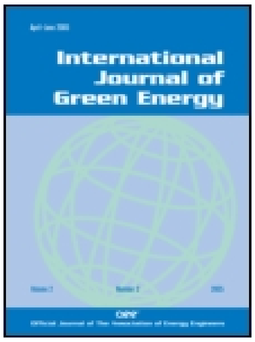

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Evaluation of Biogas Yield of Selected Ratios of Cattle, Swine, and Poultry Wastes

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ABSTRACT

Production of biogas from animal wastes could lessen the problems of energy shortage and indiscriminate animal waste disposal. A study of anaerobic digestion of selected ratios of cattle, swine, and poultry wastes was carried out to evaluate their biogas yields. Cattle (C), swine (S), and poultry (P) wastes were mixed as C:S:P in the following ratios: 1:0:0 (control), 1:0:1, 4:1:3, 2:1:1, 4:3:1, and 1:1:0 by mass to obtain six samples of of 0.4 kg each, referred to as samples 1 to 6 respectively. A quantity (0.1 kg) of inoculum (obtained by pre-fermenting equal masses of poultry waste and water for 50 days under anaerobic condition) and 0.5 kg of water were added to each of the samples. The resulting slurries were digested in triplicates for 30 days in 1.3 L laboratory-scale anaerobic digesters. The volume of biogas produced was obtained by downward displacement of water in a measuring cylinder. The cumulative biogas yields of samples 1 to 6 were 332.5, 497.5, 487.5, 467.5, 457.5, and 430.0 cm^3/kg slurry respectively. The cumulative biogas yields of samples 2 and 3 were significantly ($p < 0.05$) higher than those of the other samples but not significantly ($p > 0.05$) different from each other. However, the cumulative biogas yield of sample 1 was significantly ($p < 0.05$) lower than those of the other samples. The study revealed that a blend of equal masses of cattle and poultry wastes is optimum for biogas production.

KEYWORDS
Anaerobic digestion; bioreactor; cumulative yield; daily yield; slurry

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Introduction

The use of biogas as a source of energy is increasingly becoming important as a result of global awareness of effects of reliance on fossil fuels. These appropriate the significant and highest portion of the global fuel consumption. Global mix of fuels comes from fossil (78%), renewable (18%), and nuclear (4%) energy sources (Solar Energy International (SEI) 2009). In Nigeria, where this research was carried out, fossil fuel utilization is even higher. National Technical Working Group on Energy Sector (2009) reported that Nigeria's energy consumption mix was dominated by oil (53%), followed by natural gas (39%) and hydroelectricity (7%).

Fossil fuels are non-renewable and finite resources releasing the highest amount of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere. These are known to be the main cause of global warming and climate change (Jingura and Matengaifa 2009). Of all anthropogenic greenhouse gases, fossil fuels combustion accounts for 62% of the global warming (Scientific Research Society (SRS) 2009).

Biogas is a gaseous biofuel obtained from the anaerobic digestion of the organic fraction of biomaterials (Azar 2009). Typically, it comprises 50–75% methane (CH_4), 25–50% carbon dioxide (CO_2), 0–3% hydrogen sulphide (H_2S), 0–1% ammonia (NH_3), and 0–1% hydrogen (Munda et al. 2012).

Anaerobic digestion is a multi-step biological process in which organic carbon is converted to its most oxidized (CO_2) and most reduced (CH_4) state in the absence of oxygen (Marchaim 1992; Angelidaki, Ellegaard, and Ahring 2003). It is an energy-efficient and environment-friendly way to produce heat, cold, and power from biomass. Unlike fossil fuels, biogas does not contribute to net increase in discharge of CO_2 since release of CO_2 during biogas combustion is the same as the one bound in the plants months before (Ronja 2008; Flamos et al. 2011).

Biogas utilization improves sanitation, reduces demand for wood and charcoal for cooking, and therefore helps preserve forests and natural vegetation and provides a high-quality of organic fertilizer. Biogas' greatest benefit for the developing world may be that it can help alleviate a very serious health problem: poor indoor air quality. Indoor air pollution such as that stemming from biomass burning may increase the risk of acute lower respiratory infections in children, chronic obstructive pulmonary disease in adults, tuberculosis, low birth weight, asthma, ear infections, and even cataracts. About 2 billion people around the world, including 89% of the sub-Saharan African population, burn biomass for cooking and heating (Flavin and Aeck 2005). According to Renewable Energy Policy Network (REPN) (2005), in 2000, burning solid fuels caused 1–2 million deaths, comprising 3–4% of the total global mortality.

