or remove toxins from the environment can be extremely large and burdensome on society [2]. In Nigeria, environmental pollution and access to energy resources present challenges to human health, environmental health, and economic development. The need for alternative renewable energy sources from locally available resources cannot be over emphasized. Appropriate and economically feasible technologies that combine solid waste and wastewater treatment and energy production can simultaneously protect the surrounding water resources and enhance energy availability [3]. Animal wastes are suitable for anaerobic digestion (AD) giving high gas yields and a nutrient rich organic fertilizer. Anaerobic digestion of animal wastes offers a safe and sustainable waste management solution. In many of the developing countries, there is still need for some basic research mostly on the quantity and potential biogas yield of fermentable organic wastes available, and in the size and type of biogas digesters which can be economically viable for the potential consumers of the biogas technology. Biogas technology is also potentially useful in the recycling of nutrients back to the soil. Burning non-commercial fuel sources, such as dung and agricultural residues, in countries where they are used as fuel instead of as fertilizer, leads to a severe ecological imbalance, since the macro-nutrients, (nitrogen, phosphorus, potassium) and micro-nutrients, are essentially lost from the ecosystem [2]. Biogas production from organic materials does not only produce energy, but preserves the nutrients, which can, in some cases, be recycled to the land in the form of slurry discharge [4]. The organic digested material also acts as a soil conditioner by contributing humus. Though the fertilizing and the conditioning of the soil can be achieved by simply using the raw manure directly back to the land without fermenting it, anaerobic digestion produces a better material. This is due in part to the biochemical processes occurring during digestion, which cause the nitrogen in the digested slurry to be more accessible for plant utilization, and the fact that less nitrogen is lost during digestion than in storage or composting. In this study, blends of selected animal wastes (cow dung and pig droppings) were digested in batch type anaerobic digester under tropical environmental conditions to determine the feasibility of digesting these wastes with minimal technicalities. This will be valuable: in minimizing the indiscriminate disposal of animal wastes; in protection of the environment; production of bio-energy and bio-fertilizer for farmers in developing countries.

2. MATERIALS AND METHODS

2.1 Substrates Sources and Characteristics

Pig droppings and cow dung used in this research work were collected from Ugwu-Oba cattle ranch and from Ausco farms Nig. Limited respectively. The fresh substrates were taken immediately to Spring Board Laboratories, Udoka Housing Estate, Awka for compositional analysis. The parameters determined include: Total solid (TS), volatile solid (VS), pH, and total nitrogen content (TKN), carbon content and total ammonia. The TS and VS were determined on fresh basis, the compositional analysis is shown in Table 1 below:

Table 1. Physico-chemical characteristic of the substrates

Composition	Cow Dung	Pig Dropping
Total Solid (TS) (%)	19	38
Volatile Solid (VS)(%)	12	20
TKN (mg/g)	2.98	15.3
Carbon Content (%)	3.98	4.6
pH	7.0	6.2
Total Ammonia (mg/g)	2.5	5.6

TKN = Total Kjeldahl nitrogen

The pH measurements were taken with a pH meter (Fisher Scientific Accumet Basic, Model AB 15 pH meter). Total Solids (TS) in solid samples was determined using Standard Method 2540 G; Volatile Solids (VS) was measured using Standard Method 2540 E [5]. Total Kjeldahl Nitrogen and Total Ammonia were measured using Standard Methods 4500-Norg C, D and 4500-NH3 D, respectively [5] while Carbon content was carried out using Walkley and Black method [6].

2.2 Experimental Setup

7kg of cow dung and pig droppings were weighed in mixed ratios of 75: 25, 50: 50, 25:75 and in single digestion of 100: 0, and 0:100 accordingly. 15 litres of water was added to the substrates, homogenized and fed in the 30 litre metallic digesters for a period of thirty days to determine the biogas production potential. The 100: 0 and 0:100 were single substrate digestions, which were considered as data baseline. The wastes were seeded with three litres of slurry obtained from a previous digestion [7] to reduce the lag phase (Microbial growth). The prevailing temperature range was 24ºC - 34ºC during the period of the study. More details on the experimental setup can be found elsewhere [4].

