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Full Length Research Paper

Effects of Slurry Ratio on the Properties of Poultry Manure Biogas

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Abstract

The aim of this research is to investigate the effects of slurry ratio parameters on the properties of biogas produced from poultry manure with respect to the quality and quantity of the biogas produced. Proximate analyses of the poultry manure (used for slurry) were carried out to determine its potentials for biogas production. The biogases were produced at different levels of slurry ratios (1:1, 1:2 and 1:3). The properties determined in the laboratory were methane value, carbon (IV) oxide, H_2S, pH value, ash and moisture contents, while the calculated properties from the laboratory results were potential calorific value, average gas yield and carbon/nitrogen ratio. The laboratory investigations showed that the properties of the biogases produced ranged between 60 – 64.2% methane, 29.94 – 34.41% CO_2 and 2.71 – 2.96% H_2S contents. The treatment with ratio 1:2 produced the highest weight of biogas of 1.46 kg, while treatment 1:1 produced the least with 0.95 kg. Similarly, the ratio 1:1 gave the least value of CO_2, while ratio 1:2 gave the highest value of CO_2. The calculated calorific values ranged between 5.964 and 6.382 kWh/m^3. The mean values of C/N ratio before and after gas production were 7.5 and 8.81, respectively. The single factor analysis of variance (ANOVA), Duncan Multiple Range Test (DMRT) and t-Test showed that at 95% level of significance, methane content was seen significantly differ in all the treatments but was higher in treatments 1:1.

Key words: *Poultry manure, Biogas, Slurry ratio, Fermentation, Methane, Retention time.*

Introduction

Modern civilization and its economy have become dependent upon a prodigious consumption of energy derived mostly from burning of fossil fuels. The problems of availability and depletion of non-renewable sources, among others, promote use of renewable sources of energy as guaranteed sources especially in rural communities where materials for generation are abundant (Rai, 1989). Moreover, the dependence on fossil fuels as primary energy source has led to global climate change, environmental degradation and human health problems. Now, more than ever before, applied research has the potential to develop more efficient technologies, take advantage of renewable resources, minimize waste and optimize recycling of existing resources (Earth Trends, 2005). Rising energy prices and concerns about long term sustainability have once again brought renewable energy sources to the forefront.

Nigeria is abundantly blessed with different types of energy resources. The climate permits average solar radiation as high as 5.538 kWh/m^2/day making the country operate mainly under mesophilic temperature at ambient conditions (World Energy Council, 1993). There are equally abundant agricultural by-products that remain untapped. This energy need to be tapped especially as the energy supply of the country is grossly inadequate.

With continuous increase in world population and rise in living standards, the demand for energy is steadily increasing. Global environmental issues, such as global warming, early exhaustion of fossil fuel and accompanying potential social uprising in fossil fuel producing areas (due to agitation for resource control) poses serious problems for continuous energy generation, consumption and sustenance. In addition, environmental hazards from careless dumping of animal and human wastes will be controlled if these wastes can be converted into biogas. Deforestation will also be reduced if people no longer rely solely on firewood for cooking in addition to creation of employment for most of the rural communities. In view of this, environmentally-friendly technology and a shift to non-fossil energy resources that are renewable such as natural energy and biomass are inevitable. Biogas is said to be ideal in deciding alternative energy for rural people in the sense that it is cheap, available and local in origin and production. It is also an energy source that is useful for multiple purposes – heating, lighting, small-scale power generation, and so on, Tambuwal (2002). Consequently, this paper will investigate how the effects of slurry ratio on the quantity and qualities of biogas from poultry manure.

Research Methodology

A plastic batch-flow floating-drum biogas plant was designed and constructed. Poultry manure from a deep litter mixed with water was used as slurry for gas production. Proximate analyses of the poultry manure were carried out to determine its potentials for biogas production. The biogases were produced at different levels of manure-to-water ratio. The slurry ratios of 1:1, 1:2 and 1:3 were obtained using 67, 45 and 33.5 kg of manure, respectively. The properties determined in the laboratory were methane value, carbon (IV) oxide, H_2S, pH value, ash and moisture contents, while the calculated properties from the laboratory results were potential calorific value, average gas yield and carbon/nitrogen ratio.