Biogas has been generated from various sources such as straw, weeds, human and animal excrement, kitchen wastes, municipal solid wastes, sludge, landfills, domestic sewage, organic liquid from factories, wastes from food processing plants, ethanol distillery wastes (Karapidakis, Tsave, and Soupios 2003; Awosolu 2007; Zheng et al. 2007; Uzodinma et al. 2008; Voegeli et al. 2009). Traditionally, anaerobic

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digestion was a single substrate, single purpose treatment. However, it has been shown that in order to improve the biogas yield, two or more substrates can be mixed and digested together simultaneously (Okuo 2011).

Recently, it has been realized that anaerobic digestion as such became more stable when the variety of substrates applied at the same time is increased. The most common situation is when a major amount of a main basic substrate (e.g. manure or sewage sludge) is mixed and digested together with minor amounts of a single or a variety of additional substrate (Braun 2002).

Adelekan and Bamgboye (2009) investigated biogas productivity of blends of cassava peels and poultry wastes, cassava peels and piggery wastes, cassava peels and cattle wastes, each combined in the ratios of 1:1, 2:1, 3:1, and 4:1 by mass, using 12 Nos. 220-L batch-type anaerobic digesters in a 3 × 4 factorial experiment using a retention period of 30 days and within the mesophilic temperature range. The authors reported that biogas yield was significantly ($p < 0.05$) influenced by different mixing ratios of livestock waste with cassava peels. They also noted that for all the livestock waste types, mixing with peels in the ratio of 1:1 by mass produced the highest biogas volumes, with cassava peels and piggery waste mixture having the highest yield of 35.0, 26.5, 17.1, and 9.3 L/kg of total solids for 1:1, 2:1, 3:1, and 4:1 mixing ratios respectively.

Uzodinma et al. (2008) studied biogas production from carbonated soft drink sludge (CS) blended with organic wastes such as palm oil sludge (POS), soybean cake waste (SW), powdered rice husk (RH), and pig dung (PD) in the ratios of CS:POS (1.2:1), CS:SW (2.6:1), CS:RH (1.2:3), and CS:PD (1:1.8), and subjected to anaerobic digestion for 25 days. The mean biogas yield of CS alone was 7.1 L/total mass of slurry input, while those of CS:SW, CS:PD, CS:RH, and CS:POS were 11.6, 9.7, 7.7, and 3.5 L/total mass of slurry input respectively. Their overall results indicated that the low yield of flammable biogas from CS sludge could be enhanced significantly when blended with either SW or PD.

It has been estimated that Nigeria produces about 781,000 tons of fresh animal waste daily. Since 1 kg of fresh animal waste produces about 0.03 m^3 biogas, Nigeria can potentially produce about 23.43 million m^3 of biogas every day from animal waste only (Sambo 2009). Biogas production may therefore be a profitable means of reducing the problems of improper animal waste disposal and acute shortage of energy supply.

In order to increase biogas yield, a farmer owning more than one livestock wants to know the ratio in which he could combine his animal's waste to generate optimum biogas. Knowledge of the optimum blend of animal wastes could help to increase biogas production. The objectives of this study were to establish which of the selected blends of cattle, swine, and poultry waste mixtures give the highest biogas yield; to determine the trend of daily biogas production using polynomial equations; and to determine the effect of fluctuations in daily reactor temperature on biogas yield.

Materials And Methods

Materials Selection for Bioreactor

Steel, ceramic, and plastic materials have been used for the construction of anaerobic digesters (Sasse 1988; Yadvika et al. 2004; Adelekan and Bamgboye 2009). For this study, plastic bowls were selected because these were cheaper, more readily available compared with metallic material, and unlike metallic materials could withstand corrosion that could result from contact with the biogas produced (Maximiliano 2009). An epoxy adhesive was selected because it offers excellent resistance to a variety of chemicals, including dilute acids, bases, solvents, and oils (Plastics International 2010). Chemical attack from slurry was therefore avoided. Another reason for selecting it was that it has high cohesive and adhesive strength, good toughness, and environmental resistance (Loctite 2006).

