Anaerobic Digestion Of Selected Animal Wastes For Biogas Production In A Fed-Batch Reactor At Mesophilic Temperature

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***Abstract*—Animal manure constitutes a nuisance to the environment. This work aimed at tackling environmental problem as well dealing with energy demand crisis. This work evaluated and compared the energy produced from anaerobic digestion of Cow Slurry (CS), Pig Slurry (PS) and Chicken Waste (CW) by batch experiment at mesophilic temperature (37 $^{\circ}$C). The study was carried out in a laboratory scale batch digester. The digestion bottles were fed with 44.20, 105.70 and 11.21 g, respectively, which were calculated. The digestion took place for a period of about 40 days after which the gas production was noticed to be below 1% of the total gas produced till that time. The biogas yields from organic dry matter (oDM) of CS, PS and CW were found to be 441.33 l. kg^{-1} oDM, 277.35 l.kg^{-1} oDM and 493.08 l. kg^{-1} oDM respectively after 40 days digestion time. Methane yields (oDM) of CS, PS and CW were also found to be 296.50 l.CH_4 kg^{-1} oDM, 216.90 l.CH_4kg^{-1} oDM and 328.19 l.CH_4kg^{-1} oDM respectively. The fresh mass (FM) biogas and methane yields of CS, PS and CW were found to be 40.75, 10.70 and 156.41 l. kg^{-1} $_{FM}$; and 28.50, 8.35 and 100.69 l. CH_4kg^{-1} $_{FM}$ respectively. The equivalent energy of CS, PS and CW were found to be 11.55, 7.26 and 12.92 MJ respectively. Also, CS, PS and CW were found to have methane concentrations of 66.71, 79.71 and 66.56%, respectively. This study has established that among CS, PS and CW, CW has the highest biogas and methane yields and in turn, energy potential.**

***Keywords*—Batch experiment, biogas potential, energy, cow slurry, pig slurry, chicken waste, mesophilic temperature,**

I. INTRODUCTION

Anaerobic digestion (AD) is an environmentally sustainable technology for converting a variety of feedstocks (waste sources) including manure, the organic fraction of municipal solid waste (OFMSW), and agricultural residues to energy in the form of methane (Demirer *and Chens,* 2005). The gas produced through anaerobic digestion is called biogas. Table 1 presents theprimary compositions of biogas which are methane (CH_4) and carbon dioxide (CO_2), with varying amounts of water, hydrogen sulphide (H_2S), oxygen and other compounds (Madu & Sodeinde, 2001, Keefe & Chynowet, 2000, and Ten-Brummeler & Koster, 1990).

Biogas technology offers a very attractive route to utilize certain categories of biomass for meeting partial energy needs. Biogas is produced from organic wastes by concerted action of various groups of anaerobic bacteria. According to Mclnerrney and Bryant (1981), the production of biogas involves the breaking down of complex polymers to soluble products by enzymes produced by fermentative bacteria which ferment substrate to short-chain fatty acids, hydrogen and carbon dioxide. Fatty acids longer than acetate are metabolized to acetate by obligate hydrogen producing acetogenic bacteria. Biogas is used for the production of heat, light, and electricity, Combined Heat and Power (CHP), as vehicle fuel, transformation of organic waste into high-quality fertilizer, improvement of hygienic conditions through reduction of pathogens, reduction of work for firewood collection and cooking, and environmental advantages through protection of soil, water, air, and woody vegetation (Tafdrup, 1995, NAS, 2001).