Experimental Set-up

Slurry ratios were varied to determine their effects with respect to gas production in terms of quality and quantity. Slurry ratio (poultry manure-to-water) of 1:1, 1:2 and 1:23 were used. First, a slurry ratio of 1:1 by mass of dry poultry manure and water was used to produce gas without agitating the content throughout the gas production process, noting the quantity of gas produced daily. This process was repeated for ratios 1:2 and 1:3 by mass of dry poultry manure and water, respectively. The gases produced daily were weighed using a digital weighing (ORMA; EC 1000) balance to determine the amount of gas produced.

Sample Slurry Preparation

About 500 kg of poultry manure was collected from a laying stock deep litter system managed by White-House Farm, Ilorin - Kwara State, Nigeria using spades and buckets and dried under the shade to achieve a constant weight. The dried litter was stored in a double polythene bag and sealed to prevent moisture entering the system. All the samples collected were fresh litters. They were oven dried at 60°C for 24 hours. The product was then ground to small particles of 6 mm size to determine the proximate and ultimate analyses of the samples. It was ensured that foreign materials such as sand, cotton materials, feathers, plastics, metals, maize cobs, wood and other feed materials that might have spilled from the feeders were removed from the sample such that they were not allowed into the digester.

Three treatments were considered – ratios 1:1, 1:2 and 1:3 by weight of poultry manure to water, respectively. For the first treatment, 67 kg of the poultry manure was weighed using a 100 kg weighing scale, then an equivalent 67 litres of water was measured. These quantities were mixed in a pre-mixing tank with the aid of a curved stick of about 1m long until a homogeneous mixture was achieved. The slurry thus formed was charged into the digester through the slurry inlet valve. This mixture adequately filled $\frac{2}{3}$ of the digester volume, as recommended by Kumar (1989). The slurry inlet valve was then closed. A tyre tube was connected to the gas outlet valve of the digester. It was monitored to observe inflammation due to gas release. The amount of gas produced was recorded and weighed every 24 hours after the first release until gas production ceased. The gas being released was recorded, weighed and stored.
In the second treatment, the ratio of manure to water was varied as 1:2, respectively. Here, approximately 45 kg of manure was weighed and mixed with 90 litres of water in a similar manner as was done earlier. The process was again repeated for ratio 1:3 each time weighing and recording gas production until gas production ceased.

Determination of Moisture Content (dry basis)

The dried sample of the poultry manure was grounded to smaller particles of 6 mm size and taken to the laboratory for analysis as recommended by Marchaim (1992). The moisture contents (wet basis) were determined from the following equation

$$MCdb = \frac{Wi - Wd}{Wi} \quad (1)$$

Where: $MCdb = \text{Moisture content (dry basis)}, \%$

$Wi = \text{Initial weight of the sample}, g$ $\quad Wd = \text{Weight of the dried sample}, g$

Determination of Calorific (or Heating) Values

The calorific (heating) values of the respective biogases will be determine using equation 2

$$CVg = CVm \; x \; MC \text{ x CVg} \quad (2)$$

$\text{Where: } CVg = \text{Calorific Value of the Produced gases } (kWhr/m^3)$

$CVm = \text{Calorific Value of Methane given as } 9.94 \; (kWhr/m^3)$

$Mc = \text{Methane Value of the produced Biogases (Mederius and Gaby, 2007)}$

Biogas Collection and Recording

A car tyre tube (175/185 - 13/14) was weighed with the aid of a digital precision weighing balance (2000 g capacity and 0.01 g sensitivity) to determine its initial weight. It was then connected to the gas outlet valve of the digester. When the valve was opened every morning, biogas produced in the digester flowed into the tube as a result of pressure difference between the digester and the tube. The inflammation of the tube was observed for about 10 minutes to ensure that the tube size remained constant. The tube was then disconnected and weighed to determine the new weight. The difference in weight was recorded as the amount of the biogas produced. This process was repeated every 24 hours until no change in weight was observed, i.e. when the gas ceased to flow. The contents of the tubes were periodically discharged into the gas collection tank. Gas production was observed to begin between the 4th, 3rd and the 2nd day after feeding the digester for treatments 1:1, 1:2 and 1:3, respectively.