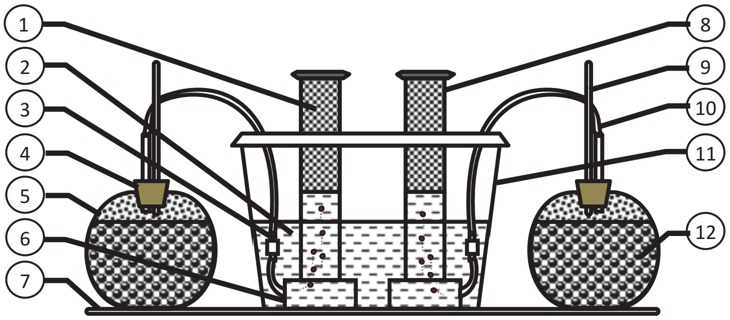
Experimental

Two hemispherical plastic dishes were sealed by means of an epoxy thermosetting adhesive. A hole was made in the top dish through which organic matter (manure) was loaded into the reactor. This hole was fitted with a rubber cork through which two holes, each of 5-mm diameter, were bored. The biogas generated was transported via a flexible drip tube inserted into one of these holes to the gas collector comprising an inverted measuring cylinder attached to an aluminium stand. A laboratory thermometer with a precision of 0.5°C was inserted into the other hole to monitor the temperature of reactor contents. Six of these gas collectors were placed in a rubber bath half filled with water as shown in Figure 1 and Plate 1.

Waste preparation

Cattle, swine, and poultry wastes were collected from the University of Agriculture Abeokuta livestock farm in Abeokuta, Nigeria. The inoculum was prepared by pre-fermenting 2 kg of poultry waste mixed with the same amount of water for 50 days in an air-tight container. Stones, sticks, and other foreign matter were removed from the waste.

Sample 1, which served as the control, comprised 0.4 kg of cattle waste, mixed with 0.1 kg of inoculum and 0.5 kg of water. This mixture was stirred thoroughly with a piece of wood to achieve even mix. The proportion of cattle dung in the samples was fixed at 50% by mass of animal waste except the control, which had 100% cattle dung. However, by adopting the methodology of Budiyono, Johari, and Sunarso (2010), the proportions of swine and poultry wastes in the samples were varied linearly from 0–50% and 50–0% at intervals of 12.5 and –12.5% respectively. This reason was that cattle dung was more readily available than swine and poultry wastes (ESCAP 1996). The compositions of various samples and their ratios with one another are shown in Table 1. A total of 18 digesters were used to anaerobically digest six samples in triplicate concurrently.



(1) Biogas, (2) Water, (3) Valve, (4) Rubber cork, (5) Bio reactor vessel , (6) Aluminium stand, (7) Laboratory bench, (8) Measuring cylinder, (9) Thermometer, (10) Drip tube, (11) Water bath, and (12) Slurry.

Figure 1. Schematic diagram of the experimental set-up.

Plate 1. Photograph of biogas production apparatus.

Table 1. Selected ratios of dung mixtures.

Sample	C: S: P ratio	C (kg)	S (kg)	P (kg)	I (kg)	W (kg)
1	1.00: 0.00: 0.00	0.4	0.00	0.00	0.1	0.5
2	1.00: 0.00: 1.00	0.2	0.00	0.20	0.1	0.5
3	4.00: 1.00: 3.00	0.2	0.05	0.15	0.1	0.5
4	2.00: 1.00: 1.00	0.2	0.10	0.10	0.1	0.5
5	4.00: 3.00: 1.00	0.2	0.15	0.05	0.1	0.5
6	1.00: 1.00: 0.00	0.2	0.20	0.00	0.1	0.5

Determination of biogas yield and reactor temperature

Ambient temperature was measured for three times daily with a laboratory thermometer. The volume of biogas generated in each of the reactors was measured by downward displacement of water, which was read daily on a measuring cylinder. Daily reading of biogas volume was done until the volume of water in the measuring cylinder remained constant.

Data analysis

All the readings of biogas yield, daily reactor temperature, and ambient temperature were analyzed using Microsoft Excel Spread Sheet Package and Statistical Analysis Software for Scientists (SAS 1999). Significant ($p < 0.05$) mean values were separated using Duncan Multiple Range Test (Duncan 1955).

Results

Daily biogas yield of the selected waste blends

Biogas was produced within the first 24 h of charging of reactors except for waste samples 1 and 2, which did not generate gas until the 3rd and 2nd day respectively. Maximum biogas yield was 22.5 cm^3/kg slurry on the 15th and 19th day for sample 1; 32.5 cm^3/kg slurry on the 15th and 16th day for sample 2; 35.0 cm^3/kg slurry on the 16th day for sample 3; 27.5 cm^3/kg slurry on the 13th–15th day for sample 4; 25.0 cm^3/kg slurry on the 12th, 17th, 19th, and 20th day for sample 5; and 27.5 cm^3 /kg slurry on the 16th day for sample 6.

