Characterization of Different Livestock Dropping Mixtures to Assess their Potential for Biogas Production

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Abstract-This research was conducted at Egerton University, Njoro, Kenya. The main objective of the research was to characterize different livestock droppings mixtures at various ratios to establish their potential for biogas production. Substrate parameters which were total and volatile solids, pH, temperature and density were determined using standard procedures. The mean influent percent total solids (TS) for the ratios (9:1, 7:3, 1:1, 3:7 and 1:9) of Cowdung to Chicken droppings (CC) and cow dung to Sheep droppings (CS) were respectively 9.70% and 10.52%. That of cowdung alone (CA) was 9.52%. The corresponding total solids for CC and CS effluents were 7.71% and 8.55%; while that of CA was 9.09%. These values were within what is established to be appropriate for biogas production. The highest and lowest daily ambient temperatures during the research period were 24.7oC and 20.6oC, respectively. This was within the mesophilic region for biogas production. The pH for all influent and effluent substrate mixtures and ratios averaged 6.94 and 7.44 respectively. These values were within the levels which are appropriate for the growth of methane generating micro-organisms. The respective densities for influent and effluent averaged 1.05g cm-3 and 0.97g cm-3. The reduction in density from influent to effluent could be attributed to decrease in total solids due to bacteria activity and biogas production. This provides a preliminary indication of bio-degradability of the substrates and their potential to produce Methane.

Key words; Substrate, total and volatile solids, anaerobic digestion, Livestock droppings

1. INTRODUCTION

Potential of biogas plants as a source of both energy and fertilizer has been recognized by several authors [9], [6], [16], [7], [17]. Unfortunately these benefits have not been fully exploited in Kenya because of a number of constraints. Studies by [13] on technological constraints to adoption and sustainability of biogas technology reported that, the adoption rate in Nakuru County was 150 out of 9,446 (1.6%). She also found that plant design was significant in the sustainability of the technology. Another study by [19] noted that, properties of substrates and environmental parameters such as pH and temperature also play a pivotal role in biogas production and must be determined and optimized. According to [8], anaerobic digestion is widely accepted as a sound technology for waste treatment applications. Municipal waste water treatment plants play a significant role in treatment of anaerobically digestible sludge than land disposal strategies [4]. Bio-digesters can be fed with animal and human waste. Biogas plants help to reduce the population of insects like flies and mosquitoes [2], resulting in a healthier environment.

The most convincing evidence that biogas production from feedstocks was feasible came from Chinese experience. Chinese family size digester have had as their major carbon source; grass, leaves and crop residues and as their major nitrogen source, human and animal wastes [5]. The C/N ratio under these conditions varies between 1:15 and 1:20; and in most cases the mode of charge of household units is intermediate between batch and semi-continuous [5]. A study by [11] suggested that, if fibrous residues were used, then the bacteria population needed time to adjust before they are able to degrade the fibre component efficiently; and [14] found that the quantity and quality of biogas was increased by mixing of fresh cow dung with small amounts of cane sugar and urea, cane sugar and calcium carbonate. Urine also increased gas production over cowdung control and the percentage of methane in the biogas was raised by upto 16% points to 70% by these additives. Slurry arising from different animal diets will undauntedly vary in their C/N ratio.

Trials by [17 suggested that pressed cane stalk is potential source of raw material for biogas production and that it can be mixed with cattle slurry upto a level of 56.7% on dry matter basis without seriously reducing total gas production. However the fibrous pressed cane stalks degrades slowly and a longer retention time would be needed to extract the same volume of gas as for pure cow dung slurry. A study of the effect of mixing pig manure and cow dung on biogas yield showed that, co-digestion of cowdung with pig manure increased the biogas yield as compared to pure samples of either pig or cowdung [14]. Pig manure mixture with cowdung manure gave the maximum biogas production of $0.35m^3$/kg of volatile solids (VS) and energy content of 1.35Kwh/kg-VS. Olive husks with piggery manure anaerobically digested as inoculums gave biogas yield of $0.28m^3$/kg-VS and methane yield $0.11m^3$/kg-VS, corresponding to an energy content of 1.07Kwh/kg-VS [10]. Table 1 shows gas production potential of some common substrates. The values indicate that cow dung which is often used as a basic raw material has lower biogas production per unit weight than sheep and chicken droppings.