Analyses of Biogas Produced

To determine the quality of the produced gas, samples of the gas were subjected to various laboratory tests in order to determine some of their important properties. These included methane (CH_4) content of the gases, carbon (IV) oxide and hydrogen sulphide (H_2S). The principle of measurement is the measurement of reduction in volume which occured when individual constituent of the gas were removed separately by absorption in liquid reagents using Orsat Apparatus. The Orsat apparatus was used to measure volumes of carbon (IV) dioxide, hydrogen sulphide, oxygen and carbon (II) oxide within a fixed volume of a sample gas (100 cc).

Results and Discussion

Analyses of the Poultry Manure and Sludge

Results of the proximate and ultimate analyses of the samples of the poultry manure both before and after the digestion process showed marked differences in the concentrations of various parameters tested as indicated in Figure 1. It revealed that the average moisture content of the poultry manure before and after the gas production was 15.69% and 13.17%, respectively. These results are in agreement with Ruffin and McCaskey (1991); Bouallagui, *et al.* (2005) and Bagley *et al*. (1994) who found the moisture content of poultry litter for biogas production to be between 12 and 25%. This could be attributed to the fact that water dissociated into hydrogen and oxygen ions during the fermentation of the slurry. The hydrogen ions combine with the carbon ions to form methane while oxygen ions combine with carbon to form carbon (IV) oxide. The high moisture content in the poultry manure was what caused it to produce various toxic gases as well as noxious odors, especially when kept in a poorly ventilated area. Moisture content reduced after digestion, this was due to hydrolysis which released the hydrogen content in the water to form methane.

Manure was also analyzed with respect to nitrogen, carbon, and hydrogen. Carbon contents before and after digestion were 32.90 and 23.81%, respectively. There was an increase in ash contents of the stabilized manure sample and the digested sample of the effluent from 25.97 to 58.84%. This higher ash content after digestion was an indication of the removal of the vital energy contents in form of biogas from the poultry manure sample leaving incombustible matter that formed bulk of the ash contents in the sludge, Ruffin and McCaskey (1991). The increase in the ash content also caused a reduction in C and N_2 contents of the digested samples. The high ash content of the manure may also have resulted from the use of wood shavings as bedding material. The initial higher carbon content of 32.90% is an indication that the substrate will produce a reasonable amount of biogas. The drop in carbon content after the production of the biogas to about 23.81% means that most of the organic carbon was burnt into ashes while the remaining quantity were converted into methane, Ruffin and McCaskey (1991).

The value of the C/N ratio before the biogas formation commenced in this study was determined to be 7.5: 1 which is in agreement with Kossmann *et al.* (2006), FAO (1996), Crow (2006) and Steffen *et al*. (1998). However, the value of C/N ratio (8.7:1) was higher at the end of the process indicating the high rate of carbon that had been burnt in form of ash content which is in line with the recommendations of Kossmann *et al*. (2006), Crow (2006) and Steffen *et al*. (1998).

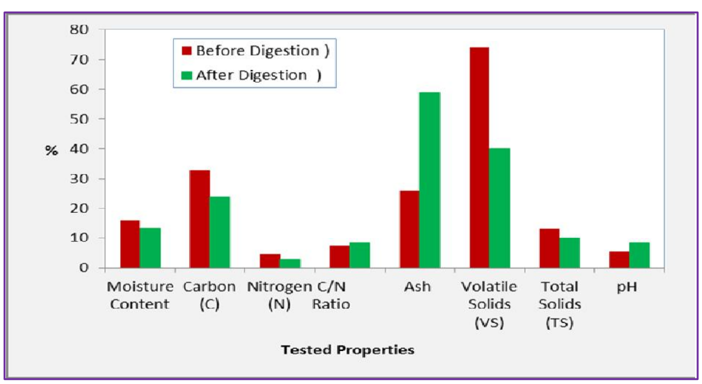

Figure 1. Mean Proximate Analysis of Poultry Manure before and after Digestion

Analysis of pH value

The average pH value of the manure before and after the digestion process was 5.6 and 8.13 respectively. These results were good, in that anaerobic digestion would take place when the pH value of the slurry was neutral, that is, 7.0; indicating that methane-producing bacteria lived well under neutral to slightly alkaline conditions. This is in agreement with Mattocks, (1994), Werner *et al.,* (1989) and Habmigegern, (2003) that the slurry was gradually transforming from alkalinity to basicity while the digestion process was taking place. Equally, it is in agreement with Bouallagui *et al.* (2005) who suggested that the optimum pH requirement of biogas production was between 6.8 and 7.4.

