BIOGAS GENERATION FROM ANIMAL WASTES

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Abstract—Alternative energy sources should be developed to replace fast depleting fossil fuels. The global energy crisis has generated interest in the use of animal waste as a substitute for fossil fuel. The production of biogas which is a mixture of methane, carbon dioxide and traces of other gases, is a biological process through which wastes are converted to fuels. Through this process, an energy resource that can be stored and used efficiently is produced and an excellent residue that retains the fertilizer value of the original waste is created. The variability in chemical composition and physical form of animal wastes is mainly due to the differences in digestive physiology of the various livestock species and the composition and form of the diet. Animal wastes should be fed to the biogas plant in such a way that conditions favouring the production of high volume of the gas are met. This paper highlights the importance of biogas production especially from animal wastes.

1. INTRODUCTION

Over the centuries, various sources of energy have been used by man in order to meet his basic life-essentials such as food, water and shelter. Starting with his own energy and sunlight, he progressed to wood fuel, draft-animal power, water and wind power, then developed engine power fuelled by wood, coal, petroleum and nuclear energy [1]. Man has utilized energy in modifying and manipulating land, water, plants and animals to obtain food, clothing and shelter. In primitive agricultural systems, the processes of providing food proceed in their natural state, with solar energy being the principal energy source, augmented only slightly by human or animal energy inputs. In order to achieve greater levels of output, other energy inputs (mostly derived from fossil fuels reserves) have been used by man to enhance solar energy transformations.

Presently, fossil fuels provide the bulk of the world’s primary energy, with hydroelectricity providing about 2% and nuclear fission, wood and other sources each probably accounting for less than 1% of the primary industrial energy used in the world [2]. Since fossil fuels are nonrenewable natural resources and man has done little to conserve the earth’s supply, supplies of fossil fuels (especially oil and gas) may very soon get completely depleted [1]. There is, thus, a need to develop alternative energy sources to replace fast depleting fossil fuels.

In Nigeria, fuelwood, petroleum, gas, kerosene and electricity constitute important sources of energy. However, the majority of Nigerians living in rural areas do not have access to gas or electricity [3,4]. Developing countries generally rely on wood, dung, straw and animal and human power to meet most of their basic needs. The recent global energy crisis has generated interest in the use of animal waste for energy to substitute for fossil fuel [5]. Due to shortage of fuel wood, animal waste is increasingly being used as fuel. It has thus been estimated that 20% of India’s energy needs are supplied by burning cow dung [6]. Ethanol and biogas production are the biological methods through which waste materials can be converted to fuels. This paper highlights the importance of biogas production especially from animal wastes.

2. WHY BIOGAS?

Biogas is a flammable gas produced by the anaerobic fermentation of organic waste materials. It is a mixture of methane (55–70%), carbon dioxide (30–40%) and traces of other gases such as nitrogen, hydrogen, carbon monoxide, water, ammonia and hydrogen sulphide [6,7,8]. Biogas technology is a modern, ecology-oriented form of appropriate technology based on the decomposition of organic materials by putrefactive bacteria at suitable, stable temperatures [9]. A combustible mixture of methane and carbon dioxide, commonly referred to as biogas, develops under anaerobic condition (leaving behind digested slurry) in the digester.

The concept of producing a clean source of energy from animal waste seems attractive. Biogas burns readily and can be used directly as a fuel for cooking, lighting or heating and indirectly to power electrical generators and agricultural equipment [6]. Biogas can easily be stored to provide energy for various uses such as refrigeration and running of engines that may help in water pumping and related operations. The residue left after biogas has been produced
is a valuable fertilizer containing all the nutrients present in the original waste materials but in a finely processed state that is ready to be utilized by crops. During biogas production, complex organic matter is degraded to relatively clean and easily purified gaseous products. About 90% of the substrate energy in the organic matter is retained in the methane [10]. Thus, the fermentation of wastes to generate biogas, rather than their direct use as fuel or fertilizer, yields a number of benefits such as producing an energy resource that can be stored and used more efficiently in many applications, creating a stabilized residue that retains the fertilizer value of the original material, and reducing faecal pathogens and improving public health [6].

Werner et al [9] maintain that benefits of biogas technology include direct monetary returns, less work, and various qualitative benefits. The monetary returns come from savings on purchased energy (oil, bottled gas, wood and charcoal); an additional energy supply for commercial activities; savings on chemical fertilizers and/or additional income from higher agricultural yields. The qualitative benefits include easier, cleaner cooking and better hygiene; better lighting during the evening hours; energy independence; improved stock-farming practice; and good soil structure due to fertilization with digested sludge. Regional and overall significance of biogas technology can be summarized as follows: (a) a development of a reliable, decentralized source of energy operated and monitored by the users themselves, (b) less local deforestation, (c) improved conditions of agricultural production, (d) more work and income for local craftsmen, (e) infrastructural development and (f) expanded indigenous technological know-how [9].

