RATE OF BIOGAS PRODUCTION AND QUALITY FOR SELECTED MIXTURES OF LIVESTOCK WASTES

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Abstract
This research was conducted at Egerton University, Njoro, Kenya. The main objective of the research was to investigate the rate and quality of biogas generation of co-digesting cow dung with sheep droppings (CS) and cow dung with chicken droppings (CC) compared to cow dung alone (CA). Mixture ratios of CS and CC studied were 9:1, 7:3, 1:1, 3:7 and 1:9. Generally, all mixture ratios of CS and CC showed improved biogas generation and quality compared to CA. For the retention time of 28 days, the mixture ratio of 7:3 for CC and CS respectively, recorded the highest biogas productions of 17.0 and 13.3 m³ compared to 6.0 m³ for CA. Methane content in the biogas for the same ratios averaged 54% for CC and 58% for CS while it was 55% for CA. Significant improvement for biogas quality was observed for CC and CS for the ratios 3:7 and 1:9 with methane contents above 64% for CC and above 62% for CS.

Key words: Substrate mixtures, biogas, percent methane content, cow dung, chicken and sheep droppings.

1. INTRODUCTION
Pure methane (CH₄) has a calorific value of 2.167MJ/m³ while calorific value of biogas varies from 1.142 – 1.643MJ/m³ (FAO, 1997). Compared to the common liquid fossil fuels, 1.33 - 1.87; and 1.5 - 2.1 m³ of biogas, are equivalent to one liter of petrol and diesel, respectively (Fulford, 2001). Biogas has an approximate specific gravity of 0.86 and low flame speed factor. The flame is therefore unstable and will tend to “lift off” burners which are not properly designed (ITDG, 2006).

Biogas is formed when bacteria anaerobically decompose organic materials such as; livestock droppings, farmyard manure, organic waste materials, slaughter house waste and others. It is a mixture of about 60% methane and 35% carbon dioxide with traces of other gases (Legget et al., 2006). Any anaerobic decomposition releases methane which is a greenhouse gas and a major contributor to global warming problem (Legget et al., 2006 and Jenkins, 1999). Biogas is a clean burning, colourless and odourless gas. It can be used for cooking, lighting, heating and running engines for electricity generation. This has already been done on large scale in countries like China, India and Nepal (Fulford, 2001 and Jawurek, 1987). Biogas programmes in Asian countries have had teething problems. Korea had 30,000 plants in 1979, but problems with poor gas production in Korea’s cold winters reduced the impetus (GATE, 1999; Ravindranath and Hall, 1995). Thailand has had small biogas study programmes for many years but an adequate supply of other fuels resulted in slow growth in the extension of biogas to rural areas (Fulford, 2001 and Teri, 1994). Escalating cost of imported fuels encouraged Brazil, along with other South American nations to start bio-fuel and biogas programmes. Between 1980 and 1985, Brazil built 7,530 biogas plants (ITDG, 2006 and Vanburgel and FLorison, 2006).

Kenya has traditionally relied on imported petroleum to meet 75% of its commercial energy needs which drains a significant proportion of foreign exchange (ITDG, 2006). The country was classified as a prospective fuel deficit area (FAO, 1981). The status of energy in the country as at the year 2010 is that, 92% of electricity is generated using renewable energy sources that is 72% hydroelectricity, 20% geothermal and 8% thermal diesel generated (Jellyfish, 2010). The country however, produces far less energy than its capacity. It is argued that because 60% to 90% of the population is not connected to the national grid electricity, many people, especially in rural areas resort to firewood and charcoal which is harmful to our environment because of loss of forest cover and desertification (Jellyfish, 2010). Wood fuel (firewood and charcoal) is the largest form of primary energy consumed, accounting for 68% of total energy needs in the country (MOE, 2006). In the year 2000, the wood fuel demand stood at 34.3 million tonnes compared to established sustainable supply of 15 million tonnes, thereby indicating a deficit of 56% (MOE, 2006). Demand was established to be growing at 2.7% per year, while sustainable supply was growing at a slower rate of 0.6% (MOE, 2006). It is therefore necessary to search for other sources of energy. This study aims at establishing the effects of selected livestock mixtures on the rate of biogas production and quality. Many Kenyan rural homesteads own cattle, chicken, sheep and/or goats. The study therefore was conducted on various mixture ratios of cow dung and...
sheep droppings, CS; and, cow dung and chicken droppings, CC. Biogas production and quality for the mixtures were compared to the production and quality of biogas from cow dung alone, CA.

