EFFECT OF SLURRY CONCENTRATION ON BIOGAS PRODUCTION FROM CATTLE DUNG

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Abstract — The effect of slurry concentration on the production of biogas cattle dung was investigated using slurry concentrations of 141.15, 187.72, 234.50, 280.14 and 326.01 kg/m³ of moisture free cattle-dung in water. It was found that the volume of gas produced and the average daily gas production increased with increase in slurry concentration. But the pattern of biogas production is practically insensitive to variation in slurry concentration.

1. INTRODUCTION

The awareness of the imminent depletion of fossil fuels coupled with a global energy crisis have stimulated interest in the search for alternative energy sources. The potential alternative sources of energy which have received much attention by researchers all over the world are water current, wind power, geothermal power, nuclear power, solar energy and organic wastes.

Naturally, each of these has its shortcomings, but solar energy and organic waste are the most reliable alternative sources of energy for third world countries. This is because they are by far more readily accessible to inhabitants of rural areas. This article is concerned with the production of biogas from cattle dung; a partially digested organic matter [mainly grass] defecated by the animal. Thus, cattle-dung falls under the category of organic waste. The technologies for the production of biogas from organic waste have been in existence for many years. For instance, it is reported that China started the production of biogas in 1920 [1]. Yet, in most part of the developing world there is a vast biogas resource untapped.

Biogas is a colourless, flammable gas consisting of methane [55-70%], carbon [iv] oxide [30-40%] and traces of other gases such as nitrogen, hydrogen and hydrogen sulphide [2]. The fuel value of biogas depends on its methane content [3]. For instance, a gas containing 65% CH₄ and 35% CO₂ has a fuel value of 24MJ/m³ compared with 37MJ/m³ for pure methane. Moreover, biogas has half the heating value per volume of methane gas, one third of propane and 50% more than coal gas. Furthermore, 1.0m³ of the gas is equivalent to 2.0kg of firewood, 0.6 litres of kerosine, 0.5 litres of petrol and 0.4 litres of diesel. In fact, the advantages of biogas were summarised by Kristoferson and Bokalders [4] as:

(i) The biogas itself could be used either for direct combination in cooking or lighting or indirectly to fuel combustion engines for delivery of electrical power.

(ii) The biogas slurry contains high concentrations of nutrients making it especially effective and valuable as fertilizer.

(iii) The biogas slurry could inhibit pathogens (usually found at high concentration in manure) like chizotonia solani of rice, Helminthosporrium satium of wheat etc.
In view of the above, the need for exhaustive research into the production of biogas from organic waste is compelling.

In general, biogas is obtained by anaerobic fermentation of domestic, industrial and agricultural organic wastes. These include animal faeces, municipal sludge and garbage, abattoir waste, paper waste, night soil and water weeds. Animal wastes often vary in chemical composition and physical forms mainly due to variability in the digestive physiology of the various species, the composition and form of the diet, the stage of growth of the animal and management system of waste collection and storage. Thus, the composition, quantity and quality of biogas produced from different animal wastes may vary. For this reason, investigation of the quantity, quality and composition of biogas produced from different animal wastes is imperative. Accordingly, we report the effect of slurry concentration on biogas production from cattle dung.

2. EXPERIMENTAL

2.1 Material

The cattle dung was collected from a small cattle ranch (containing seven cattle) in Kwankwasiya Village on the permanent site of Usman Danfodiyo University, Sokoto, Nigeria. The dung was collected over three days period and was dried inside the laboratory for a period of one month. The dung was crushed using analytical mill and mixed thoroughly in order to ensure homogeneity.

2.2 Method

2.2.1 Moisture determination

The moisture content of the dung was estimated by heating 51.43 g of the dung in an oven at 105°C for 4 hours. This was sufficient to give constant weight (2.66 g) of moisture free dung in three subsequent weighings. The moisture content was calculated as 5.17%.

2.2.2 Ash determination

The ash content of the dung was determined by heating five samples (51.34 g each) in a muffle furnace at 600°C for 3 hours. The samples were removed, placed in a desiccator containing calcium chloride pellets and allowed to cool. The weight of residues were 21.12 g, 19.20 g, 21.96 g, 21.01 g and 21.30 g. The average weight, 20.92 g, was determined and ash content was calculated as 40.75% of the sample.

2.2.3 Determination of total acid as ethanoic acid

20.0 cm³ sodium hydroxide solution was pipetted into a conical flask, 20.0 cm³ of the supernatant liquid of the slurry in a newly prepared digester was pipetted (after shaking) and added into the sodium hydroxide solution. The excess sodium hydroxide was titrated against 0.02m hydrochloric acid solution using phenolphthalein indicator. This procedure was repeated daily for a period of six days including the day the slurry was prepared. The results obtained are given in Table 1.