Because fuelwood compares very poorly with gas as a cooking fuel, biogas should be produced from animal wastes to substitute for it. Fuelwood supplies are dependent on a supporting ecosystem that is being destroyed in many areas by population growth. Thus, the need to exercise caution when using fuelwood as a source of fuel. The search for alternative energy sources such as biogas should therefore be intensified in order to arrest deforestation.

3. THE BIOGAS PLANT

A typical biogas plant consists of two main parts: a digester (where fermentation occurs) and a gas holder (where the gas produced is stored). Various kinds of biogas plants (e.g. the Indian, Taiwanese, Chinese and Philippine plants) are in use [6, 8]. A plant that could produce 425 litres of biogas per day which would be sufficient to cook meals for one person has been designed at Usmanu Danfodiyo University, Sokoto [11]. The digester is a rectangular metal tank (120cm length, 120cm height and 100cm breadth) designed for continuous feeding with 30 litres of slurry (1:1 dry cattle waste: water v/v) per day on a 40 day cycle. The slurry inlet is a conical funnel. After day 40, the digested slurry would flow out through the slurry outlet fixed 100cm from the bottom of the digester. The biogas produced in the digester is allowed to flow into a gas holder consisting of two inverted drums.

In a typical digester, the gas formed is trapped by an inverted drum covering the surface of the liquid. As the gas is produced, the drum rises, acting as a storage chamber. The gas can then be drawn off for use as needed.

4. NATURE AND USES OF ANIMAL WASTES

Practically, any kind of watery organic substance can be a substrate for anaerobic digestion. Most simple biogas plants are fuelled with manure (dung and urine), because such substrates usually ferment well and produce good biogas yields [9]. Wastes from ruminant animals are very useful for starting the fermentation process since they already contain the necessary methanogenic bacteria. How much of the gas yield from ruminants’ waste could be lower than obtained from non-ruminants because ruminant animals extract a higher percentage of nutrients out of the fodder, and the lower lignin complexes from high-fibre fodder are very resistant to anaerobic fermentation [9].

Animal wastes vary in chemical composition, physical form and quantities produced mainly due to the variability in the digestive physiology of the various species; the composition and form of the diet; the stage of growth and productivity of the animal; and the management system of waste collection and storage [5]. The quantity and composition of manure are primarily dependent on a number of factors including (i) the amount of feed eaten and its digestibility. About 40-80% of the organic content of the feed reappears as manure (for instance, cattle excrete about 33% of their fibrous fodder) and (ii) quality of fodder utilization and the liveweight of the animal [9].

Approximate fresh waste values for livestock are summarized in table 1.

It should be noted that in extensive livestock operations, animal waste is mostly handled in the solid form (more than 20% dry matter). However, with the development of intensified confinement production units, larger quantities of animal wastes are being collected and stored as slurry (semi-solid) or liquid forms.

Wastes from different species of animals have different physical characteristics. Thus, wastes from sheep, horse (equus) and poultry contain less moisture than dairy and beef wastes. This is due to differences in the physiological mechanisms for water retention and excretion in the various species. The diet and digestion process of the animal will determine particle-size distribution of fresh manure. Thus, chicken manure will generally have a greater portion of fine particles and a lesser content of coarse particles than dairy cattle waste.

Voided nutrients in animal waste will decrease with increasing digestibility and
efficiency of utilization of nutrients in the diet. Similarly, with increasing addition of ingredients or nutrients above the level required by the animal, the concentrations of these nutrients voided in the waste increase. In table 1, the relatively higher fibre content in waste from ruminants, higher nitrogen content of non-ruminants’ waste, lower phosphorous content in waste from ruminants and higher calcium content of cage layer waste are reflections of the differences in the nutritional - physiological requirements between species [5].

Animal wastes can be used for a number of purposes including sources of plant nutrients, feed ingredients and fuel energy. They contain high levels of organic matter which could be converted to energy to substitute for fossil fuel. Animal wastes are abundant all over the world with Nigeria being capable of producing about 227,500 tons of fresh wastes each day [3]. Since 1 kg of fresh animal waste produces about 0.03 m³ of gas, theoretically, Nigeria can produce 6.8 million m³ of biogas daily, which, in terms of energy, is equivalent to about 3.9 million litres of petroleum [3]. The fuel value of the gas produced will depend on its methane content. Pure methane has a calorific value of 37 MJ/m³ [5,6]. Therefore, biogas containing 60% methane would have a calorific value of about 22.2 MJ/m³. It has been estimated that when methane is produced from animal waste, 18% of the gas energy could be recovered as electrical energy and 55% as thermal energy [7].