Cheruiyot et al., (2009), studied the behaviour and performance of plastic biogas digesters using cow dung under natural and greenhouse conditions and suggested further studies on a variety of substrates such as chicken waste, pig waste, sheep and goat droppings or combinations of these. Laura and Idnani (1991) had found that the quantity and quality of biogas was increased by addition of small amounts of cane sugar, urea or calcium carbonate to fresh cow dung. Addition of urine also increased gas production over cow dung alone and the percentage of methane in the biogas was raised from 54% to 70% by these additives.

A study of the effect of mixing pig manure and cow dung on biogas yield showed that co-digestion of cow dung with pig manure increased the biogas yield as compared to pure samples of either pig or cow dung perhaps suggesting a possibility of synergistic effect among the waste (Kasisira and Muyiiya, 2009). The maximum increase of almost seven and three fold of pure cow dung and pig dung was respectively achieved when pig manure and cow dung were mixed in proportions of 1:1. Inglis and Gooch (2007) studied the effects of co-digesting cow dung and food waste and concluded that, “Consistent feeding of small amounts of substrate appears to be a better strategy for mixed digesters than larger amounts of influent over a shorter period of time”. Another study conducted by Abadeyo et al., (2012) on co-digesting cow dung waste and maize combs showed increased biogas and methane generation compared to cow dung alone. There are indications that there could be synergistic effect in both quantity and quality of biogas when cow dung is co-digested with other animal and plant wastes but the right ratios are unknown. It was therefore important to find out if co-digesting cow dung with other substrates at ratios would increase biogas quantity and quality.

The rate of biogas production and proportion of methane to carbon dioxide in any digestible biomass depends on substrate and may be predicted by equation 7:

$$C_xH_yO_z + \left(\frac{x}{2} - \frac{y}{4} - \frac{z}{2}\right)H_2O = \left(\frac{x}{2} - \frac{y}{8} + \frac{z}{4}\right)CO_2 + \left(\frac{x}{2} + \frac{y}{8} - \frac{z}{4}\right)CH_4$$

Where the subscripts x, y and z are numbers used to balance the atoms in the equation for the respective elements.

Measuring the methane content in the biogas and the volume of the gas produced per unit of organic matter of the substrate including the total solids (TS) and volatile solids (VS) indicates the state of digestion process. Typical gas composition for carbohydrate feedstock’s are 55% methane, 40% carbon dioxide and 5% trace gases while for fats the gas contains as much as 68% methane (Mursec et al., 2009). Biogas contains combustible and non-combustible gases. Table 1, shows the biogas yield of some domestic animals waste.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Typical gas yield/Kg) of manure</th>
<th>CH4 %</th>
<th>CO2 %</th>
<th>Thermal content MJ/m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>200-350lt</td>
<td>57.4</td>
<td>36.5</td>
<td>23</td>
</tr>
<tr>
<td>Poultry</td>
<td>550 -650lt</td>
<td>70.0</td>
<td>30.0</td>
<td>28</td>
</tr>
<tr>
<td>Pig</td>
<td>400-500lt</td>
<td>65.0</td>
<td>35.0</td>
<td>26</td>
</tr>
</tbody>
</table>

(Adopted from Abdulkareem, 2005)

### 2. MATERIALS AND METHODS

**Experimental set up**

The digesters consisted of 11 units which served to produce gas from the substrates. Figure 1 shows the schematic diagram of the experimental set up. The basic set up consisted of a 20 liter plastic container, 5 liter displacement bottle and a measuring conical flask all connected through rubber and capillary tubes. At the top of the experimental digester a plastic cork with a well fitting capillary tube was used to close the outlet. The lid was then sealed using reinforced plastic resin. The well fitting plastic and capillary tubes were used to connect the digester via a release valve to the 5 liter displacement bottle filled with water to capacity. The displacement bottle was then connected through one of the capillary and plastic tubing to the graduated conical flask. Eleven units of digesters were each filled with 13.3 liters of the respective substrates. All substrates were diluted with water to a consistency of about 11% total solids. The substrates mixtures for each digester were thoroughly mixed by a handle rotated by hand to make them homogenous.