Organic wastes are known to have high energy potential, as indicated by Odeyemi (1995) who obtained biogas from palm oil effluents. Various agricultural residues and manure had been used in the past for the production of biogas (Adebayo *et al.,* 2013, 2014a and 2014b). Anaerobic microorganisms are responsible for the bio-degradation of organic materials in the absence of oxygen. Biogas is produced through a series of metabolic interactions among various groups of microorganisms. This occurs in three stages, hydrolysis/liquefaction, acidogenesis and methanogenesis. The first group of microorganism secretes enzymes, which hydrolyses polymeric materials to monomers such as glucose and amino acids. These are subsequently converted by second group (acetogenic bacteria) to higher volatile fatty acids, H_2 and acetic acid. Finally, the third group of bacteria, methanogenic, convert H_2, CO_2, and acetate, to CH_4. Biogas, the gas produced when organic matter of animal or plant origin ferments in an oxygen-free environment occurs naturally in swamps and spontaneously in landfills containing organic waste. It can also be induced artificially in digestion tanks to treat sludge, industrial organic waste, and farm waste.

Anaerobic digestion of animal wastes for production of biogas is a widely studied subject. The population of cattle, pigs, goats, sheep and fowl have been increasing from time past on different farms (Table 2). The discovery of biogas has therefore brought about animal wastes recycling to produce usable fuel for lighting, heating, and fueling agricultural machinery while the digested slurry can be converted into compost through the use of "vermiculture" to improve the fertility of the soil.

The objective of this work is to carry out a comparative analysis of biogas production potential of cattle dung, pig slurry and chicken waste at mesophilic temperature.

II. Materials and Methods

The substrates used for this experiment were obtained from the Institute for Animal Breeding and Animal Husbandry (ABAH), Ruhlsdorf / Grosskreutz, Germany. All samples were kept in the laboratory at a temperature of +3°C prior to feeding into the digester. Samples of CD, PS and CW were taken to the laboratory for analysis. The amount of substrate and seeding sludge weighed into the fermentation bottles were determined in accordance to German Standard Procedure VDI 4630 (2004) using the equation 1:

$$\frac{oTS_{substrate}}{oTS_{seedingsludge}} \leq 0.5 \qquad (1)$$

Table 1: Typical Composition of Biogas

Constituents	% Composition
Methane, CH_4	50 – 75
Carbon dioxide, CO_2	30-50
Hydrogen Sulphide, H_2S	0-1
Nitrogen, N_2	0-1
Hydrogen, H_2	0-1
Carbon monoxide, CO	0-3
Oxygen, O_2	0-2

Source: Madu and Sodeinde (2001), Keefe and Chynowet (2000) and Ten-Brummeler and Koster (1990).

Table 2: Nigerian Livestock Population for 2008

Species	Number
Cattle	16293200
Goats	53800400
Pigs	6908030
Sheep	33874300
Chicken	175000000
Horses	207830
Camels	18800
Asses	1050000

Source: FAO, 2008.

Where:

$oTS_{substrate}$ = organic total solid of the substrate and;

$oTS_{seeding\ sludge}$ = organic total solid of the seeding sludge (the inoculum)

Equation (2) is the mass ratio equation from which the mass of the substrate m_s fed into the reactor was calculated.

$$p_i = \frac{m_i . c_i}{m_s c_s} \qquad (2)$$

Where

p_i= mass ratio=2 ; m_i= amount of inoculum, g

c_i=Concentration of inoculum, oDM in % Fresh mass

m_s= amount of substrate,g

c_s= Concentration of substrate, oDM in % fresh mass

The experiment was carried out in a Fed-Batch Reactor at Mesophilic Temperature (37°C). In batch systems, a reactor is loaded with feedstock, run to completion, emptied and reloaded