3. RESULTS AND DISCUSSION

In co-digestion of pig droppings with cow dung, three of the digestion mixtures could be classified as failed digesters because they could not produce significant gas. There was a significant increase in gas production because of the effect of co-digestion principle especially for the 50% PGD + 50% CD digester. The plot of the gas yield with respect to time is shown in Fig. 1 below:

The 25% PGD + 75% CD and 0% PGD+100% CD digesters started gas production within 24 hours of digestion, this could be attributed to the effect of seeding of the substrates [1,8]. The 75% PGD + 25% CD mixture was the last to produce gas with a lag period of six days. The 50% PGD + 50% CD digester started gas production on the fourth day of digestion. The 100% PGD + 0% CD digester had the least gas production of 1.21L/TMS (7kg of Total Mass of Slurry), while the 50% PGD + 50% CD had the highest gas production of 39.69L/TMS. The gas production is in the order 50% PGD + 50% CD > 0% PGD + 100% CD >75% PGD + 25% CD >25% PGD + 75% CD > 100% PGD + 0% CD. Digester 25% PGD + 75% CD, 75% PGD + 25% CD, and 100% PGD + 0% CD could be classified as failed digesters, because they failed to produce significant amount of gas. In this research work, the three digesters in question produced only 1.52 L/TMS, 3.72 L/TMS and 1.21 L/TMS biogas respectively. Gas production was observed only for three days in 25% PGD + 75% CD, and 100% PGD + 0% CD digesters and four days in 75% PGD + 25% CD digester. The poor performance of these digesters which is an object of further research was not ascertained in this study because of the present scope of the research. However, it could be attributed to ammonia inhibition or excess VFA common to pig slurry which has been reported by several researchers [9,10]. Several researchers also have reported that pig droppings have a better biogas yield potential than cow dung [10,11]. However, there are reports by researchers like [12, 13] that indicated higher gas yield by cow dung. In anyway, the margin between the cow dung (16.30L/TMS) and pig droppings (1.21L/TMS) biogas yield shows the likelihood of ammonia inhibition or antagonistic effect of co-digestion, coupled with just three days of gas production by the single pig substrate digestion. The pH values of the substrates were analyzed on the seventh day of digestion, the result is shown in Table 2 below:

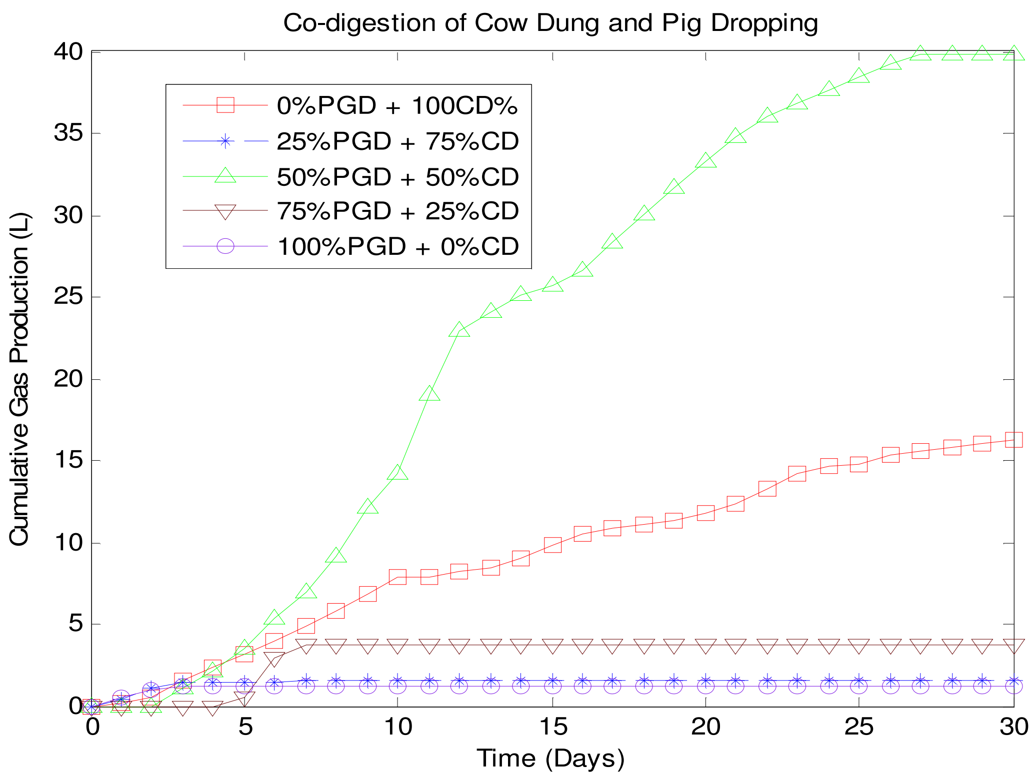

Fig. 1. Biogas accumulation through time of single and different mixing ratios of cow dung and pig dropping

Table 2. The pH Values of Co-digestion of pig droppings and Cow dung on the 7th Day of digestion period

Digester CD:PGD	0: 100	25:75	50:50	75:25	100:0
pH	5.9	5.6	6.4	5.3	7.1

The result showed a general decrease in pH for all digesters that contained pig droppings, this could be attributed to anaerobic fermentation taking place. The decrease in pH may also be due to action of acetogenic and methanogenic bacteria as they break down sulphur containing organic and inorganic compounds as well as fatty acids [13,14]. Optimum pH is in the range of 6-8, thus only the 0%PGD+100%CD and 50%PGD+50%CD digester that had the pH of 7.1 and 6.4, respectively, were further monitored as progressive digesters. The 50%PGD + 50%CD digester mixture had the highest gas production among all the mixture, this is in line with the recent research work by Iortyer, et al. [12], who investigated the effect of mixing ratio of cattle and pig dung on biogas generation. Their findings highlighted that the maximum yield was obtain in the 4:1 mixture of cattle and pig dung. There was a general decrease in the gas yield as the pig dung was increased in the course of the research work. The 1:1 mixture ratio of cow dung and pig dropping is the optimum mixture ratio in this research work, this could be attributed to the synergistic effect of co-digestion and optimum C/N ratio within this digester. This also agrees with a study conducted by Kasisira and Muyiiya [15].

3.1 Kinetic Assessment of Biodegradability of the Substrates

The first-order kinetic model use in assessing the degradation process of substrates is given by Chen and Hashimoto [16]:

$$\frac{dp}{dt} = -kp \tag{1}$$

Where p is the substrate concentration

T is the digestion time
K is the first order substrate decay rate constant

Integrating equation 1

$$\int_{p_0}^{p} \frac{dp}{p} = -k\int_0^t dt \tag{2}$$

$$\ln\left(\frac{p}{p_0}\right) = -kt \tag{3}$$

The gas production can also be correlated with substrate concentration [17]:

$$\frac{Y_\beta - Y_t}{Y_\beta} = \frac{p}{p_0} \tag{4}$$

Y_β is the maximum biogas production or ultimate biodegradability of the substrates, Y_t is biogas yield at any time.

Substituting equation (4) into (3), we obtain

$$\frac{Y_\beta - Y_t}{Y_\beta} = \exp\left(-kt\right)$$

$$y_\beta\left(1 - \exp\left(-(kt)\right)\right) = y_t \tag{5}$$

The rate constant associated with the degradation of the biodegradable fractions is represented by *k* (1/days), while the period of digestion is represented by *t* (in days).

The application of Eq. (5) in assessing substrate biodegradability and the rate constant was accomplished by attempting to linearize Eq. (5) as shown below [18] by differentiating Eq. (5), we obtain,

$$\frac{dy_t}{dt} = y_\beta k(\exp(-kt)) \tag{6}$$

Taking natural logarithm on both sides of the equation we obtain

$$ln\frac{dyt}{dt} = (lny_\beta + lnk) - \text{kt}) \tag{7}$$

This equation can be reduced to the form

$$\frac{1}{t}ln\frac{dyt}{dt} = \frac{1}{t}(lny_\beta + lnk) - \text{k}) \tag{8}$$