**Biogas production:**

Biogas yield was measured daily using the displacement method. A five-liter plastic bottle was filled with water to capacity and connected to a graduated conical flask for each treatment (digester). The pressure of the gas from the

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digester forced water to flow from the plastic bottle into the conical flask graduated in milliliters. A valve placed in between the digester and the displacement bottle was open for gas measurement at a specific time and closed after all the gas for each day was exhausted. The volume of water displaced represented the volume of gas generated in one day for each treatment (Plate 1).

Figure 1: Schematic representation of the experimental set up

Plate 1: Experimental set up showing biogas collection system

Quality of biogas:
Biogas composition was determined on the 17th day of the retention period for each substrate. A gas chromatograph, GC, as shown on Plate 2 was used to analyze the gas. The procedure involved extracting gas samples using syringes from the experimental digesters and injecting the same into the chromatograph. The carrier gas (nitrogen) in the chromatograph then swept the gas sample injected into the capillary column packed with the stationary phase. The column has high boiling point and interacts with the sample while separating it into various components. The gases with least affinity for stationary phase were exited first. The separated gaseous compound was then carried into the detector unit known as the flame ionization detector (FID). The FID identified the various gaseous compounds present in the sample according to their retention times. The monitoring unit (a computer) then picked up the detected gases.

Plate 2: Gas chromatograph
Presence of methane in the biogas was also subjectively tested by lighting the gas released which burned easily on the burner. It was however not possible to quantify the composition of gases using this method. In this case, it can be concluded that, the gas contained more than 50% methane since it burned with ease (Fulford, 2001).

Data analysis:
Analysis of variance was run for the biogas yields and quality. An F-test was used for hypothesis testing at 95% confidence level. The F-values, for the parameters studied, were obtained by dividing the mean squares of gas yields by the error mean squares. The calculated F-values were compared with tabulated/critical F-values to decide whether to accept the alternative hypothesis of difference or the null hypothesis. If the null hypothesis was not rejected the analysis was concluded but if the null hypothesis was rejected then a t-test was used to determine Fishers least significance difference. Scatter points of mean gas yields were plotted for the corresponding time in (days) of the observations and a polynomial regression fitted to predict how well the coefficient of determination \( r^2 \) explained the trend.

3. RESULTS AND DISCUSSIONS

Biogas Production
The weekly daily means gas produced by the mixture ratios for cow dung to chicken droppings, cow dung to sheep droppings and cow dung alone are shown in Table 2. They ranged from 236 to 1,104 ml/day, 243 to 814ml/day for CC and CS respectively and that of cow dung alone ranged from 202 to 398ml/day. From the table, it is evident that weekly gas production was highest and significantly different \( (\alpha < 0.05) \) on the third week for all mixture ratios. The results also indicate a general increase in total gas produced by the mixture ratios in comparison with cow dung alone. This shows that mixing of the substrates improved the population of bacteria and growth conditions. It is an indication of availability of an optimum mixture level where the conditions are favorable.

### Table 2: Weekly daily mean gas production (ml/day) for the different mixture ratios

<table>
<thead>
<tr>
<th>Week</th>
<th>9:1</th>
<th>7:3</th>
<th>5:5</th>
<th>3:7</th>
<th>1:9</th>
<th>10:0</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>0^d</td>
<td>0^d</td>
<td>0^d</td>
<td>0^d</td>
<td>0^d</td>
<td>0^d</td>
</tr>
<tr>
<td>CS</td>
<td>324^c</td>
<td>352^b</td>
<td>761^b</td>
<td>403^c</td>
<td>240^d</td>
<td>254^b</td>
</tr>
<tr>
<td>CC</td>
<td>612^a</td>
<td>438^a</td>
<td>1,104^a</td>
<td>814^a</td>
<td>653^a</td>
<td>483^b</td>
</tr>
<tr>
<td>CS</td>
<td>433^b</td>
<td>448^b</td>
<td>574^a</td>
<td>505^b</td>
<td>409^b</td>
<td>491^a</td>
</tr>
<tr>
<td>CA</td>
<td>95.5</td>
<td>29.8</td>
<td>95.5</td>
<td>29.8</td>
<td>95.5</td>
<td>29.8</td>
</tr>
</tbody>
</table>

Means with the same superscript in the same column are not significantly different \( (\alpha < 0.05) \)

Key: CC = Cow dung to Chicken droppings; CS = Cow dung to Sheep droppings

The cumulative total means of gas produced for the entire hydraulic retention period (28 days) for each mixture ratio are presented in Table 3.