Sample 3 had the highest daily biogas yield, which was not significantly ($p > 0.05$) different from the highest daily yield of sample 2. Both of these waste blends gave significantly ($p < 0.05$) higher daily yield than other samples. Sample 1, which comprised cattle dung only, had an average daily biogas yield that was significantly ($p < 0.05$) lower than all other treatments (Table 2).

Trend equations of daily biogas yield along with their R^2 values are shown in Table 3. Those of samples 1, 2, and 5 are the 5th-order polynomial models with R^2 values of 0.968, 0.979, and 0.967 respectively; while those of samples 3, 4, and 6 were 6th order polynomial models with R^2 values of 0.959, 0.950, and 0.965 respectively.

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Table 2. Daily Biogas yield of the selected ratios of cattle, swine and poultry wastes.

Day	Biogas yield (cm^3/kg msl) to the nearest 2.5 cm^3 Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	SEM
1.	0.0^{b}	0.0^{b}	2.5^{b}	2.5^{b}	5.0^{a}	5.0^{a}	0.80
2.	0.0^{c}	2.5^{c}	2.5^{c}	7.5^{ab}	5.0^{bc}	10.0^{a}	1.25
3.	2.5^{d}	5.0^{cd}	5.0^{cd}	10.0^{a}	7.5^{bc}	10.0^{a}	1.18
4.	2.5^{c}	5.0^{c}	10.0^{b}	15.0^{a}	7.5^{b}	10.0^{b}	1.65
5.	5.0^{c}	7.5^{bc}	17.5^{a}	15.0^{a}	7.5^{bc}	10.0^{b}	2.05
6.	5.0^{c}	10.0^{b}	12.5^{b}	20.0^{a}	12.5^{b}	12.5^{b}	1.87
7.	10.0^{c}	15.0^{b}	15.0^{b}	20.0^{a}	12.5^{bc}	12.5^{bc}	1.48
8.	10.0^{d}	20.0^{a}	15.0^{b}	20.0^{a}	12.5^{cd}	15.0^{b}	1.41
9.	10.0^{e}	22.5^{a}	20.0^{ab}	17.5^{bc}	15.0^{d}	10.0^{e}	2.27
10.	12.5^{c}	22.5^{ab}	25.0^{a}	17.5^{c}	17.5^{c}	20.0^{b}	1.73
11.	12.5^{c}	22.5^{ab}	25.0^{a}	20.0^{b}	20.0^{b}	22.5^{ab}	1.92
12.	15.0^{b}	27.5^{a}	25.0^{a}	25.0^{a}	25.0^{a}	25.0^{a}	1.61
13.	17.5^{c}	27.5^{a}	30.0^{a}	27.5^{a}	22.5^{b}	25.0^{a}	1.74
14.	20.0^{d}	27.5^{b}	32.5^{a}	27.5^{b}	22.5^{cd}	20.0^{d}	1.91
15.	22.5^{d}	32.5^{a}	30.0^{ab}	27.5^{bc}	22.5^{d}	22.5^{d}	1.65
16.	20.0^{d}	32.5^{a}	35.0^{a}	25.0^{bc}	22.5^{cd}	27.5^{b}	2.17
17.	20.0^{c}	30.0^{a}	30.0^{a}	22.5^{bc}	25.0^{b}	22.5^{bc}	1.56
18.	20.0^{c}	27.5^{ab}	30.0^{a}	22.5^{bc}	22.5^{c}	20.0^{c}	1.58
19.	22.5^{bc}	25.0^{b}	32.5^{a}	25.0^{b}	25.0^{b}	20.0^{c}	1.64
20.	20.0^{b}	22.5^{ab}	25.0^{a}	22.5^{ab}	25.0^{a}	17.5^{b}	1.09
21.	20.0^{ab}	22.5^{a}	17.5^{bc}	15.0^{c}	22.5^{a}	15.0^{c}	1.44
22.	15.0^{cd}	22.5^{a}	17.5^{bc}	12.5^{d}	20.0^{ab}	15.0^{cd}	1.35
23.	12.5^{bc}	20.0^{a}	7.5^{c}	10.0^{c}	17.5^{a}	15.0^{ab}	1.91
24.	10.0^{c}	15.0^{ab}	5.0^{d}	10.0^{c}	17.5^{a}	12.5^{abc}	1.84
25.	7.5^{b}	12.5^{a}	5.0^{b}	5.0^{b}	12.5^{a}	12.5^{a}	1.47
26.	5.0^{bc}	7.5^{ab}	2.5^{c}	7.5^{ab}	12.5^{a}	7.5^{ab}	1.14
27.	5.0^{bc}	5.0^{bc}	2.5^{c}	7.5^{ab}	10.0^{a}	5.0^{bc}	0.92
28.	2.5^{a}	2.5^{a}	5.0^{a}	5.0^{a}	5.0^{a}	5.0^{a}	0.40
29.	5.0^{a}	2.5^{a}	2.5^{a}	2.5^{a}	2.5^{a}	2.5^{a}	0.26
30.	2.5^{a}	2.5^{a}	2.5^{a}	2.5^{a}	2.5^{a}	2.5^{a}	0.00
Avg. Yield	12.5^{c}	17.5^{a}	15.0^{b}	15.0^{b}	15.0^{b}	15.0^{b}	0.77
Cum. Yield	*332.5^{d}*	497.5^{a}	487.5^{a}	467.5^{b}	457.5^{c}	430.0^{c}	23.09

