ANAEROBIC CO-DIGESTION OF WASTED VEGETABLES AND ACTIVATED SLUDGE

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ABSTRACT
Anaerobic co-digestion of activated sludge (AS) and wasted vegetables (wasted cucumbers (WC) and wasted tomatoes (WT)) was carried out at mesophilic conditions (34 ± 0.5 °C). A continuously stirred bioreactor with volume of 5 dm³ (3 dm³ working volume) was used. The digestion was examined in semi-continuous mode and 30 days hydraulic retention time. Total solids, volatile solids, COD and volatile fatty acids (VFA) were determined according to the standard methods. Daily the total biogas production as well as CH₄ and CO₂ content were determined using a graduated gasholder and an infrared sensor, respectively. pH was measured with Seibold pH-meter.

The initial AS/WC ratio of the mixture used was 90/10. The average biogas production was 0.150 dm³ dm⁻³ d⁻¹. The VFA concentrations were low during the process. After 127 days WT was added to the mixture. The AS/WC/WT ratio was 80/10/10. The CH₄ and CO₂ content in the biogas varied in the range of 64 - 72 % and 13 - 25 %, respectively. The data obtained during this study confirm that the co-digestion of the vegetables with AS is more favourable compared to the single digestion of the vegetables.

Keywords: anaerobic co-digestion, activated sludge, biogas, wasted vegetables

Introduction
Traditionally, anaerobic digestion was a single substrate treatment (1). Recently, it has been realized that this process becomes more stable when the variety of substrates applied at the same time is increased. Large quantities of fruit and vegetable wastes are generated in the markets. These residues are difficulty degraded because of the high quantity of polysaccharides. Co-digestion of activated sludge with fruit and vegetable wastes has been proposed as a solution of the problems mentioned above (2).

The potential of mesophilic co-digestion of primary sludge and fruit/vegetable fraction of the municipal solid wastes was observed by Gomez et al. (3). Good results were obtained for reactors with limited mixing when different mixing conditions have been studied. The results showed better performance for the mixture compared to the pure substrates. The anaerobic digestion was also examined at different organic loading rates (OLRs) under low mixing condition. The process was stable even when the systems were overloaded.

Rizk et al. (4) examined the co-digestion of FVW and sewage sludge. They used 70 liter stainless steel anaerobic reactor at temperature 25±5°C without mixing. The inoculum was prepared from an anaerobic domestic sewage station. The biogas yield was around 331 l and most of it was produced during the first month of the experiment. Around 20 % of COD was removed and the pH, alkalinity and VFA were stabilized. The authors suggested that the low COD removal and the biogas generation almost only in the first month were due to the high organic load, the lack of mixing system and the difficulties in the degradation of those residues.

Anhuradha et al. (5) studied the co-digestion of vegetable market waste and sewage sludge. They compared the digestion of mixed wastes with the separate digestion of sewage sludge and vegetables. Three bench-scale reactors with working volume of 1.5 l were used. During the processes 63-65 % of VS were removed in the three digesters. The biogas production for the vegetable waste, sewage sludge and mixture were 0.75, 0.43 and 0.68 l g⁻¹ VS, respectively. The higher biogas yield for vegetables was due to higher easily biodegradable organic matter content.
Two-phase anaerobic co-digestion of fruit and vegetable mixture and wasted activated sludge was observed by Dinsdale et al. (6). CSTRs were used for acidogenesis and inclined tubular digesters for methanogenesis both operated at 30°C, loading rate of 5.7 kg VS m\(^{-3}\) d\(^{-1}\). The overall hydraulic retention time (HRT) was 13 days (3 day acidogenic HRT and 10 day methanogenic HRT). The volume of biogas obtained was 0.37 m\(^3\) kg VS\(^{-1}\) added, with 40% VS destruction and methane content of 68%. When the overall HRT was increased to 17 days, the VS destruction was 44%.

The aim of the present study was to evaluate the effect of the anaerobic co-digestion of cucumber and tomato wastes and activated sludge.

Materials and methods
Substrate Characteristics
The cucumber and tomato wastes were collected in a local food market. The material was homogenized with an electric blender. The TS of the wasted cucumber (WC) was 4% and the wasted tomatoes (WT) were concentrated to value of TS 7%. Then the residues were stored at 0°C in a refrigerator before usage. The activated sludge (AS) was obtained from a wastewater treatment plant near Sofia. It was stored at 0°C with TS of 4%. The substrates were mixed at preliminary determined ratio before feeding into the reactor.