The highest gas production per retention period was by 17.00 m³ for the ratio 7:3 of CC compared to 6.04 m³ for cow dung alone (CA). The lowest was by 8.52 m³ for the ratio 9:1 of CS. The mean daily gas produced was between 0.34m³ to 0.61m³ for the CC, and varied from 0.31 m³ to 0.48 m³ for the CS, while that for CA was 0.22m³. Table 4 shows, the maximum daily gas production (ml/day) for the mixture ratios.

### Table 3: Daily and Total gas production (m³) per retention time (28days)

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Ratio</th>
<th>9:1</th>
<th>7:3</th>
<th>1:1</th>
<th>3:7</th>
<th>1:9</th>
<th>1:0</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>Total</td>
<td>10.37</td>
<td>17.00</td>
<td>9.52</td>
<td>11.54</td>
<td>9.56</td>
<td>6.04</td>
<td>10.67</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>0.37</td>
<td>0.61</td>
<td>0.34</td>
<td>0.41</td>
<td>0.34</td>
<td>0.22</td>
<td>0.38</td>
</tr>
<tr>
<td>SC</td>
<td>Total</td>
<td>8.52</td>
<td>13.29</td>
<td>8.85</td>
<td>9.87</td>
<td>11.74</td>
<td>6.04</td>
<td>9.72</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>0.31</td>
<td>0.48</td>
<td>0.32</td>
<td>0.35</td>
<td>0.42</td>
<td>0.22</td>
<td>0.35</td>
</tr>
</tbody>
</table>

### Table 4: Maximum daily gas production (ml/day) for the mixtures CC and CS

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Ratio</th>
<th>1:9</th>
<th>7:3</th>
<th>1:1</th>
<th>3:7</th>
<th>1:9</th>
<th>1:0</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>1:9</td>
<td>674</td>
<td>1,223</td>
<td>680</td>
<td>714</td>
<td>860</td>
<td>454</td>
</tr>
<tr>
<td>CS</td>
<td>1:0</td>
<td>521</td>
<td>854</td>
<td>555</td>
<td>638</td>
<td>692</td>
<td>454</td>
</tr>
</tbody>
</table>
The daily variation of gas produced for each mixture ratios (CC, CS & CA) showed significant differences at $\alpha < 0.05$ for each day. The results also show that, the ratio 7:3 of CC had the highest gas production of 1,223 ml/day. The highest mean gas production for CS was 854 ml/day for the ratio 7:3 and the lowest was 454 ml/day for the ratio 1:0 (CA). This showed a similar pattern in gas production for both mixtures with increase in chicken or sheep droppings. This suggests that there is a certain mixture level at which the conditions are optimum for enhancing maximum gas production as earlier noted.

Figures 1 and 2 show the daily variation of gas produced for some mixture ratios. The variation shows respective peak values are obtained followed by a general decline. There are noticeable subsidiary oscillations in the gas produced for some ratios. This could be due to breakdown of easily digestible materials such as fats, sugars and carbohydrates while the lower gas produced could be due to less digestible materials such as cellulose and lignin.

The scatter lines for the ratios 7:3 and 1:9 follow the same pattern though the ratio 1:9 was at a much lower level than the ratio 7:3. This suggest similar pattern in the bacteria activity of the substrates for both the ratios. The results agree with the findings of Maramba (1978) and Chowdhurry (1987), who observed that, there are two regions of higher rate of biogas production at short times of at least 22 days, and lower production at longer times of 32 days.

**Figure 1: Daily variation of gas produced for mixture ratios CC and CA**

**Figure 2: Daily variation of gas produced for the mixture ratios CS and CA**
The findings are further confirmed by the results obtained for the gas production to reach the peak for each mixture ratio as shown in Table 5. The gas production for the mixture ratios of cow dung to chicken droppings indicate that the peak production was achieved between the 13th and the 21st day. The ones for cow dung to sheep droppings indicate that the peak production was achieved between the 20th and the 23rd day. This implies that the mixture and ratios of CC had more easily digestible materials and at shorter time periods than that of CS.

### Table 5: Time taken (days) for the Mixture ratios to reach the peak gas production

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Ratio</th>
<th>1:9</th>
<th>7:3</th>
<th>1:1</th>
<th>3:7</th>
<th>1:9</th>
<th>1:0</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>21</td>
<td>14</td>
<td>19</td>
<td>18</td>
<td>13</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>23</td>
<td>20</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

### Quality of Biogas:

The results of gas quality for each of the substrate mixture ratio are indicated in Table 6. The quality of biogas is determined by the composition of gases which is mainly a mixture of Methane (CH₄); 40-70%, carbon dioxide (CO₂) 30-60% and trace gases; of 1-5% (Hoetz et al., 2006). The mean values of methane from the ratios of CC ranged from 57 to 65%.