Note *a.b.c.d.e Means with different superscripts along the same row are significantly ($p < 0.05$) different. SEM is an abbreviation for standard error of the mean.

Cumulative biogas yield of selected waste blends

After 30 days of anaerobic digestion, cumulative biogas yields (Figure 2) of sample 2 (497.5 cm^3/kg slurry) and sample 3 (487.5 cm^3/kg slurry) were significantly ($p < 0.05$) higher than those of other samples but not significantly ($p > 0.05$) different from each other (Table 2). The control (sample 1, i.e. cow dung only) produced a cumulative biogas yield of 332.5 cm^3 /kg slurry, which was significantly ($p < 0.05$) lower than all other treatments. Samples 4, 5, and 6 produced moderate cumulative biogas yields of 467.5, 457.5, and 430.0 cm^3/kg slurry respectively. Trend equations of cumulative biogas yield along with their R^2 values are presented in Table 4. They were all 4th order polynomial models with $R^2 = 0.999$ except that for sample 5, which was a cubic equation.

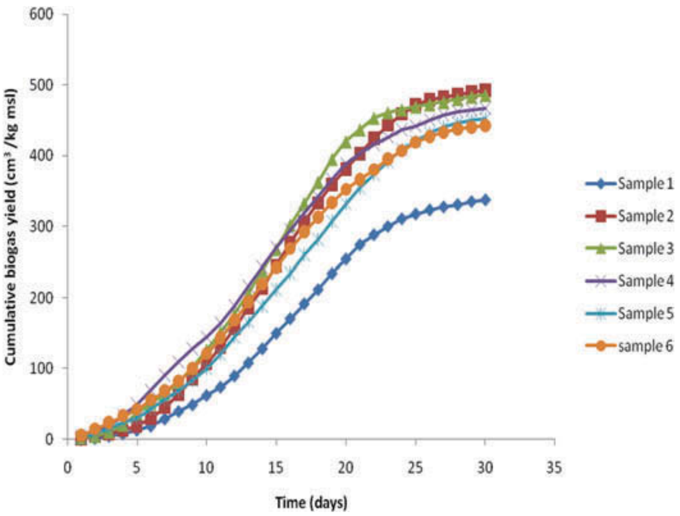

Figure 2. Graph of Cumulative biogas yield (cm^3 /kg slurry) against time (days).

Temperature of bioreactors

The daily reactor temperature was in the range of 28.0–30.5°C. At the start of anaerobic digestion, the temperature of reactor 1 was 30.5°C; reactors 2, 3, and 4 had equal temperature of 30.0°C; reactors 5 and 6 had equal temperature of 29.5°C; while the ambient temperature was 29.5°C. Maximum temperature of reactor 1 was 30.5°C on the 1st to 3rd day, while minimum temperature was 28.5°C on the 6th, 11th, 25th, 26th, and 29th day. A maximum temperature of 30.0°C was attained by reactor 2 on the 1st, 2nd, and 4th day; likewise reactor 3 attained maximum temperature from 1st to 3rd day; reactor 4 attained maximum temperature on the 1st, 3rd, and 19th day; reactor 5 on the 3rd and 16th day; and reactor 6 on the 3rd and 17th day.