Eq. (8) is of the form of a straight line equation $y = mx + c$, in which ($\ln y_\beta + \ln k$) represents the slope while, ($-k$) represents the intercept of the equation. The term ($\ln y_\beta + \ln k$) is a measure of the availability of readily and moderately degradable fractions of the substrates. Thus, the term can be used to select substrates with the potential for high biogas production. In substrate rate constant and biodegradability index assessment of pig droppings and cow dung mixtures, only the 0%PGD + 100% CD and 50%PGD+50%CD digester mixtures were assessed, others due to digester failure could not produce significant biogas. Hence they are classified as failed digesters and were not assessed. From Fig. 2 below, the ambient temperature short term biodegradability index of the substrates in digester 0%PGD+100%CD for the period under study was observed to be 2.4 while the intercept, depicting the removal rate constant (k) of biodegradable fractions was estimated to be 0.28 day^{-1}. The model was able to fit the data set with a goodness of fit (R^2) of 0.9487.

Thus the first order kinetics model successfully fitted the experimental data used in assessing the ambient temperature short term biodegradability and removal rates of biodegradable fractions of 0%PGD+100%CD digester in anaerobic digestion in this research work. The linear polynomial was able to fit the experimental data as shown in the figure above. The linear polynomial used for the single substrate above was not able to fit the experimental data for the 50%PGD+50%CD digester. The linear Polynomial model fitting showed that R-square was 0.0002544, which indicates weak correlation. Nonlinear regression analysis of the experimental data was then used to obtain the kinetic parameters. From equation (5) above, the first order model which gives analytical relation between the volumes of biogas produced and digestion time was obtained and used to quantify the extent of process inhibition as follows:

$$\frac{Y_\beta - Y_t}{Y_\beta} = \exp(-kt) \quad \text{Or} \quad Y_t = Y_\beta[1 - \exp(-kt)] \tag{9}$$

The values of Y_β and k were obtained from a non-linear regression analysis using Matlab 2007 software. The 50%PGD+50%CD digester fitting curve is shown in Fig. 3 below:

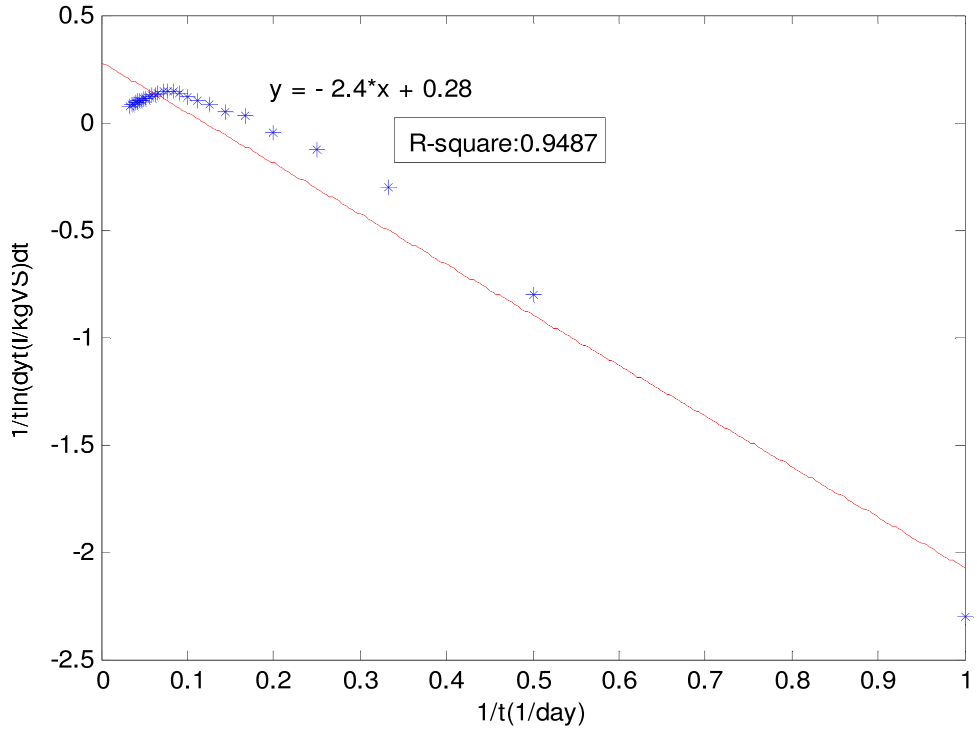

Fig. 2. Plot of 1/t (In(dyt(l/kgVS)/dt against 1/t for 0%PGD+100%CD

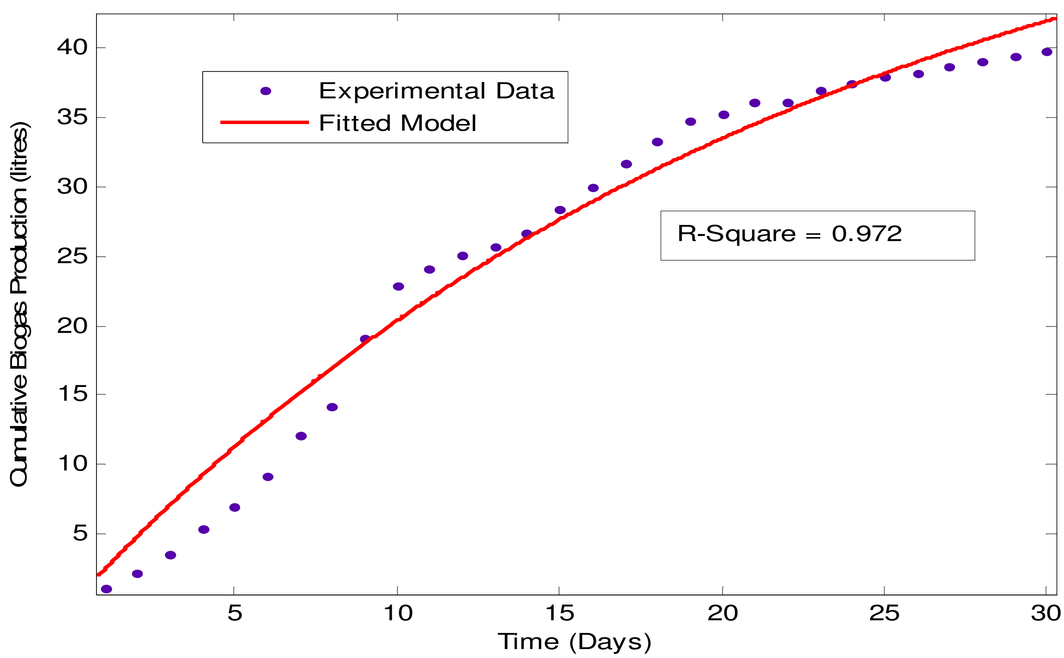

Fig. 3. First order kinetic plot for 50%PGD+50%CD digester

The first order kinetic model adequately fitted the experimental data of 50%PGD+50%CD digester used in determination of Y_β and k values. The R-square value of the fitted curve is 0.972 and the adjusted R-square value is 0.971. This indicates good correlation between the experimental data and the first order kinetic model. The maximum biogas production or ultimate biodegradability of the substrates (Y_β) was determined to be 57.38l, while the removal rate constant (k) of biodegradable fractions was estimated to be 0.4375 day^{-1}. First order kinetic model used in this study, though not a precise model of the biogas production process, it however does give useful information on the kinetic parameters which is very useful in the selection of the best blend leading to higher biogas production and in the design of digesters for biogas production.

4. CONCLUSION

The mixture effect of Pig droppings with cow dung investigated in this research work shows that the maximum biogas production potential for the pig dropping and cow dung mixture is in the order 50% PGD + 50% CD > 0% PGD + 100% CD >75% PGD + 25% CD >25% PGD + 75% CD > 100% PGD + 0% CD. Thus the 1:1 mixture ratio of pig droppings to cow dung is the optimum mixing ratio, obtained from 50%PGD + 50%CD digester. The first order kinetic model used in the study adequately fitted the experimental data of the digesters, hence providing useful information on the kinetic parameters. Further investigation would be directed to the cause of the failed digesters in this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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