Biogas production and quality from Cattle Dung (CD), Pig Slurry (PS) and Chicken Waste were analyzed in batch anaerobic digestion test at 37°C according to German Standard Procedure VDI 4630 (2004). Batch experiments were carried out in lab-scale vessels and replicated twice as described by Linke and Schelle (2000). A constant mesophilic temperature of 37°C was maintained through a climatic chamber (Plate 1). Anaerobically digested material from a preceding batch experiment was used as inoculum in this study. 800g of the stabilized inoculum was mixed separately with *44.20, 105.70 and 11.21 g* of CD, PS and CW respectively for anaerobic digestion. The fermentation vessels were properly shaken each day in order to fully re-suspend the sediments and the scum layer. The biogas produced was collected in graduated gas sampling tube inserted in a confining liquid in the defined period of about 30-40 days and was measured daily. This duration of the test fulfilled the criterion for terminating batch anaerobic digestion experiments given in VDI 4630 (daily biogas rate is less or equal to only 1% of the total volume of biogas produced up to that time). Methane contents of the gas produced were determined at least two times in a week during the batch test using the gas analyzer, GA 2000 model. Biogas production of the inoculum without substrate was also recorded as a control. The biogas and methane yields were then calculated at the standard temperature and pressure (0^{o}C, 1013 mbar). Readings of the gas production (ml), air pressure (mbar), gas temperature (^{o}C) and time of the day were taken on daily basis throughout the period of the experiment. The gas factor was calculated as well as the fresh mass biogas and methane yield with the volatile solid biogas and methane yields also determined on daily basis. The amount of gas formed was converted to standard conditions (273.15 K and 1013.25 mbar) and dry gas. The factor was calculated according to equation (3).

Plate 1: Batch Experimental set-up

$$F = \frac{(p - P_{H_2O}).T_o}{(t + 273.15).p_o} \qquad (3)$$

Where

T$_o$= 273.15 ^{o}C (Normal temperature)
t= Gas temperature in ^{o}C
P$_o$= 1013.25 mbar (standard pressure)
P= Air Pressure

The vapour pressure of water P_{H_2O} is dependent on the gas temperature and amounts to 23.4 mbar for 20^{o}C. The respective vapour pressure of water as a function of temperature for describing the range between 15 and 30^{o}C is given as in equation (4)

$$P_{H_2O} = y_o + a.e^{b.t} \qquad (4)$$

Where:

y_o = -4.39605; a = 9.762 and b= 0.0521

The normalized amount of biogas volumes is given as

$$Biogas[N\,ml] = Biogas[ml] \times F \qquad (5)$$

Normalized by the amount of biogas, the amount of gas taken off the control batch is given as

$$Biogas[N\,ml] = (Biogas[Nml] - Control[Nml]) \qquad (6)$$

The mass of biogas yield in standard liters / kg FM fresh mass (FM) is based on the weight

The following applies:

1 standard ml / g FM=1 standard liters / kg FM = 1 m^3 / t FM

$$Mass\,of\ biogas\ yield = \sum \frac{Biogas[N\,ml]}{Mass[g]} \qquad (7)$$

The oDM biogas yield is based on the percentage of volatile solids (VS) in substrate

$$oDM\ biogas\ yield = \sum \frac{Biogas[N\,ml).100]}{Mass[g].VS[\%FM]} \qquad (8)$$

$$CH_{4corr.} = \frac{CH_4[vol\%].100}{(Mass[g] + CO_2[vol\%])} \qquad (9)$$

$$Fresh\,mass\,methane\ yield = \frac{Fresh\,mass\,biogas\ yield \times CH_{4corr}}{100} \qquad (10)$$

$$oDM\ Methane\ yield = \frac{oDM\ biogas\ yield \times CH_{4corr.}}{100} \qquad (11)$$

III. Results and Discussion

CS, PS and CW were analysed in the laboratory for chemical and thermal properties (Table 3). The tested samples showed monophasic curves of accumulated biogas production. The cumulative curves of Figures 1-4 show how biogas production increased steadily at the beginning before it began to decline. Anaerobic digestion of CS, PS and CW produced 40.75, 10.70 and 156.41 l_N/kg_{FM} biogas respectively (Figure 1). Also, the fresh –mass methane yields of CS, PS and CW gave 28.50, 8.35 and 100.69 l_NCH_4/kg_{FM} respectively (Figure 2). Organic Dry Matter (oDM) biogas and methane yields of CS, PS and CW were 441.33, 277.35, 493.08 l_N/kg_{oDM} and 296.50, 216.90 and 328.19 l_NCH_4/kg_{oDM} respectively (Figures 3 and 4). CS, PS and CW were found to have methane concentrations of 66.71, 79.47 and 66.56% respectively. Table 4 presents energy productions from CS, PS and CW.