Quantitative Analysis of the Biogas Produced

The daily values of the biogas produced from the various treatments were observed and recorded as indicated in Figure 2. Comparison of these results revealed that gas production in treatments with ratio 1:1, 1:2 and 1:3, respectively started on the fourth, third and second day after charging the digester. While treatments 1:1 could be said to have same contents of water and manure, early gas formation in treatment 1:3 may be attributed to the effects of adequate moisture to kick-start its fermentation. This emphasizes the importance of provision of adequate moisture in the preparation of the slurry for a more conducive microbial activity in order to achieve satisfactory digestion which resulted in more gas production, thus supporting the findings of Mattocks (1994), Kumar (1989), Werner *et al.* (1989), and Jantrania (1985). It was also observed that the biogas produced on the first day in treatment 1:2 was higher than that of treatment 1:1. The treatment with ratio 1:2 produced the highest weight of biogas of 1.46 kg with the shortest retention period of 18 days; however, biogas formation was actually for 16 days only. Its peak production day was the 9th with 164.01 g and steadily dropped to the 18th day when biogas production ceased. This was followed closely by the treatment 1:3 with water ratio whose total produced gas weight was 1.29 kg and a retention period of 22 days. This shows that moisture content affected retention time and total gas production agreeing with agreeing with Hill (1984), Werner *et al.* (2001), Broughton (2009), and Kossman *et al*. (2006) that excess moisture content delays fermentation. Similarly, treatment 1:1 (19 days) that has less water content had longer retention time than treatment 1:2 (18 days) since there is not enough moisture to facilitate suitable microbial activities thus delaying biogas formation, further supporting the argument put up by Thy (2003), Steffen *et al*. (1998), Medyan (2004) and Werner and Habamehl (2001) that relatively un-moist slurries inhibits biogas formation due to unfavourable conditions for proper digestion.

Further observation on Figure 2 indicates that biogas production for all the treatments went on smoothly with limited disruption, perhaps due to the fact that the experiment was conducted in a relatively constant condition where no significant temperature changes were noticed throughout the process (Appendix I) thereby permitting an approximate stability of micro-organisms activities within the system (Sathianathan, 1999; Hajamis and Ranade, 1992; FAO, 1996; and Mitel, 1996). The retention periods of all the treatments were not beyond 22 days agreeing with Steffen *et al.* (1998), Thy (2003), Adrian, (2007), Yisa and Manga, (2004).

Analyses for the Properties of the Produced Biogases

The contents of methane values, CO_2, and H_2S were determined in all the three treatments studied. The average values of these properties are indicated in Table 1. The biogas from ratio 1:2 treatment has the highest methane content of 64.2 %, while the lowest amount of 60 % was found in the treatment of ratio 1:1. However, their CO_2 and H_2S contents when compared showed that the former treatment had lower content, perhaps due to the earlier conclusion that most of the carbon content in the sample were burnt and turned to ash while the gas production process was on. This also indicated that H_2S is soluble in water forming a weak acid. Generally, it can be seen that treatments 1:2 produced more biogas than the other set-ups

