Anaerobic Digestion of Vegetable Wastes for Biogas Production in a Fed-Batch Reactor

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Abstract. Vegetable wastes (Banana stem, Cabbage and Ladies finger) were anaerobically digested in a fed-batch laboratory scale reactor at mesophilic conditions (35°C). The Organic Loading Rate (OLR) was maintained at 2.25 g/l.d with a Hydraulic Retention Time (HRT) of 30 days. The average methane content in the biogas was 65% and the Methane yield was 0.387 l CH₄/g VS added for the selected types of wastes. The objective of this paper was to study the performance of the selected vegetable wastes in a single stage fed-batch anaerobic reactor for biogas production.

Keywords: Vegetable wastes, Biogas, Methane yield, anaerobic digestion.

1 INTRODUCTION

India stands second in the production of Fruits and Vegetables in the world. It contributes about 10 and 14% of Fruit and Vegetable in the world production [1]. Vegetable Wastes are created during harvesting, transportation, storage, marketing and processing. Due to their nature and composition, they deteriorate easily and cause foul smell. According to Food and Agricultural Organization (FAO), the estimated Fruit and Vegetable wastes percentage for each commodity group in each step of the food supply chain are 15, 9, 25, 10 and 7% in agricultural production, post harvest handling and storage, processing and packaging, distribution and consumption respectively in South and South-East Asia [2]. Indian Agricultural Research Data Book 2004 showed the estimated production of fruits and vegetables in India at 150 million tones and the total waste generated at 50 million tones per annum. i.e., 30% of the estimated production of Fruits and Vegetables. The high moisture and organic content in these wastes can be utilized in biological treatment like anaerobic digestion than other techniques like incineration and composting.

Anaerobic digestion is the biological degradation by a complex microbial ecosystem of organic and occasionally inorganic substrates in the absence of an organic source. There are four metabolic stages involved in the production of methane using anaerobic digestion process. First, the particulate organic matters undergo hydrolysis by extra cellular enzymes to convert polymers into monomers. Then the soluble organic matter and the products of hydrolysis are converted into
organic acids, alcohols, hydrogen and carbon dioxide by acidogenic bacteria. Thirdly, the acetogenic bacteria convert the products of acidogens into acetic acid, hydrogen and carbon dioxide. Finally, methanogenic bacteria are responsible for methane production from acetogen products. The main advantage in using anaerobic digestion is the biogas production, which can be used for steam heating; cooking and generation of electricity [3-5]. The effluent produced can be used as a biofertiliser or soil conditioner [6].

Vegetable wastes generated largely in markets were disposed in municipal landfill or dumping sites [7]. Bioconversion processes are suitable for wastes containing moisture content above 50% than the thermo- conversion processes [8]. Vegetable wastes, due to high biodegradability nature [9, 10] and high moisture content (75 – 90%) seemed to be a good substrate for bio-energy recovery through anaerobic digestion process. A major limitation of anaerobic digestion of vegetable wastes is the rapid acidification due to the lower pH of wastes and the larger production of volatile fatty acids (VFA), which reduce the methanogenic activity of the reactor [11]. Preliminary treatment is required to minimize organic loading rate, hence aerobic processes are not preferred for vegetable wastes [12]. The rate limiting step in vegetable wastes is by methanogenesis rather than by hydrolysis because methanogenic bacteria take long mass doubling time of 3-4 days in anaerobic reactors.

There are different types of reactors used for the Bioenergy recovery from solid wastes and waste water. They include batch reactors, one stage reactors and two stage reactors. In batch reactors, wastes are fed in to the system and all the degradation steps are allowed to follow sequentially. It is one time feed, i.e. after all the feed is converted to products, fresh feed will be added to the reactors. More retention time is required for these types of reactors for complete conversion into products. In one stage systems, all the reactions simultaneously take place in a single reactor. One stage systems are commonly preferred for full scale anaerobic digestion of organic solid wastes in the world. One stage systems are preferred than the batch and two stage systems because of their easier and simpler designs and low in investment costs. In two stage systems, two different reactors are used for acidogenesis and methanogenesis.

The objective of this paper was to study the performance of the selected vegetable wastes in a single stage fed-batch anaerobic reactor for biogas production.