Table 1: Biogas potential of some common substrates (Adopted from [5]

Substrates	Typical yield per kg of manure (m^3)	Methane (%)	Carbon dioxide (%)
Cowdung	0.20 - 0.35	57.5	42.5
Sheep	0.30 – 0.61	67	33
Poultry	0.55 – 0.65	70	30
Pig	0.40 – 0.50	65	30
Cowdung/pig manure	- 0.35	-	-
Cowdung/Olive husks	- 0.28	-	-

Substrates vary in physical and chemical characteristics from feedstock to feedstock. This research was therefore conducted to determine the characteristics of selected livestock dropping mixtures and ratios to establish their potential for biogas production.

2.0. Materials and methods

Total and volatile solids analysis is important for assessing digester efficiencies and sludge cake processing parameters. Other parameters which are known to affect anaerobic digestion are; temperature, slurry density and pH. Procedures of measuring each of the parameters are outlined in the following sub-sections.

2.1. Total solids

A sample of the slurry was transferred into a pre-weighed dish and then weighed. The dish plus its contents were placed in an oven set at 105°C for 12 hours. Thereafter, the dish and its content were removed and allowed to cool to room temperature ensuring that the dried sample does not re-absorb moisture from the atmosphere before it was weighed. After the dry sample attained room temperature, it was removed and immediately weighed as shown in Fig 1. The proportion of the total solids in the sample is given by the weight of the dried sample divided by the weight of the original wet sample as shown in Equation (1).

$$TS = \left(\frac{x-b}{w-b}\right) \times 100\% \qquad (1)$$

Where;

TS = Total solids (%)
X = Weight of dish + dry sample (g).
W = Weight of dish + wet sample (g).
b = Weight of empty dish (g)

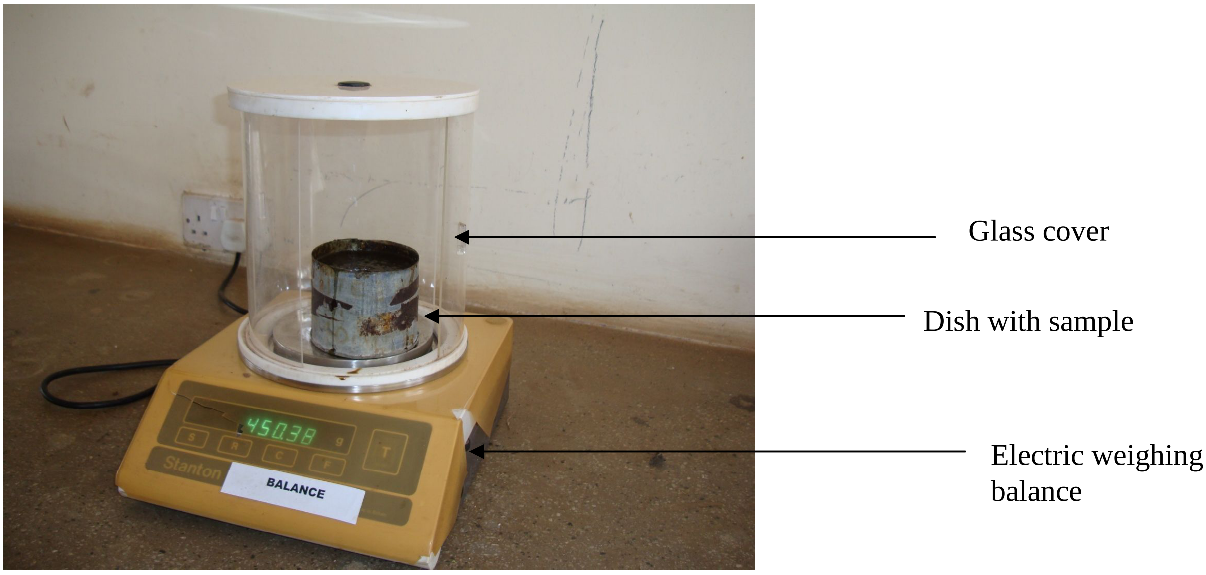

Fig 1: Measurement of total solids.