5. BIOLOGICAL PROCESSES DURING BIOGAS PRODUCTION

The composition, fuel value and yield of the gas produced will depend on a number of factors including the nature of the substrate and the operating conditions. The theoretical aspects of microbial methane production have been reviewed by Bryant [10]. Basically, the processes involve the conversion of complex organic matter to biogas (methane and carbon dioxide). 3 general metabolic groups of bacteria are involved (see figure 1).

Fermentative bacteria hydrolyse polysaccharides (carbohydrates), proteins and lipids and degrade their products to organic acids, alcohols, carbon dioxide and H₂. The hydrogen producing acetogenic bacteria obtain energy for growth by producing acetate, carbon dioxide and hydrogen from the organic acids and alcohols that have been produced by the fermentative bacteria. The methanogenic bacteria utilize the products of the first two stages (mainly acetate, hydrogen and carbon dioxide) in the fermentation of methane and carbon dioxide which mainly constitute biogas.

6. IMPORTANT FACTORS AFFECTING BIOGAS PRODUCTION

To facilitate optimum efficiency of production, conditions in the biogas plant should be favourable to the bacteria involved. Bacteria are sensitive to changes in their environment. A number of factors such as the nature of organic waste, concentration of slurry, temperature, pH, degree of mixing and even seeding with bacteria are known to affect biogas production [12]. The nature of feedstock affects the volume of the gas produced. Mean gas yields from different animal wastes are shown in Table 2. In many cases, various substrates should be mixed together in order to ensure a favourable gas yield while stabilizing the fermentation process and promoting gas production [9]. Samples containing a combination of cow dung and poultry droppings (mixed in a ratio of 2:1 w/w) gave the highest volume of gas (5850 cm³) while poultry droppings alone yielded the lowest quantity of gas (1290 cm³) [12]. Chemical composition of the feed - stock will determine such factors as contents of carbon, nitrogen and pH of the slurry which in turn affect the yield of the gas. In most livestock - waste units operated at 35°C, the gas composition by volume is about 60% methane and 40% carbon dioxide [7].

Optimum yield of biogas can be obtained with both mesophilic (30-40°C) and thermophilic (45-60°C) processes. Although the mesophilic range may be preferred since (i) it is easy to maintain the digester at this temperature, (ii) mesophilic bacteria are more stable than thermophilic bacteria and (iii) they produce a high quality sludge [8], significantly higher rates of methane production can be achieved with the thermophilic process [7]. At lower temperatures of about 15°C, the production of biogas is substantially reduced [8].

Effects of some parameters on biogas production are shown in Table 3, while Table 4 gives a general guideline on biogas production. It takes about 60-90 days for an anaerobic digester to reach equilibrium. Indications of a stable digester include gas production rates, methane concentration of biogas, pH and volatile acids [5].

The optimum pH range for methane production is between 7.0-7.2, although gas production will proceed when the pH is between 6.6 and 7.6. When the pH drops below 6.6, there is significant inhibition of the methane-producing bacteria, and a pH of 6.2 is toxic to them [6].

To facilitate better utilization, animal wastes should not contain high levels of fibre and lignin since these constituents are difficult to digest. Grinding of the waste can increase bacterial attack and therefore better utilization. Feedstock preparation generally

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Table 2: Mean gas yields per volatile-solids and carbon to nitrogen ratios of some animal wastes (from [9])

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Average gas yield (1/kg volatile-solids)</th>
<th>C:N Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow manure</td>
<td>250</td>
<td>10-20</td>
</tr>
<tr>
<td>Swine manure</td>
<td>450</td>
<td>9-13</td>
</tr>
<tr>
<td>Poultry manure</td>
<td>460</td>
<td>5-8</td>
</tr>
<tr>
<td>Horse manure</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Sheep manure</td>
<td>200</td>
<td>30</td>
</tr>
</tbody>
</table>
Table 3: Effects of some parameters on biogas production (After [12])

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Volume of gas produced (cm³)</th>
<th>Min. time for gas production to start (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH 5</td>
<td>102</td>
<td>1</td>
</tr>
<tr>
<td>pH 10</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>Stirring</td>
<td>144</td>
<td>8</td>
</tr>
<tr>
<td>No stirring</td>
<td>2,870</td>
<td>12</td>
</tr>
<tr>
<td>Occasional shaking</td>
<td>5,850</td>
<td>10</td>
</tr>
<tr>
<td>Temp. 50°C</td>
<td>9,060</td>
<td>2</td>
</tr>
<tr>
<td>35°C</td>
<td>6,250</td>
<td>8</td>
</tr>
<tr>
<td>Seeding with bacteria</td>
<td>1,900</td>
<td>0</td>
</tr>
</tbody>
</table>

improves the digestibility of materials.

