Jute caddis — A new substrate for biogas production

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Biogas containing 55-65 per cent methane can be produced from jute caddis — a lignocellulosic waste of jute mills by anaerobic fermentation, using cattle dung as sole source of inoculum. Biogas production from a lignocellulosic material like jute caddis is a slow but steady process where methane rich biogas comes mostly from hemicellulose and cellulose but not from lignin. Batch fermentation has been adopted for utilization of jute caddis in a modified KVIC model (floating dome type) biogas plant although problem of hard scum formation could not be completely eliminated. However the results indicate that jute waste is a promising substrate for biomethanation because of its slow and steady nature of decomposition. Thus jute mills can adopt this eco-friendly technology for their commercial exploitation.

Keywords: Jute caddis, Lignocellulosic waste, Biogas, Methane, Biomanure, Ecofriendly

Introduction

Biogas containing 55-60 per cent methane can be produced from various lignocellulosic wastes in which jute caddis is a new addition1. Agricultural residue of jute cultivation mainly goes back in the field as manure and thus has less importance in its commercial exploitation as substrate for biogas production. On the other hand, a large quantity of this short fibre waste from loom shade and sweepings of mills is available for biogas production from the jute processing industry which is used as cheap fuel in jute mills and this also creates pollution problem in and around jute mills.

Jute fibre is known to contain 60-65 per cent cellulose and 15-16 per cent lignin unlike cotton, which is almost pure cellulose with very small quantity of lignin. As such, 50 per cent of these cellulosic residues are known to produce methane in biogas digester while lignin is supposed to remain inert during production of biogas2.

Jute caddis, 2-4 per cent of the processing residue, is unspinnable short fibre deposited in loom shade of jute mills. This fibre material is mostly used uneconomically as boiler fuel. Though recently a diversified use of high quality jute caddis has been developed through non-woven fabric as geotextile3, the low grade jute caddis and shaker dust remain mostly unexploited. Biomethanation or production of methane rich biogas from such a carbonaceous waste cannot only provide energy in energy deficient days but also provide a high grade biomanure for agriculture through an ecofriendly, clean and low cost technology suitable for the developing countries like India4.

Materials and Methods

Jute caddis was procured from M/s The Ganges Manufacturing Co. Ltd, Hooghly, West Bengal, India and were properly sampled. The caddis contained about 4 per cent batching oil and 0.1 per cent dust by weight and the rest were lignocellulosic fibre material.

Determination of Chemical Constituents of Fibre Sample and Cattle Dung

Chemical constituents of cattle dung and jute caddis before and after biogas production viz., organic carbon, fat and wax, α-cellulose, pentosan, lignin and ash content were determined. Organic carbon was determined following Walkley and Black method5, while fat and wax, α-cellulose, pentosan, lignin and ash content were determined following methods described in Tappi Standard6.

Production of Biogas in Portable and Pilot Plant Biogas Digester

Jute caddis was soaked in 2 per cent (w/v) NaOH solution with a liquor ratio 1:10 for 7 d at 30 ±2 °C. The pretreated jute caddis was used as substrate for biogas production in a 50 L capacity KVIC model biogas digester. Since jute caddis do not contain cellulolytic and/or methanogenic bacteria responsible for biogas generation, cattle dung containing 17 per cent dry matter was used as seeding material at a ratio
of 1:5 (w/w) with jute caddis. Water was added to make substrate liquor ratio of 1:5 (w/v) to make slurry for biogas production. Three sets of experiments were conducted using jute caddis and cattle dung containing 12 per cent solid matter, mixed with appropriate quantity of water as substrate.

Determination of Environmental Parameters in the Digester Slurry and Composition of Generated Gas

\( pH \), redox potential \( (E_h) \), and temperature of digester slurry were determined following method of Banik \textit{et al.}\(^5\). Composition of biogas generated from the digesters was estimated by chemical absorption method. Degree of polymerisation of \( \alpha \)-cellulose from digester slurry was determined from viscosity using Battista equation, described in Tappi standard methods\(^6\). Crystallinity of fibre sample before and after fermentation were determined by X-ray diffraction study. Degree of humification in digester slurry was determined following method of Jackson\(^5\). Scanning electron photographs of fibre samples were determined from digested slurry.

Determination of Nutrient Elements Present in Manure

Nitrogen from manure samples was determined by Kjeldahl’s method\(^5\) and phosphorus was determined by spectrophotometric method. Other elements viz., K, Ca, Fe, Mn, Zn, and Cu were determined in a Perkin-Elmer (model-370) Atomic Absorption Spectrophotometer from ash samples obtained by heating at 550\(^\circ\)C for 6 h in a Muffle furnace using standard methods\(^6\).

Results and Discussion

The results of the present experiments are presented in Tables 1-6 and Plates 1-3. The lignocellulosic industrial waste - jute caddis was found to produce methane rich biogas. From Table 1, it is evident that organic carbon is reducing on fermentation, especially the components fat and wax, \( \alpha \)-cellulose and pentosans but not the lignin. Results further indicate that plant nutrient rich biomanure can be obtained from the residual slurry after biogas generation evident by the increase in C:N, C:P and C:K ratio due to decomposition of substrate for biogas production.

From results presented in Table 2, it is evident that when jute caddis was mixed with cattle dung, it caused higher methane content in biogas from the portable biogas digester than that of cattle dung alone, while no gas evolved from jute caddis alone as sole substrate. This is due to non-availability of cellulolytic and methanogenic microorganism in jute caddis which is essential for biomethanation from a lignocellulosic material\(^8\).