2.2. Volatile solids

Volatile solids (VS) are the organic solids lost when the dry matter is incinerated at 550^{o}C. A weighed sample of each mix ratio was transferred into a crucible dish and placed into a muffle furnace set at 550^{o}C for four hours. Thereafter, samples were removed and taken to a dessiccator and left to cool to room temperature. After cooling, the crucible dishes with their contents were removed and new weights taken. The volatile solids proportion is the difference between the weight of the dried sample before and after combustion, divided by its weight before incineration as illustrated in Equation (2).

$$VS = \left(\frac{(N-m)-(Z-m)}{(N-m)} \right) \times 100\% \qquad (2)$$

Where;

VS=Volatile solids (%)

N = Weight of dish + dried sample

Z= Weight of dish + weight of ash

m= Weight of dish.

The procedure was repeated three times.

2.3. Measurement of temperature

Ambient temperature measurements were recorded daily at 0.8.30am, 12.30pm and 4.30pm; the ambient temperature for each day was the average of the three. This was done for three hydraulic retention periods. The average was then compared with maximum and minimum temperature taken from the weather station. To prevent extreme temperature variations between day and night woolen blankets were used to insulate the digesters.

2.4. Determination of slurry pH

The pH meter was set to equilibrate with the ambient temperature and then adjusted to read the pH. Calibration of the pH meter was done by inserting a probe into a pH buffer solution of 8.0 and then adjusting while swirling the solution to achieve homogeneity. After the pH meter was calibrated the probe was rinsed with distilled water and then dipped into the test sample and the pH reading recorded.

2.5. Determination of Density

A sample from each ratio was filled into a beaker of known volume and then weighed. The density of the sample was obtained by dividing the weight by the volume. This was done for all the mixture ratios.

Preliminary Studies of substrate mixtures for all the ratios placed in laboratory digesters for thirty days yielded combustible gases. Parameters for all mixture effluents were then determined as was the case for the influent mixtures.

3.0. RESULTS AND DISCUSSIONS

3.1. Total solids

Dry matter (DM) content of pure chicken and sheep droppings were found to be 15.78% and 27.78% respectively, while the recommended value for biogas digester slurry is between 8 to 12%. Thus, the droppings were diluted with water to the required consistency before being introduced into the digester. Table 2 shows the percent total solids (TS) of substrate mix ratios for both influent and effluent. The percentage total solids for the influent varied from 8.57 to 11.40% for CC while that of for cow dung alone was 9.52%. The ratio 9:1 had the highest value of 11.40%, which was significantly higher than those of cow dung alone and other ratios at the 0.05 level of significance. However, the dry matter contents for all the mixture ratios were within what is recommended for biogas digesters. The effluent total solids varied from 7.14 to 8.52% for the substrate mixtures and that of cow dung alone was 9.09%.

Table 2: Percent Total and volatile solids means of substrates for influent and effluent

Ratio	CC				CS			
	Influent		Effluent		Influent		Effluent	
	TS	VS	TS	VS	TS	VS	TS	VS
1:0	9.52^b	7.45^a	9.09^a	6.18^{ba}	9.52^{ba}	7.44^a	9.09^b	6.18^{ba}
9:1	11.40^a	8.95^a	8.52^{ba}	5.81^{ba}	9.01^b	7.14^a	7.50^b	5.24^a
7:3	9.65^b	7.74$_a$	7.42^{ba}	5.11^{ba}	10.40^{ba}	8.23^a	7.78^b	5.26^{ba}
1:1	9.27^b	7.26^a	7.14^b	4.78^b	10.36^{ba}	8.00^a	8.33^b	5.63^{ba}
3:7	8.57^b	6.54^a	7.65^{ba}	5.09^b	11.21^{ba}	8.73^a	8.55^b	5.75^b
1:9	9.41^b	7.58^a	7.81^{ba}	5.55^a	11.25^a	8.81^a	10.61^a	7.00^b

Means followed by the same letter(s) in the same column are not significantly different at $\alpha = 0.05$

The ratio 1:1 had the lowest effluent total solids of 7.14, which was significantly different with that of cowdung alone but not with other mixture ratios.