The C/N ratio of cattle slurry, pig slurry and chicken waste has been found to be 19:1, 16:1 and 8:1 respectively (Singh *et al*, 2009). The C/N ratio of the chicken waste (8:1) indicated that there was too much nitrogen and thereby making the carbon to be soon exhausted, leading to early stoppage of fermentation.

The results also revealed that chicken waste had the highest biogas yields of 493.08 l_N/kg_{oDM} when compared with cattle slurry and pig slurry which respectively have 441.33 l_N/kg_{oDM} and 277.35 l_N/kg_{oDM}. However, the laboratory analysis of the chicken waste revealed very high nitrogen content (Table 3). Since anaerobic bacteria do not digest lignin or various hydrocarbons, high nitrogen contents in the waste can produce toxic substance like ammonia in the anaerobic medium for anaerobes and this usually results into early failure of the reactor.

Table 3: Results of laboratory analysis of the selected animal manure and the inoculum

Parameters	Cow slurry	Pig slurry	Chicken waste	Inoculum
Dry Matter, DM (%)	10.91	5.10	39.80	1.96
oDM (%DM)	84.60	75.76	77.09	52.28
Organic Dry Matter (%FM)	9.23	3.86	30.68	1.02
NH4-N (g/kgFM)	1.22	4.18	2.05	0.779
N_{kjel}, g/kgFM	3.87	7.49	21.81	1.47
Pmg/kg TS60°	1082.7	1285.1	13439.3	306.6
K %DM	2.05	3.87	2.19	15.50
Crude Fibre (%DM)	26.75	-	-	-
pH	6.56	7.98	6.67	7.95
Conductivity	9.98	21.90	3.26	12.70
DM (60°-105°C)	96.89	97.23	96.32	-
Ethanol (g/l)	<0.04	<0.02	<0.04	<0.04
Propanol	0.04	<0.02	<0.04	<0.04
Total Acetic Acid	8.12	11.49	6.07	0.33

Table 4 : Energy productions from CS,PS and CW

Substrate	Biogas yield (m^3/kgoDM)	Energy (MJ)
Cow slurry	0.441	11.55
Pig slurry	0.277	7.26
Chicken Waste	0.493	12.92

Note: Energy per cubic meter of biogas=26.2MJ (Nielson *et al.*, 2007 and Anunputtikul and Rodtong, 2007).