2.2.4 Test for ethanoic acid

The procedure recommended by Mann and Saunders [5] was adopted. 10.0 cm³ of the supernatant liquid in a three day old cattle dung slurry was pipetted and placed into a boiling tube. Concentrated ammonia solution was added dropwise into the tube until the solution was alkaline to litmus paper. Boiling chips were added to the solution and the tube was heated gently until the odour of ammonia has ceased completely. The neutral solution was allowed to cool down to the laboratory temperature and then divided into two portions and placed in test tubes labelled A and B.

To test tube A, two drops of neutral iron (II) chloride solution were added. A red coloration developed which indicates the presence of ethanoic or methanoic acid. To test tube B, 5.0 cm³ of 10% sodium carbonate solution was added followed by dropwise addition of 1% potassium permanganate solution. The colour of the permanganate solution persisted which confirms the presence of ethanoic acid.

2.2.5 Preparation of digesters

Five 4 litre cylindrical tins were cleaned thoroughly and used as the digesters. A hole was bored on top of each digester and a PVC rubber tube (length = 1.5 m, diameter = 0.8 cm) was inserted
into the hole and glued using araldite adhesive. The biogas slurry was prepared by mixing thoroughly the appropriate masses (300g, 400g, 500g, 600g or 700g) of the cattle dung with 1000 cm$^3$ of tap water in a beaker. The slurry was fed into the digester through the normal inlet on the tin. The beaker was rinsed with 500 cm$^3$ of water and the rinse was added into the digester followed by additional 500 cm$^3$ of water. The inlet of the digester was then sealed to ensure that it was air-tight. Five digesters labelled A, B, C, D and E corresponding to slurry concentrations of 141.15, 187.72, 234.50, 280.14 and 326.01 kgm$^{-3}$, respectively were prepared in which their moisture contents were taken into account.

The unattached end of the PVC tube for each digester was placed in an acidified brine solution in a trough and a 2 litre measuring cylinder, filled with acidified brine solution was inverted into the trough such that the outlet of the PVC tube was directed upward within the cylinder. The downward displacement of the solution in the cylinder was used as a measure of the volume of biogas produced. Readings were taken at 12.00 noon daily for a period of six weeks from 17th December, 1993 to 28th January, 1994. The ambient air temperature over the period varied from 22.0°C to 30°C with an average of 26.2°C.

3. RESULTS AND DISCUSSION

The moisture content of the cattle dung was found to be 5.17%. This low value is obviously due to the one month drying of the sample in the laboratory. Maishanu and Sambo [6] have reported a correlation between the moisture content of leaves and the cumulative volume of biogas produced by the leaves. Their findings indicated that low moisture content leads to high cumulative volume of gas and vice versa. It is therefore, expected that the low moisture content of this cattle dung will facilitate high biogas yield. The ash content of the cattle dung was found to be 40.75%.

The ash content of an organic matter is an excellent index for measuring its minerals content, and of course, its nutritional value to both man and animal. Thus, the relatively high ash content of this cattle dung suggests that the dung is a valuable substrate for bio-fertilizer. Once the ash and moisture contents of the dung were determined, the organic matter was calculated by difference as 54.08%. Since biogas is obtained by the anaerobic biodegradation of the organic matter content of the waste, the dung used in this work could be considered as a rich source of biogas on account of its high organic content.

<table>
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<tr>
<th>Table 1: Total acid produced as ethanoic acid</th>
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<tr>
<td>Time (Day)</td>
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<td>Conc. g/dm$^3$</td>
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The total acid (as ethanoic acid) in the slurry was monitored for six consecutive days starting from the day the slurry was mixed. The results obtained (Table 1) shows that the concentration of the acid increased from zero on day 1 to a maximum of 0.32 g/cm$^3$ on day 4 and decreased to zero on day 6. Since measurable quantity of biogas was not produced by any of the five digesters until the fourth day (see Figure 1). It is safe to assume that the acid plays some role in the mechanism of generating biogas from cattle dung. In fact, this seems to agree with hypothesis [7] reported that the generation of biogas from organic wastes proceeds via the following three stages:

(i) Interaction between several species of cellulytic and hydrolytic bacteria to decompose complex insoluble organic molecules to form soluble compounds.

(ii) Conversion of the soluble organic compounds to organic acids (primarily ethanoic acid) and

(iii) Production of methane by either fermentation of ethanoic or reduction of carbon.

(iv) Oxide and carbonic acid using hydrogen gas. The chemistry of the process is often summarised by following equations:

$$ (C_6H_{12}O_6)^n \xrightarrow{\text{acid forming bacteria}} 3nCH_3COOH \quad (1) $$
Effect of slurry concentration on biogas production