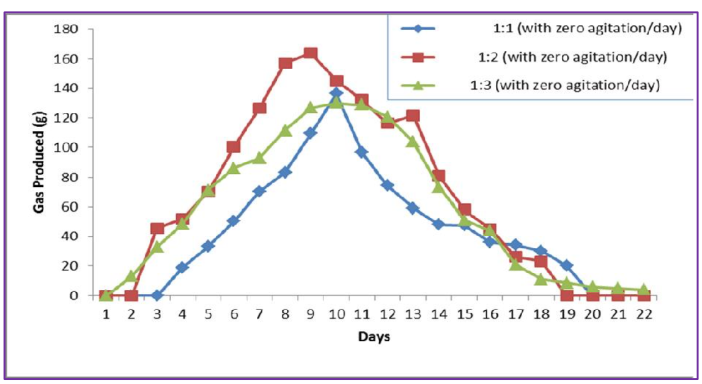

Figure 2. Graphical Representation of Biogas Produced from the Treatments

This emphasizes the importance of adequate moisture in the preparation of the slurry for a more conducive microbial activity in order to achieve satisfactory digestion which results in more gas production further supporting the findings of Mattocks (1994), Kumar (1989), Werner *et al.* (1989), and Jantrania (1985). Although treatment 1:3 had more water content than the other treatments, its methane content was less than treatment 1:2, perhaps because it had excess water content than required for ideal fermentation.

Table 1. Mean Values of the Tested Properties of the Produced Biogas

S/N	Parameter	Samples (%)		
		1:1	1:2	1:3
1.	Methane (CH_4)	60.00	64.20	62.05
2.	Carbon (IV) Oxide (CO_2)	34.41	29.94	31.18
3.	Hydrogen Sulphide (H_2S)	2.96	2.84	2.71

Analyses of the Properties of the Produced Biogases with Respect to Treatments

The ANOVA analysis in Table 2 show the analytical comparison of the tested gas properties and the various treatments involved in the gas production. Column represents different treatments with F-cal = 0.007848 which is less than F-critical = 4.757063 and having a probability value (P-value) of 0.998936 implying that there was no significant effect in the rate of slurry formation and the results of the total amount of gas produced.

Row represents the tested properties of the produced gases and showed that F-cal = 696.0484 which is greater than F-critical = 5.143253 having a P-value of 7.9 x 10^-8. This implies that there is a significant difference in the values of the tested properties of the biogases produced in all the treatments. It should be noted that all the gasses produced are significant and should not be neglected.

Table 2. ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Gas Properties	7201.873	2	3600.937	696.0484	0.001	5.143253
Treatment	0.1218	3	0.0406	0.007848	0.998	4.757063
Error	31.0404	6	5.1734			
Total	7233.036	11				

Duncan Multiple Range Test (DMRT) tests revealed that all the chemical parameters tested were significant across the four treatments at 5% level of significance. Methane contents were seen to have differed between other treatments with 1:1 ratio; Table 3. Treatments 1:2 and 1:3 are relatively the same but are significantly higher than treatments 1:1.

Table 3. Multiple Tests for Methane (CH_4)

Parameters`	Gas Production
CH_4 (1:1)	60.00a
CH_4 (1:2)	64.20b
CH_4 (1:3)	62.05b

Means with the same alphabet are not significantly different from each other

Determination of Calorific (or Heating) Values

Substituting the values of methane values for the respective treatments in equation (2), the calorific (heating) values of the respective biogases were determined. The range obtained in the research was between 5.964 – 6.38 kWh/m³. This is strongly in agreement with Tusar (2007) and Navickas (2007) who found the range of calorific value of biogas from poultry manure to be between 4 – 8 kWh/m³.

Conclusion

Non-renewable gases are environmentally unfriendly, relatively costly and subject to rapid depletion (Rai, 1989). On the other hand, the renewable gases create less pollution, are capable of being renewed at a relatively short period of time and may even be relatively cheaper than non-renewable gases. It has been observed that the importance of biogas for economic and waste management is increasing, with environmental aims as the main driving force in some instances. The abundant availability of animal manure in Nigeria, particularly from poultry enterprises makes it an attractive and cheap source of raw material for biogas production which could be commercialized and made available to both rural and urban dwellers. It is important not that poultry waste could cause health hazards (if not properly handled for effective biodegradation). There is yet another wave of renewed interest in biogas usage due to increasing concerns of climate change, indoor air pollution and increasing oil prices (Earth Trends, 2005).

The study has shown that moisture content has proved to be a very important factor in biogas production when using poultry manure as substrate. Biogas production increases with increasing quantity of water in the mix to an acceptable level. This was because increasing water quantity changes the sample pH and temperature in addition to decreasing total solid ratio thereby speeding up the microbial activities in the digester. Maximum gas production was obtained when the slurry ratio of manure to water was 1:2. Among the three components of the gasses that were identified and analyzed, methane dominated both hydrogen sulphide and carbon (IV) oxide.

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