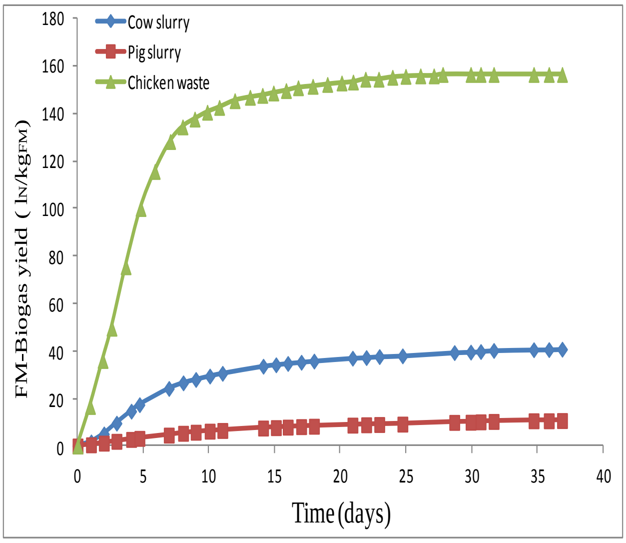

Figure 1: Daily Fresh-mass biogas yields of CS, PS and CW at 37°C

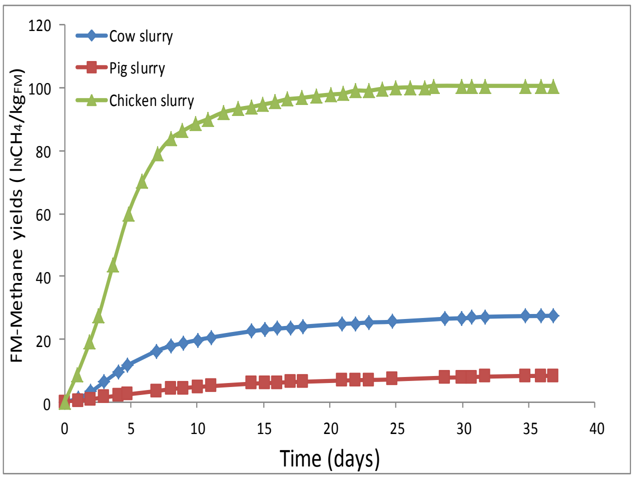

Figure 2: Daily Fresh-Mass Methane yields of CS, PS and CW

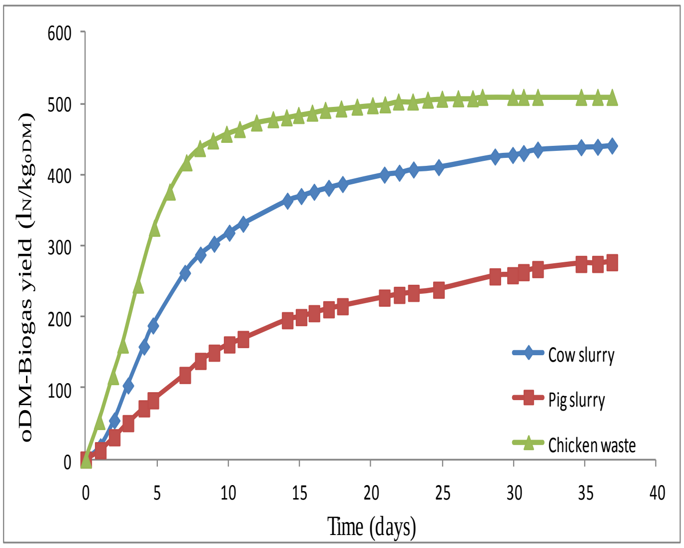

Figure 3: Daily oDM Biogas yield of CS, PS and CW

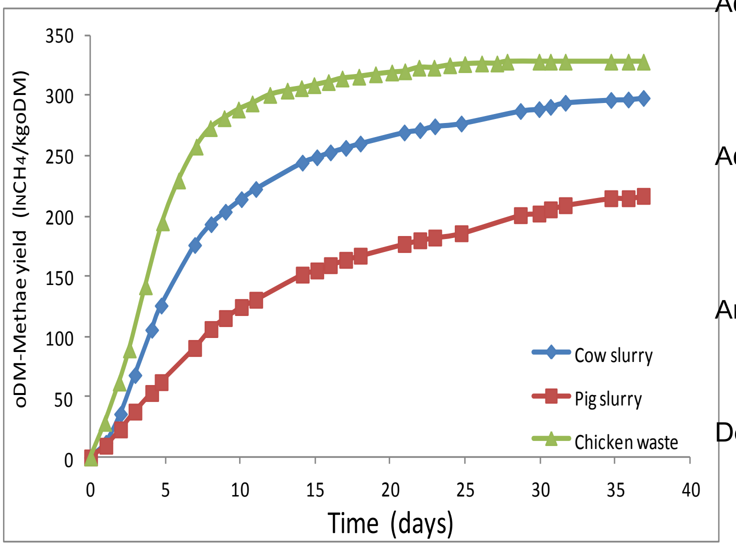

Figure 4: Daily oDM- Methane yields of CS, PS and CW

Conclusions

From the results obtained, the following conclusions were drawn

- Cow slurry (CS), Pig Slurry (PS) and Chicken Waste (CW) are good substrates for anaerobic digestion.
- The biodegradability of Chicken Waste (CW) was the highest with biogas and methane potentials of *493.08 L/(kg $_{oDM}$)* and *328.19 LCH_4/(kg $_{oDM}$)* respectively at mesophilic temperature in batch experiment.
- It has been established that CW has the highest energy yields when compared to CS and PS.

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