2 RELATED WORK

Many researchers studied anaerobic digestion of vegetable wastes in one stage systems in laboratory scale reactors. Knol et al [13] studied different fruit and vegetable wastes in a continuously stirred tank reactor (CSTR). The wastes used include spinach waste, asparagus peels, French bean waste, strawberry slurry, apple pulp, apple slurry, carrot waste and green pea slurry. All the wastes above mentioned were operated with a capacity of 1 l and temperature of 33°C. Spinach waste operated with 0.83 – 1.18 g VS/ l. d organic loading rate (OLR) gave a methane yield of 0.316 l/g VS fed and a volatile solids (VS) reduction of 70%.
Asparagus peels, French bean waste, strawberry slurry, apple pulp, apple slurry, carrot waste and green pea slurry with OLR of 0.74 – 1.06, 0.96 – 1.15, 1.02 – 1.15, 1.02 – 1.60, 0.83 – 1.15, 0.8 – 0.9 and 0.87 – 1.25 g VS/l. d respectively resulted in a methane yield of 0.219, 0.343, 0.261, 0.308, 0.281, 0.417 and 0.310 l/g VS fed respectively and VS reduction of 40, 70, 50, 40, 60, 75 and 75% respectively. Lane et al [14] worked in a CSTR continuous with 10l capacity where the effluent solids were recycled to improve the VS reduction. The wastes used were Apricot fibre, corn cobs, apple cake, asparagus waste, sugar beet pulp and pineapple pressings with OLR of 3.74, 3.90, 3.88, 3.43, 3.17, 4.06 and 3.87 g VS/l. d respectively. The methane yield of 0.286, 0.267, 0.252, 0.228, 0.230, 0.263 and 0.335 l/g VS fed respectively and VS reduction of 96.3, 95.7, 93.4, 88.1, 89.7, 95.2 and 93.2 were obtained respectively. Stewart et al [15] treated Banana wastes and Potato waste in a continuous CSTR with volume of 20l under mesophilic conditions. The OLR and HRT used were 2.5 g VS/l. d and 20 days and reported VS reduction of 100% for both the substrates. The methane yield obtained were 0.529 and 0.426 l/g VS fed respectively. Sarada et al [16] studied tomato processing waste in a semi-continuous CSTR in 5.5 l reactor with a HRT of 24 days , OLR of 4.3 g VS/l. d and methane yield of 0.42 l/g VS fed. The effect of OLR and HRT were studied in a semi continuous CSTR of 60l capacity by Prem Viswanath et al [17]. They made successive addition of tomato, mango, orange peel with oil, deoiled orange, pineapple and jack fruit wastes with a constant OLR of 3.8 g VS/l. d and varying HRT of 8,12,16,20 and 24 days with methane yield of 0.030, 0.090, 0.25, 0.37 and 0.32 respectively. Then with a constant HRT of 16 days and varying OLR of 3.8, 5.7, 7.6 and 9.5 g VS/l. d respectively obtained methane yield of 0.637, 0.835, 0.551 and 0.218 l/g VS fed respectively. Bouallagui et al [18] worked in a tubular digester with Fruit and Vegetable wastes (FVW) with varying HRT of 12, 15 and 20 days and varying feed concentration of 4, 6 and 8% Total Solids (TS). The feed concentration of 4% TS and HRT of 12, 15 and 20 days gave VS degradation efficiency of 61.8, 67.5 and 74.45% respectively with biogas yield of 0.582, 0.629 and 0.695 l/g VS fed respectively. For 6% TS, the maximum VS degradation efficiency of 75.91% and maximum biogas yield of 0.707 l/g VS fed was achieved in 20 days HRT. For 8% TS, the maximum VS degradation efficiency of 64.58% and maximum biogas yield of 0.638 l/g VS fed was achieved in 20 days HRT. Bolzonella et al [19] studied anaerobic digestion of mechanically sorted organic fraction of municipal solid wastes (MS-OFMSW) in thermophilic conditions with an OLR of 9.2 g VS/l d with feed concentration of 20% TS and achieved specific gas production (SGP) of 0.23 l/g VS fed. Nagori et al [20] worked on biogas generation from kitchen wastes to study the influence of OLR with a HRT of 30 days. The OLR used were 0.6, 1.2, 1.8, 2.4 and 3.0 g VS/l d. Maximum biogas production of 614.3 l/ kg VS/d was achieved with an OLR of 1.8 g VS/l d. For a stable reactor operated with FVW, as suggested by Lane, alkalinity should be more than 1500 mg caco3/l and Volatile fatty acids (VFA): alkalinity ratio should be less than 0.7. Mata-Alvarez et al [21] studied in continuous one stage CSTR with a loading rate of 1.6 g VS/l d and HRT of 20 days in a 3l reactor. The VS removal and methane yield were 88% and 0.47 l/g VS fed respectively. Verrier et al [22] worked on vegetable wastes in a 16l reactor with an OLR of 3.6 and HRT of 23
days. The VS removal and methane yield were 83% and 0.37 l/g VS fed respectively.

3 MATERIALS AND METHODS

3.1 Reactor set-up

A laboratory scale reactor of total volume of 2 liters was used. The reactor was made of borosilicate glass. The effective volume of the reactor was maintained at 1.5 liters. The reactor was provided with suitable arrangements for feeding, gas collection and draining of residues. The reactor was operated by draw and fill method. Biogas production from the reactors was monitored daily by water displacement method. The volume of water displaced from the bottle was equivalent to the volume of gas generated. The reactor was mixed manually by means of shaking and swirling once in a day. The reactor was operated at mesophilic conditions (35°C) using a constant temperature water bath.

3.2 Analytical methods

pH was measured using digital pH meter. Total solids (TS), Volatile solids (VS), Alkalinity and Volatile fatty acids (steam distillation method) were estimated according to the procedures recommended in the Standard methods for examination of water and waste water [23]. A gas chromatograph (Mayura Analytical, India) containing a Porapak Q of 2m length using thermal conductivity detector (TCD) was used to measure the content of methane concentration in the reactor. Nitrogen was used as a carrier gas with a flow of 30ml/min. The oven, injector and detector temperatures were kept at 50, 100 and 100°C respectively.