Since carbon and nitrogen are the main nutrients used by anaerobic bacteria, carbohydrates and proteins (as well as other nitrogenous substances such as nitrates and ammonia) should be provided in the right ratio. An optimum C:N ratio is important in maximizing gas yield [5]. The animal waste should ideally contain a C:N ratio of 10 - 30:1. Although poultry manure can give a high gas yield (table 2), its C:N ratio is only about 5:8:1 [9]. This ratio is virtually outside the ideal ratio of 10-30:1 which is favourable for biogas production. This could be one of the main reasons why samples of poultry droppings alone produced the lowest quantity of biogas [12]. Other important factors that may affect biogas production include dilution rate of the waste, occasional stirring/mixing of the waste and regular feeding of the digester to facilitate continuous supply of the gas [8]. Thus, slurry concentrations greatly influenced the volume of biogas produced, with 10% voltage solids (as percentage of total slurry) giving the highest amount of gas production [12].

A minimum of about 4 to 5 cattle are needed to keep a viable Biogas Plant operating. Biogas generation from animal waste is feasible at a relatively cheap rate. It can be operated at village, commercial and farm levels. Its requirements for both technology level and capital are among the lowest compared to other processes of fuel generation [6].

7. CONCLUSIONS

The increasing cost of conventional fuels necessitates the exploration of other sources. Animal wastes are abundant throughout Nigeria but especially in rural areas. Biogas can be produced from animal wastes to substitute for fossil fuels. The generation of biogas from animal wastes produces an energy resource that can be stored and used more efficiently. It also creates an excellent residue that retains the fertilizer value of the original waste. The search for alternative energy sources such as biogas should be intensified so that ecological disasters like deforestation can be arrested. Wastes from different livestock species have different physical and chemical characteristics. Animal wastes should be fed to the biogas plant in such a way that conditions favouring the production of high volume of gas are met. Thus, the C:N ratio and pH of the slurry should be optimum for gas production. Offering diets that contain less fibre and lignin to farm animals will ensure that wastes voided by these animals are less ligno-fibrous and therefore serve as better stuff for biogas production through bacterial fermentation.

REFERENCES

Table 1: Production and Composition of selected Fresh Animal Wastes (After [5])

<table>
<thead>
<tr>
<th>Source</th>
<th>Size (kg)</th>
<th>Total Production (kg/day)</th>
<th>Dry Matter (%)</th>
<th>Ash</th>
<th>Crude Fibre</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>beef cow</td>
<td>520</td>
<td>29</td>
<td>12</td>
<td>15</td>
<td>37</td>
<td>2.0</td>
<td>.4</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Finishing:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>high conc</td>
<td>450</td>
<td>27</td>
<td>11</td>
<td>11</td>
<td>12</td>
<td>3.2</td>
<td>.7</td>
<td>2.4</td>
<td>.6</td>
</tr>
<tr>
<td>med. conc</td>
<td>450</td>
<td>36</td>
<td>12</td>
<td>13</td>
<td>20</td>
<td>3.2</td>
<td>.9</td>
<td>2.6</td>
<td>.8</td>
</tr>
<tr>
<td>Dairy Cow</td>
<td>640</td>
<td>50</td>
<td>14</td>
<td>18</td>
<td>26</td>
<td>2.5</td>
<td>.6</td>
<td>2.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Poultry:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cage layer</td>
<td>2</td>
<td>.10</td>
<td>26</td>
<td>30</td>
<td>13</td>
<td>4.8</td>
<td>1.8</td>
<td>1.8</td>
<td>5.5</td>
</tr>
<tr>
<td>broiler</td>
<td>1</td>
<td>.06</td>
<td>25</td>
<td>22</td>
<td>17</td>
<td>4.4</td>
<td>1.7</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Sheep</td>
<td>40</td>
<td>2</td>
<td>26</td>
<td>15</td>
<td></td>
<td>4.4</td>
<td>.6</td>
<td>3.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Table 4: Biogas guideline data (source:[9]).

Suitable digesting temperature: 20 - 35°C
Retention time: 40 - 100 days
Biogas energy content: 22MJ/m³
1 Cow yields: 9 - 15kg dung/day = 0.4 m³ gas/day
Gas requirements, for cooking: 0.1 - 0.3 m³/gererson
for 1 lamp: 0.1 - 0.15 m³/hour
for engines: 0.17 m³/MJ

Figure 1. Fermentation of Organic Wastes to Biogas
(Adapted from [10]).