A minimum temperature of 28.0°C was reached by reactor 2 on the 13th and 14th day; likewise by reactor 3 on the 6th and 12th day; reactor 4 on the 8th, 12th, 13th, 25th, and 26th day; reactor 5 on the 22nd and 24th day; and reactor 6 attained minimum temperature on the 12th day. Reactor 1 had an average temperature of 29.5°C, while reactors 2 to 6 had an average temperature of 29.0°C. The average temperatures of all reactors were not significantly ($p > 0.05$) different from each other (Table 5).

The ambient temperature was maximum (30.5°C) on the 2nd day, and was minimum (28.0°C) on the 12th, 22nd, and 26th day. There was a weak correlation ($r = -0.086$; $p > 0.05$) between daily reactor temperature and biogas yield as shown in Table 6. A scatter plot of biogas yield against temperature

Table 3. Trend equations of daily biogas yield of the waste samples

Sample	Trend equation	R^2 value	Equation number
1	$DY = 0.00004t^5 - 0.002t^4 + 0.047t^3 - 0.34t^2 + 2.228t - 1.78$	0.968	(1)
2	$DY = -0.000002t^5 - 0.04t^3 + 0.635t^2 - 0.913t + 1.608$	0.979	(2)
3	$DY = -0.000007t^6 - 0.026t^4 + 0.433t^3 - 3.392t^2 + 13.61t - 11.45$	0.959	(3)
4	$DY = -0.000006t^6 - 0.023t^4 + 0.416t^3 - 3.608t^2 + 16.36t - 12.92$	0.950	(4)
5	$DY = 0.00001t^5 + 0.004t^3 + 0.068t^2 + 0.832t + 2.962$	0.967	(5)
6	$DY = -0.000003t^6 - 0.008t^4 + 0.115t^3 - 0.574t^2 + 2.096t - 4.793$	0.965	(6)

DY = Daily biogas yield (cm^3/kg slurry); t = Time (days); R = Correlation coefficient

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Table 4. Trend equations of cumulative biogas yield of the waste samples.

Sample	Trend equation	R^2 value	Equation number
1	$CY = -0.01t^4 + 0.279t^3 - 2.181t^2 + 10.46t - 11.46$	0.999	(7)
2	$CY = -0.007t^4 + 0.145t^3 + 0.337t^2 - 0.862t + 2.56$	0.999	(8)
3	$CY = -0.02t^4 + 0.486t^3 - 3.556t^2 + 19.07t - 20.32$	0.999	(9)
4	$CY = -0.009t^4 + 0.213t^3 - 1.285t^2 + 16.06t - 17.95$	0.999	(10)
5	$CY = -0.004t^3 + 1.193t^2 - 1.191t - 6.635$	0.999	(11)
6	$CY = -0.008t^4 + 0.166t^3 - 0.48t^2 + 7.49t - 0.129$	0.999	(12)

CY = Cumulative biogas yield (cm^3/kg slurry); t = Time (days); R = Correlation coefficient