The percentage values of influent total solids for cowdung to sheep droppings varied from 9.01 to 11.25 and for cow dung alone was 9.52. The ratio 1:9 had the highest value of 11.25% although it was not significantly different with that of cow dung alone. The other ratios were the same except the ratio 9:1 which had the lowest value of 9.01%.

The values for effluent total solids for CS varied from 7.50 to 10.61%. These values were not significantly different with that of cowdung except the ratio 1:9 with a value of 10.61 which was significantly higher than that of CA. A report by [6] indicated that the values of parameters vary depending on the nature of substrate, temperature, pre treatment and the retention time employed in the digestion process. This may have played part in the apparent differences of values in the mixtures because all the other conditions were similar. The Percent influent total solids for all ratios varied between 8.57 and 11.40% which is acceptable for digester slurry fluidity (8 to 12%) [9].
Generally, the values of effluent total solids show a consistent drop in every ratio in comparison with the influent. This suggests a healthy metabolic activity involved in formation of methane having taken place. Some substrates indicated a higher drop in total solids from influent to effluent than others. This may be due to active ingredients involved in combining the two substrates which may have, enhanced or otherwise, the digestion process. This is also reported by [20], who states that the total solids vary from substrate to substrate due to different degradable speeds.

3.2. Volatile solids

The values for the influent substrate mixtures of cow dung to chicken droppings varied from 6.54 to 8.95 and that of cow dung alone was 7.45%. These values were not significantly different at $\alpha = 0.05$. The values for the effluent volatile solids varied from 4.78 to 5.81 and that of cow dung alone was 6.18%. The mixture ratios 1:9, 1:1 and 3:7 were significantly different with that of cow dung while the remaining ratios were the same. The influent percentage volatile solids for CS varied from 7.14% for the 9:1 ratio to 8.81% for the 1:9 ratio, while that of cow dung alone was 7.45% as stated earlier. These values were not significantly different.

Volatile solids for the effluent of the substrate mixtures varied from 5.24 to 7.00%, while that of cow dung alone was 6.18%. These values were also not significantly different except for the ratios 9:1, 3:7 and 1:9, which were significantly lower than for the others. The results show that increasing concentration of chicken or sheep droppings in the influent for the ratios did not affect the volatile solids significantly. This could be attributed to sourcing of substrate from a controlled source of animals grazing in the same area.

The differences in effluent volatile solids of the mixtures could be attributed to the presence of carbon sources in the substrate which may be as a result of feed intake. This could also be attributed to the presence of more complex molecules in some ratios than others. The interactive effects in the mixtures may have enhanced the bacterial activity in some ratios than others as reported earlier. These effects are also noted by [21], who reported that volatile solids made up of different organic compounds have varying degradable speeds.

3.3. Temperature

The highest and lowest daily ambient temperatures during the experimentations were respectively 24.7^{o}C and 20.6^{o}C. The temperatures during the morning were mostly below 20^{o}C and in the mid-morning they were elevated to approximately 23^{o}C while in the evening they were mostly at an average of 25^{o}C. Methane producing bacteria are known to be sensitive to sudden temperature fluctuations of more than 5^{o}C [9, 6]. To maintain a narrow range of temperature variation within the slurry, blankets were used to insulate the digesters. In general unheated biogas digesters perform satisfactory only where mean annual temperatures are around 20^{o}C or above or where the average daily temperature is atleast 18^{o}C [12]. This implies that the digesters were operating within acceptable ambient temperature limits.