3.3 Inoculum

Inoculum was collected from 30MT Vegetable market wastes Biomethanation plant at, Chennai, India. The Total solids, Volatile solids and pH of the inoculum were 8.21%, 50.42% and 7.56 respectively. The inoculum used in the study was a predigested vegetable market wastes which contain all the required microbes (hydrolyzing, fermentative, acetogenic and methanogenic bacterial consortium) essential for anaerobic digestion process. The inoculum was passed through 1mm sieve mesh and kept at 4°C until used.

3.4 Feedstock

Fresh Vegetables consisting of Banana stem, Cabbage and Ladies finger were collected from a near by vegetable market. The wastes were ground in a kitchen
blender to make it as a pulp and used as feed to the reactor and kept at 40°C until used. The characteristics of the feed were shown in Table 1.

**Table 1.** Characteristics of the feed

<table>
<thead>
<tr>
<th>Wastes</th>
<th>pH</th>
<th>TS (%)</th>
<th>VS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana stem</td>
<td>5.93</td>
<td>6.55</td>
<td>83.21</td>
</tr>
<tr>
<td>Cabbage</td>
<td>6.45</td>
<td>8.50</td>
<td>90.45</td>
</tr>
<tr>
<td>Ladies finger</td>
<td>6.30</td>
<td>12.28</td>
<td>90.65</td>
</tr>
</tbody>
</table>

4 RESULTS AND DISCUSSION

4.1 pH, Alkalinity and VFA Variation in the reactor

In an anaerobic system, the acetogenic bacteria convert organic matter to organic acids, possibly decreasing the pH, reducing the methane production rate and the overall anaerobic digestion process unless the acids were quickly consumed by the methanogens. pH in the range of 6.8 to 7.4 should be maintained in the anaerobic digestion process, which is the optimum range for methanogens growth [24]. The vegetable wastes were fed with an average pH of 5.75 and the reactor residue average pH was 7.55 which was slightly above the optimal pH. The pH profile was shown in Figure 1. Due to rapid acidification of the vegetable wastes, high VFA were formed and that leads to instability of the reactor. For a stable digestion, alkalinity should be in the range of 2000-4000 mg CaCO₃ / l [24]. Alkalinity maintained in the reactor was above the optimal range i.e. 4750 mg / l. The reactor stability can also be estimated using VFA/alkalinity ratio. This ratio should be less than 0.4 for the reactor to be stable [25]. The VFA/alkalinity ratio ranged between 0.3 to 0.4 in the reactor during the study period. This value clearly indicated that the reactor was completely stable and steady throughout the HRT. The VFA/alkalinity ratio in the reactor was shown in Figure 2.
Figure 1. pH of Feed and Drain in the reactor

Figure 2. VFA / Alkalinity ratio in the reactor

4.2 Solids removal and Biogas yield in the reactor

The Total solids in the feedstock and in the residue were 3.504g and 1.374g respectively. The removal efficiency of Total solids was 60.77%. The Volatile solids in the feedstock and in the residue were 2.701g and 0.848g respectively. The removal efficiency of Volatile solids was 68.6%. The daily biogas production was shown in Figure 3.
The average biogas produced was 1.607 l/day with an OLR of 2.25 g/l.day and HRT of 30 days. The biogas yield was 0.59 l/g VS added. The methane content in the reactor was 65% and the methane yield was 0.387 l CH₄/g VS added. From literature, the methane yield for vegetable wastes [26] was 0.19 – 0.4, fruit wastes [26] was 0.18 – 0.732, fruit and vegetable mixture [8] was 0.510, banana wastes [14] was 0.529, potato wastes [14] was 0.426, cauliflower leaves [27] was 0.423, banana peeling [27] was 0.409 and green wastes [28] was 0.15 l CH₄/g VS added respectively.

5 CONCLUSION

Anaerobic digestion of vegetable waste has been carried out in a laboratory scale reactor with a HRT of 30 days and an OLR 0f 2.25 g/l.d. The stability of the reactor was justified with the pH and VFA/alkalinity ratio values. Methane yield was 0.387 l CH₄/g VS added. Hence, it was noteworthy that vegetable wastes were potential source for energy production.

6 RECOMMENDATIONS

The conversion of Vegetable Wastes to biogas using anaerobic digestion process represents a viable and commercial one. But the rapid acidification of Vegetable Wastes tends to operate the reactor in a lower Organic loading rate. If sufficient buffering is provided, these wastes can be better utilized for energy production. Since protein rich substrates provide good buffering capacity, highly nitrogenous wastes can be co-digested with Vegetable Wastes to increase the stability of the reactor. Many advantages using co-digestion processes include increase in waste organic load, potential toxic compounds can be diluted, nutrient balance can be improved and increase in biogas yield. Further research can be studied using
nitrogen-rich substrates with Vegetable Wastes for energy production and environmental protection using co-digestion process.

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