Table 5. Daily temperature reading of bioreactors

Daily Reactor Temperature (° C)								
Day	T 1	T 2	T 3	T 4	T 5	T 6	Amb. T	SEM
1.	30.5^a	30.0^b	30.0^b	30.0^b	29.5^b	29.5^b	29.5^b	0.17
2.	30.5^a	30.0^{ab}	30.0^{ab}	29.5^b	29.5^b	29.5^b	30.5^a	0.17
3.	30.5^a	29.0^b	30.0^a	30.0^a	30.0^a	30.0^a	30.0^a	0.16
4.	30.0^a	30.0^a	29.5^{ab}	29.0^b	29.5^{ab}	29.5^{ab}	30.0^a	0.16
5.	29.0^a	29.0^a	28.5^a	29.0^a	29.5^a	29.0^a	29.0^a	0.09
6.	28.5^a	29.0^a	28.0^a	29.0^a	28.5^a	29.0^a	29.0^a	0.12
7.	29.0^a	29.5^a	29.0^a	28.5^a	28.5^a	29.0^a	29.5^a	0.16
8.	29.5^a	29.5^a	29.0^{ab}	28.0^c	29.0^{ab}	28.5^{bc}	29.0^{ab}	0.19
9.	29.5^a	29.0^a	29.0^a	29.0^a	29.0^a	29.0^a	29.5^a	0.12
10.	29.0^a	29.5^a	29.0^a	29.5^a	29.0^a	29.0^a	29.5^a	0.15
11.	28.5^b	29.5^a	28.5^b	28.5^b	29.5^a	28.5^b	28.5^b	0.19
12.	29.0^a	29.0^a	28.0^c	28.0^c	28.5^b	28.0^c	28.0^c	0.18
13.	29.5^a	28.0^b	28.5^{ab}	28.0^b	28.5^{ab}	28.5^{ab}	28.5^{ab}	0.19
14.	29.5^a	28.0^b	29.0^a	28.5^{ab}	28.5^{ab}	28.5^{ab}	29.0^a	0.23
15.	29.0^{ab}	29.0^{ab}	30.0^a	29.5^{ab}	29.5^{ab}	28.5^b	29.5^{ab}	0.15
16.	29.0^a	29.5^a	29.5^a	29.5^a	30.0^a	29.5^a	29.0^a	0.09
17.	29.0^{bc}	29.5^{ab}	29.5^{ab}	28.5^c	29.0^{bc}	30.0^a	30.0^a	0.21
18.	29.5^a	29.5^a	29.5^a	29.0^a	29.5^a	29.5^a	29.0^a	0.09
19.	30.0^a	29.0^b	29.0^b	30.0^a	29.0^b	29.5^{ab}	29.0^b	0.17
20.	29.5^a	29.0^{ab}	28.5^b	29.0^{ab}	29.5^a	29.5^a	29.5^a	0.13
21.	30.0^a	29.5^{ab}	29.0^{bc}	29.5^{ab}	29.0^{bc}	28.5^c	29.5^{ab}	0.16
22.	29.5^a	29.5^a	29.0^{ab}	28.5^{bc}	28.0^c	29.5^a	28.0^c	0.24
23.	29.0^{ab}	29.5^a	29.0^{ab}	28.5^b	28.5^b	29.0^{ab}	29.0^{ab}	0.19
24.	29.0^a	29.0^a	28.5^a	28.5^a	28.0^a	28.5^a	29.0^a	0.13
25.	28.5^b	29.5^a	28.5^b	28.0^b	28.5^b	28.5^b	28.5^b	0.18
26.	28.5^a	28.5^a	29.0^a	28.0^a	28.5^a	29.0^a	28.0^a	0.13
27.	29.0^{ab}	29.0^{ab}	28.5^b	29.0^{ab}	28.5^b	29.5^a	28.5^b	0.15
28.	29.0^{ab}	28.5^{bc}	29.0^{ab}	29.0^{ab}	29.5^a	29.0^{ab}	29.0^{ab}	0.15
29.	28.5^b	29.0^{ab}	29.0^{ab}	28.5^b	29.5^a	29.0^{ab}	29.0^{ab}	0.15
30.	29.0^a	29.5^a	29.0^a	29.0^a	28.5^a	29.0^a	28.5^a	0.12
Avg. Temp	29.5^a	29.0^a	29.0^a	29.0^a	29.0^a	29.0^a	29.0^a	0.06

Note *a.b.c Means with different superscripts along the same row for are significantly ($p < 0.05$) different. T 1 to T 6 represents temperatures of reactors 1 to 6

Table 6. Correlation between biogas yield and reactor temperature.

		Yield	Temp
Yield	Pearson Correlation	1	-.086*
	Sig. (2-tailed)		.046
	N	540	540
Temp	Pearson Correlation	−.086*	1
	Sig. (2-tailed)	.046	
	N	540	540

*. Correlation is significant at the 0.05 level (2-tailed).

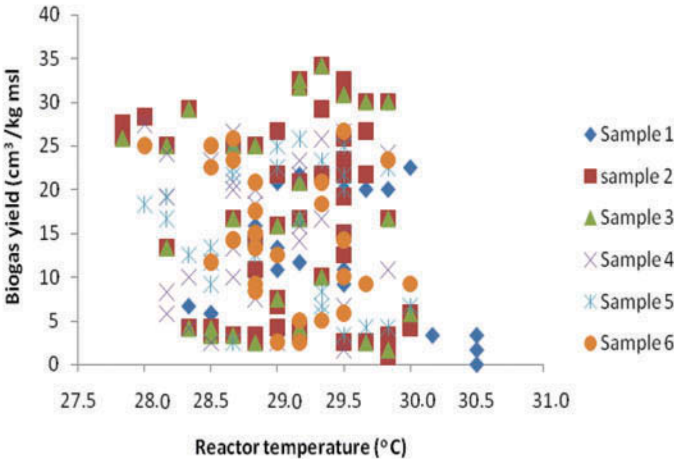

Figure 3. Scatter plot of daily biogas yield (cm^3/kg msl) against reactor temperature (°C).

(Figure 3) also shows that biogas yield was not linearly dependent on reactor temperature.