<table>
<thead>
<tr>
<th>Chemical constituents</th>
<th>Cattle dung Before biogas production</th>
<th>Jute caddis After biogas production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic carbon</td>
<td>8.90</td>
<td>14.51</td>
</tr>
<tr>
<td>Fat &amp; wax</td>
<td>2.26</td>
<td>4.17</td>
</tr>
<tr>
<td>( \alpha )-cellulose</td>
<td>6.65</td>
<td>11.93</td>
</tr>
<tr>
<td>Pentosan</td>
<td>1.80</td>
<td>3.24</td>
</tr>
<tr>
<td>Lignin</td>
<td>0.70</td>
<td>1.23</td>
</tr>
<tr>
<td>Ash</td>
<td>0.12</td>
<td>0.20</td>
</tr>
<tr>
<td>C:N ratio</td>
<td>25:1</td>
<td>33:1</td>
</tr>
<tr>
<td>C:P ratio</td>
<td>23:1</td>
<td>56:1</td>
</tr>
<tr>
<td>C:K ratio</td>
<td>100:1</td>
<td>96:1</td>
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</table>

<table>
<thead>
<tr>
<th>Number of d</th>
<th>Experiments</th>
<th>Gas composition (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Set 1</td>
<td>Methane</td>
</tr>
<tr>
<td></td>
<td>Set 2</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>24</td>
<td>Set 1</td>
<td>Methane</td>
</tr>
<tr>
<td></td>
<td>Set 2</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td></td>
<td>Set 3</td>
<td>Methane</td>
</tr>
<tr>
<td></td>
<td>Set 3</td>
<td>Carbon dioxide</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of d</th>
<th>Methane</th>
<th>Carbon dioxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle dung</td>
<td>53.16</td>
<td>46.06</td>
</tr>
<tr>
<td>Jute caddis + Cattle dung</td>
<td>58.94</td>
<td>41.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of d</th>
<th>Methane</th>
<th>Carbon dioxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(^{st}) Charge</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>64.0</td>
<td>36.0</td>
</tr>
<tr>
<td>30</td>
<td>50.2</td>
<td>49.8</td>
</tr>
<tr>
<td>45</td>
<td>38.5</td>
<td>61.5</td>
</tr>
<tr>
<td>2(^{nd}) Charge</td>
<td>69.5</td>
<td>30.5</td>
</tr>
<tr>
<td>75</td>
<td>59.7</td>
<td>40.3</td>
</tr>
<tr>
<td>90</td>
<td>57.8</td>
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<td>105</td>
<td>52.2</td>
<td>47.8</td>
</tr>
<tr>
<td>120</td>
<td>49.0</td>
<td>51.0</td>
</tr>
</tbody>
</table>

Note : Modified KVIC model biogas plant was used
Production of biogas in a modified KVIC model biogas plant was reported by Banik et al. using pretreated jute caddis as main substrate and cattle dung as inoculum to determine the methane content in produced biogas. From the results presented in Table 3, it is evident that methane production started on 15th d and then went on increasing up to 30th d and then declined. There was significant fall in methane content on 45th d. After 45 d a second charge was given and biogas production continued to increase again. On 60th d again methane production reached to a peak and remained fairly constant for a reasonable period of time and then again declined. The study was continued up to 120 d. From our earlier and present work (Plates I, II and III), it was concluded that being a lignocellulosic material jute caddis is suitable for biogas generation for longer period when batch fermentation was adopted, instead of continuous
fermentation. However, one constrain faced by this substrate through KVIC model biogas plant was hard scum formation which need to be broken mechanically periodically for continuous generation of biogas from the digester and as a result significant amount of biogas was lost which could not be accounted for.

In another experiment, pH, $E_h$, and temperature changes in digester slurry was determined along with methane content in generated biogas. From the data presented in Table 4 it is evident that pH of digester slurry remains slightly acidic during active biomethanation while the redox potential or $E_h$ values reaches to a high degree of negative value which is indication of anaerobiosis and this continued over the entire biomethanation period. The temperature in biogas digester remained in mesophilic range. Methane content in biogas remained constant over a reasonable length of time and then declined. At this stage, a second charge was given in the digester and as a result again favourable condition for biomethanation was established and methane content in biogas reached to a peak and then continued to produce methane rich biogas for a reasonable length of time and then slowly declined. The experiment was continued for 100 d. Total production of biogas was
estimated to be 14 cu m over a period of 60 d from a 2 cu m capacity KVIC model biogas plant fed with 75 kg alkali pretreated jute caddis plus 200 kg fresh cattle dung. When biogas generation was conducted with 200 kg fresh cattle dung as sole substrate in the same digester initial biomethanation started after 10 d but generation of biogas in peak condition continued for a very short period and total quantum of biogas was also much less. Thus, it can be concluded that being a lignocellulosic substance jute caddis decomposes slowly producing volatile fatty acids especially acetic acid\(^1\) responsible for production of methane rich biogas probably via acetoclastic pathway\(^2\) and continues for a longer period of time. From the SEM photographs the fibre decomposing action of microbes is clearly understood. Thus, it can be concluded that generation of biogas from industrial waste of jute mills viz., jute caddis is an appropriate technology for jute mills which converts a waste to wealth. This not only helps to create a pollution-free technology but also promises to convert a potential technology to a real success.

Moreover, high plant nutrient rich biomanure should be considered as a valuable byproduct from biomethanation of jute caddis which, of course, should be in favour of its profitability of the technology. We, therefore, conclude from the study that biogas generation from jute caddis should be adopted as a powerful and low cost technology by the jute industry.

Conclusions

Methane rich biogas can easily be obtained from jute caddis – a lignocellulosic waste of jute mills by anaerobic fermentation. Alkali pretreated jute caddis produces biogas steadily. By eliminating the problem of hard scum formation, biogas production from jute caddis should be an excellent technology for jute mills for producing energy from waste like jute caddis along with a valuable byproduct – a plant nutrient rich biomanure, in an eco-friendly manner.

References