### Table 6: Composition of Biogas from CC and CS substrate mixture at different ratios

<table>
<thead>
<tr>
<th>Ratio</th>
<th>CH₄</th>
<th>CO₂</th>
<th>Trace gases</th>
<th>CH₄</th>
<th>CO₂</th>
<th>Trace gases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:0</td>
<td>55.0⁸</td>
<td>38.7³</td>
<td>6.3</td>
<td>55.0⁹</td>
<td>38.7⁴</td>
<td>6.3</td>
</tr>
<tr>
<td>9:1</td>
<td>57.2³</td>
<td>34.5³</td>
<td>8.3</td>
<td>55.8³</td>
<td>34.6³</td>
<td>9.6</td>
</tr>
<tr>
<td>7:3</td>
<td>54.4³</td>
<td>34.8³</td>
<td>6.0</td>
<td>58.2³</td>
<td>33.9³</td>
<td>8.0</td>
</tr>
<tr>
<td>1:1</td>
<td>61.0³</td>
<td>34.2³</td>
<td>5.0</td>
<td>59.2³</td>
<td>34.0³</td>
<td>6.8</td>
</tr>
<tr>
<td>3:7</td>
<td>63.7a</td>
<td>32.1d</td>
<td>3.9</td>
<td>62.2a</td>
<td>32.2d</td>
<td>5.5</td>
</tr>
<tr>
<td>1:9</td>
<td>65.4a</td>
<td>32.0d</td>
<td>2.6</td>
<td>62.6a</td>
<td>32.3d</td>
<td>5.1</td>
</tr>
<tr>
<td>LSD</td>
<td>1.95</td>
<td>2.41</td>
<td>1.35</td>
<td>2.44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Means in the same column followed by the same letter are not significantly different, α < 0.05*

These values are lower than those reported in the literature for poultry of 70% (Table 1). Percent methane observed for cow dung alone was 55%. The variation in methane content may be as a result of mixing of the two substrates which may have enhanced the gas content. The methane content for cow dung to sheep droppings averaged from 56 to 63%. These values were lower than that of sheep droppings alone of 64% and higher than that of cow dung alone. The apparent difference may be attributed to the mixing of the two substrates as reported earlier. It was difficult to make the system air tight; this may have contributed to dilution of the biogas, hence the lower methane content. Stucky (1983) has reported that the content of methane in the biogas is affected by temperature as well as pressure and oxidation state of the carbon in the substrate. These parameters may also have played part in the apparent differences since they were not controlled.

### Conclusions and Recommendations:

The study was primarily conducted to study the effects of the rate of biogas production and quality for selected livestock waste mixtures. It was observed that, biogas production and quality for mixture ratios of cow dung with chicken droppings (CC) and cow dung with sheep droppings (CS) averaged higher than for cow dung alone (CA). Biogas yield for CC and CS were 0.41m³/day and 0.38m³/day compared to 0.22m³/day for CA. The results obtained in the research showed that, methane content in the biogas for the mixture ratios averaged 61% and 60% for CC and CS respectively, while that of CA was 55%. From the foregoing therefore, it can be concluded that, mixing cow dung with chicken droppings and with sheep droppings improved both the quantity and quality of biogas generated. These findings also compare well with those of Kasisira and Muyiwa, (2009); Inglis and Gooch (2007); and Abadeyo et al., (2012); who respectively, reported improved biogas production on co-digestion of cow dung with pig manure; cow dung and food waste; and cow dung with maize cobs.

This research considered mixing of only cow dung with chicken and sheep droppings one at a time. It did not consider using other wastes or mixtures of more than two wastes. It is thus recommended that, further research could be done to study biogas production of cow dung with other substrates of animal and plant origin such as pig waste, tea waste,
coffee waste, water hyacinth and wheat husks to mention but a few. Also, further research could be conducted using mixtures of more than two substrates.

REFERENCES
[21] Stuckey, D.C. (1983). Biogas in developing countries; A critical appraisal in proceedings of Third International Symposium on anaerobic digestion; Boston, USA