Discussion

Biogas production from blends of cattle, swine, and poultry wastes was investigated. The results from this study revealed that biogas was produced within the first 24 h of charging of reactors except for waste from cattle dung only (sample 1) and sample 2 which did not generate gas until the 3rd and 2nd day respectively. This is similar to the findings of Ofoefule and Uzodinma (2009), who also reported that biogas was produced from cassava peels blended with cow dung, poultry droppings, and swine dung in the ratio of 1:1 within the first 24 h of charging biodigesters. However, Ojolo et al. (2007) reported that biogas was produced from poultry droppings, cow dung, and kitchen waste after the 7th day of setting up of experiment, while Iyagba et al. (2009) reported that biogas was produced from cow dung and rice husk mixture after the 3rd day. The earlier onset of biogas production was due to the use of pre-fermented poultry dung as inoculum. This ensured the availability of metanogenic bacteria at the start of anaerobic digestion. Addition of inoculum has been reported to increase gas yield and reduce retention period (Kanwar and Guleri 1995; Kotsyurbenko et al. 1993; Dangaggo, Aliya, and Atiku 1996).

Biogas yield of sample 1 peaked on the 15th and 19th day. Its production from the blends of equal masses of cattle and poultry wastes (samples 2) peaked on the 5th and 16th day. Maximum biogas yields were attained by the blends of cattle, swine, and poultry wastes in the ratio of 4:1:3 (samples 3) on the 16th day; ratio of 2:1:1 (samples 4) on the 13th–15th day; and ratio of 4:1:3 (sample 5) on the 12th, 17th, 19th, and 20th day. The blend of equal masses of cattle and swine waste (sample 6) attained maximum biogas yield on the 16th day. This is similar to the findings of Ofoefule and Uzodinma (2009) that maximum biogas yield from cassava peels and swine waste blend occurred on the 18th day. Cumulative biogas yields of samples 2 to 6, between 430 and 497.5 cm^3/kg slurry, were close to the results of Adeyemo and Adeyanju (2008), who reported that 455 cm^3/kg slurry of biogas was generated from poultry manure.

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The cumulative biogas production curves for all the samples tend to follow the sigmoid function (S-curve) similar to the results of Budiyono, Johari, and Sunarso (2010). Biogas production was very low at the beginning and end of the experiment. Nopharatana, Pullammanappallil, and Clarke (2007) stated that biogas production rate in batch condition increases with specific growth rate of methanogenic bacteria in the bio-digester. At the beginning of anaerobic digestion, microbial growth was in the lag phase, hence biogas production was low. Thereafter, biogas production significantly increased due to exponential growth of microorganisms. Subsequently, as the stationary phase of microbial growth set in, biogas production decreased, similar to the results of Castillo, Luengo, and Alvarez (1995).

The trends of cumulative and daily biogas yield of the samples were modeled by polynomial equations of order 3 to 6. The R^2 values of these models, between 0.950 and 0.999, were comparable with those (between 0.9093 and 0.9509) of the quadratic models developed by Ojolo et al. (2008) for different substrate loadings of municipal solid waste anaerobic digester. Polynomial equations of higher order were chosen for this study so as to improve the sensitivity of the models developed.

The temperature of the reactors ranged from 28.0 to 30.5°C. Mesophilic bacterials were reported to grow between 25°C and 35°C (Centre for Energy Studies 2001), which is favorable for anaerobic digestion. Marchaim (1992) had noted that all bacterial populations in digesters were fairly resistant to short-term temperature upsets, up to about 2 h, and return rapidly to normal gas production rates when the temperature was restored. Changes in temperature may have resulted in unbalanced bacterial populations. Therefore, reactors 1 and 2, which had the highest average temperatures (29.5°C and 29.0°C respectively), produced the least and the highest biogas yields respectively, indicating that the digestion system is independent of temperature. Moreover, differences in biogas yields may have been due to other factors. A weak correlation ($r = -0.086$; $p > 0.05$) between daily reactor temperature and biogas yield also support this claim.

Conclusions

In this study, it has been shown that biogas yield of cattle dung can be improved by combining it with swine or poultry wastes. It was revealed that a blend of cattle dung, swine, and poultry wastes in the ratio 1:0:1 or 4:1:3 is optimum for biogas production. The study has shown that polynomial equations of order 3 to 6 are appropriate models for the trends of daily and cumulative biogas yields. It also confirmed that temperature variations within the mesophilic range do not affect biogas production.

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