<table>
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<th>Table 2: Volume (% total volume) of gas produced per week</th>
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<td><strong>Digester</strong></td>
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<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
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<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
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<tr>
<td>E</td>
</tr>
<tr>
<td><strong>AV. Temp. (°C)</strong></td>
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\[
\text{CH}_3\text{COOH} \xrightarrow{\text{bacteria}} \text{CH}_4 + \text{CO}_2 \quad (2)
\]

\[
\text{CO}_2 + 4\text{H}_2 \xrightarrow{\text{reduction}} \text{CH}_4 + 2\text{H}_2\text{O} \quad (3)
\]

\[
\text{CO}_2 + \text{H}_2\text{O} \xrightarrow{\text{hydrolysis}} \text{H}_2\text{CO}_3 \quad (4)
\]

\[
(C_6\text{H}_{12}\text{O}_6)n + 3n\text{H}_2\text{O} \xrightarrow{\text{hydrolysis}} 3n\text{CH}_4 + 3n\text{H}_2\text{O} \quad (5)
\]

\[
\text{H}_2\text{CO}_3 + 4\text{H}_2 \xrightarrow{\text{reduction}} \text{CH}_4 + 3\text{H}_2\text{O} \quad (6)
\]

In general, the higher the temperature the faster the digestion and biogas production. However, at temperatures below 10°C and above 65°C biogas production is negligibly low due to inactivity of bacteria in the former case and the inability of bacteria to survive in the latter. Between 10°C to 65°C there are two optimum temperature ranges for methanogenic production of biogas, which are called mesophilic (30 - 40°C) and thermophilic (50 - 60°C) [4].

The work reported in this article was carried out under a laboratory temperature which varied between 22°C and 30.3°C over a period of 42 days. The average temperature over this period was 26.2°C which is below the mesophilic temperature range. This means that the production of biogas did not take place under optimum conditions. Consequently, the rate of biogas production was slow resulting in a six weeks period for the fermentation of the organic content of the cattle dung. It is also possible that the digestion of the substrate was not efficiently done which may suggest incomplete digestion of the substrate. These points should be taken into cognisance in interpreting the findings reported in this work.

The quantity of biogas generated per week as shown in Table 2 is the percentage of the total volume of biogas produced in six weeks. The average laboratory temperature for each week is also given in the table. The results revealed that the volume of biogas produced per week varies with the concentration of the slurry. For all the five slurry concentrations, over 70% of the biogas was produced in weeks 3, 4, and 5 with the maximum weekly production occurring in week 4. This may be explained in terms of temperature fluctuation since temperature profoundly influences the action of methane forming bacteria.

Although the average temperatures for weeks 1 and 6 (28.5°C and 28.2°C respectively) are the highest in the six weeks, the relatively low biogas production in these weeks is hardly surprising. As seen from fig. 1, there was no gas evolution in the first four days of week 1 which may be associated with the period required for the decomposition of the organic substrate by acid forming bacteria. The remaining three days of the week could be linked to the commencement of the gas production due to the action of methane forming bacteria. The low biogas production in week 6 is obviously due to the exhaustion of digestible substrate. The relatively low gas production in weeks 2 and 3 may be due to the drop in temperature to 24.1°C while the sudden rise in temperature to 27.4°C in week 4 may account for the maximum biogas production in this week. The sub-
sequent drop in temperature to 24.8°C in week 5 could be responsible for sustaining the gas production to week 6.

The total volume (m³) of biogas produced over the six weeks period and the average daily gas production (m³/day) are shown in Table 3. A plot of the cumulative volume of gas against the number of days of production is shown in Fig. 2. It is obvious from both the table and figure that the quantity of biogas produced is a function of the slurry concentration. Moreover, the plot shown in Fig. 3 revealed a linear relationship between the slurry concentration and the average daily biogas production. Extrapolation of the line onto the concentration axis gives a threshold slurry concentration 10.4 kg/m³ below which no biogas production is expected.

However, a closer examination of Figs. 1 and 2 shows that slurries from digester A and B gave practically the same quantity of biogas to the nearest meter cubic. In other words, the linear relationship in Fig. 2 applies to slurries in digester B, C, D and E. This may imply that the direct proportionality between total cumulative volume of biogas and the slurry concentration does not hold for very dilute slurry concentrations.
**Table 3: Total volume and average daily production of biogas**

<table>
<thead>
<tr>
<th>Digester</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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<tr>
<td>Slurry conc. (kg/m³)</td>
<td>141.15</td>
<td>187.72</td>
<td>234.50</td>
<td>280.14</td>
<td>326.01</td>
</tr>
<tr>
<td>Total vol. (×10⁴ m³)</td>
<td>0.48</td>
<td>0.49</td>
<td>0.60</td>
<td>0.71</td>
<td>0.86</td>
</tr>
<tr>
<td>Av. daily production (×10⁴ m³/day)</td>
<td>1.14</td>
<td>1.17</td>
<td>1.41</td>
<td>1.70</td>
<td>2.06</td>
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</table>

This work substantiates the findings of Dhawale and Danawade [8] who reported that daily biogas generation as well as efficiency of methane generation increases with increase in total solid (TS) content - a measure of slurry concentration. However, they went on to recommend an optimum TS of 13% for running a biogas plant, which does not conform to the direct proportionality between slurry concentration and total volume of biogas observed in this week.

4. CONCLUSION

The total volume of biogas produced in six weeks of digestion of the cattle dung is directly proportional to the slurry concentration in the range 187.72 to 326.01 kg/m³.

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REFERENCES