3.4. The pH

Table 3 shows the mean variation of pH in the influent and effluent of the substrate mixtures of cow dung to chicken droppings (CC) and cow dung to sheep droppings (CS). The values of CC varied from 6.91 to 6.96 and 7.29 to 7.35 respectively for influent and effluent. The corresponding values for CS varied from 6.94 to 7.22 and 7.29 to 7.55. These values were not significantly different at α equals 0.05. This shows that the experimental digesters were working normally since the condition for methane generating micro-organism growth requires a pH value of between 7 and 8 [9, 6]. The difference in pH values between influent and effluent slurry in both cases may be explained by the fact that the working digesters were buffered. In other words the acid level is controlled by the process itself, some of the carbon dioxide (CO_2) produced by the bacteria dissolves in the water to form bicarbonate ions (HCO_3^-) which cause the solution to become mildly alkaline. Methane formation is inhibited below a pH of 6.6 and the conditions become toxic below 6.2 [3]. In this experiment the pH values were within the values recommended for biogas digesters.

Table 3: pH of CC and CS mixture and ratios of Influent and Effluent

Ratio	Influent		Effluent	
	CC	CS	CC	CS
1:0	6.94[a]	6.94[a]	7.29[a]	7.29[a]
9:1	6.95[a]	6.94[a]	7.29[a]	7.37[a]
7:3	6.91[a]	7.11[a]	7.39[a]	7.43[a]
1:1	6.94[a]	7.18[a]	7.35[a]	7.47[a]
3:7	6.96[a]	7.22[a]	7.34[a]	7.51[a]
1:9	6.95[a]	7.29[a]	7.29[a]	7.55[a]

Means followed by the same letter in the same column are not significantly different at α = 0.05.

3.5. Slurry Densities

Table 4 shows the mean variations in slurry densities for Cow dung to Chicken droppings and Cow dung to Sheep droppings. The densities of influent mixture ratios of cow dung to chicken droppings averaged at 1.03 and 1.04g/cm^3 while that of cow dung alone was 1.03g/cm^3. These values were not significantly different at α = 0.05. The effluent densities averaged at 0.97 and 0.98g/cm^3 for all slurries. Statistically these values were the same. The values for influent densities of the mixture ratios for cow dung to sheep droppings averaged from 1.03 to 1.06g/cm^3 and that of cow dung alone was 1.03g/cm^3. These values were statistically the same. The values for effluent densities averaged at 0.98 and 0.99g/cm^3 while that of cow dung alone was 0.97g/cm^3.

Table 4: Density of CC and CS means of Slurry of Influent and Effluent

Ratio	Influent		Effluent	
	CC	CS	CC	CS
1:0	1.03[a]	1.03[a]	0.98[a]	0.97[a]
9:1	1.03[a]	1.03[a]	0.98[a]	0.98[a]
7:3	1.03[a]	1.03[a]	0.98[a]	0.98[a]
1:1	1.03a	1.05[a]	0.98[a]	0.99[a]
3:7	1.03[a]	1.04[a]	0.98[a]	0.99[a]
1:9	1.03[a]	1.06[a]	0.98[a]	0.99[a]

Means followed by the same letter in the same column are not significantly different at α = 0.05

These values were also not significantly different at α = 0.05. The results show a consistent drop in densities from the influent to effluent which is about 6%. These could be attributed to decrease in total solids due to digestion of the organic materials.

IV. CONCLUSIONS AND RECOMMENDATIONS

This study was primarily conducted to characterize different substrate mixture ratios to assess their potential for biogas production. The substrate parameters studied for both influent and effluent mixtures were: percent total and volatile solids, slurry densities and pH. The values for these parameters were all within the values recommended for biogas production. Furthermore, the gases generated in the preliminary studies for all the mixture ratios were found to be combustible. To this endeavor therefore, it can be concluded that, all mixture ratios studied for CC and CS are potential substrates for biogas digesters.

However, the study did not include the rate and quality of gas generated in the preliminary studies. It is therefore recommended that, further studies be conducted to establish the substrate mixture ratios with the best potential in terms of quantity and quality for biogas generation.

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