Laboratory installation
An anaerobic reactor with volume of 5 dm\(^3\) (working volume of 3 dm\(^3\)) with mixing system was used in the experiment (Fig.1). The digester was equipped with inlet and outlet ports for feeding and residue discharge, respectively. The system was operated in semi-continuous mode and mesophylic condition (34 ± 0.5°C). The biogas produced during the process was collected into a gasholder where its volume was continuously measured. The HRT was 30 days.

Mixing provides good contact between the microorganisms and the wastes matter, reduces the resistance to mass transfer and decreases the buildup of inhibitory intermediates. In this experiment the reactor was continuously stirred mechanically.

Analytical methods
Total Solids (TS), Volatile Solids (VS), Chemical Oxygen Demand (COD), Total sugars and Total proteins were determined during the process by standard methods (7). The Volatile Fatty Acids (VFA) concentration was analyzed in accordance with (8). The total gas production was measured daily by the water displacement technique and the gas composition was periodically determined by an infrared sensor.

Results and Discussion
The residues used in this study presented a percentage of organic matter of around 67.6, 77.2 and 93 for the AS, WC and WT, respectively (Table1). The high VS content in these vegetable wastes can help the digestion of AS.

TABLE 1
Proximate compositions of the feedstocks

<table>
<thead>
<tr>
<th></th>
<th>AS</th>
<th>WC</th>
<th>WT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS, %</td>
<td>4</td>
<td>4.4</td>
<td>7.17</td>
</tr>
<tr>
<td>VS, %</td>
<td>67.6</td>
<td>77.2</td>
<td>93</td>
</tr>
<tr>
<td>pH</td>
<td>5.4</td>
<td>4.75</td>
<td>2.9</td>
</tr>
<tr>
<td>Total sugars, g dm(^{-3})</td>
<td>1.34</td>
<td>0.76</td>
<td>1.23</td>
</tr>
<tr>
<td>Protein, g dm(^{-3})</td>
<td>5.2</td>
<td>0.42</td>
<td>0.71</td>
</tr>
</tbody>
</table>

It is well known that a considerably long period is required for establishing a balanced microbial culture for the new substrate. Through this special feature the experiment was carried out by stepwise addition of the vegetable wastes to the AS. The initial mixture consisted of AS and WC in proportion 90:10. The average biogas production slowly increased from 0.12 to 0.21 dm\(^3\) dm\(^{-3}\) d\(^{-1}\) after WC addition (Table 2, the average production is taken for 30 days long steady state period). This was due to the easy degradable organic matter in the WC. The TS, VS and COD reduction was 44.3, 68.3 and 73.3, respectively. It can be seen from Table 3 that after the addition of the WC, the reduction of TS, VS and COD is greater than that at digestion of AS as a single substrate.
Comparison of the performances obtained with AS and different mixtures of AS, WC and WT

<table>
<thead>
<tr>
<th></th>
<th>TS, %</th>
<th>Average daily biogas production, dm$^3$ d$^{-1}$</th>
<th>Average biogas production, dm$^3$ dm$^{-3}$ d$^{-1}$</th>
<th>Biogas yield, dm$^3$ kg$^{-1}$ VS$_{added}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS</td>
<td>4</td>
<td>0.37</td>
<td>0.12</td>
<td>4.4</td>
</tr>
<tr>
<td>AS:WC 90:10</td>
<td>4.1</td>
<td>0.65</td>
<td>0.21</td>
<td>7.2</td>
</tr>
<tr>
<td>AS:WC:WT 80:10:10</td>
<td>4.1</td>
<td>0.41</td>
<td>0.13</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Fig. 2. Biogas production during the process.

Fig. 3. Changes in VFA during the process.

Comparison of the experimental data obtained with different mixtures of AS, WC and WT

<table>
<thead>
<tr>
<th></th>
<th>Extent of biodegradation of TS, %</th>
<th>Extent of biodegradation of VS, %</th>
<th>Extent of biodegradation of COD, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS</td>
<td>36.2</td>
<td>52.4</td>
<td>42.5</td>
</tr>
<tr>
<td>AS:WC 90:10</td>
<td>44.3</td>
<td>68.2</td>
<td>73.3</td>
</tr>
<tr>
<td>AS:WC:WT 80:10:10</td>
<td>53.2</td>
<td>63.2</td>
<td>74.5</td>
</tr>
</tbody>
</table>
After 138 days of digestion WT was added to the feedstock. The components ratio in percentage was AS: WC: WT = 80:10:10. It can be seen that the addition of the WT slowly decreased the biogas production (Fig. 2), at the same time decreasing the fluctuations in the daily biogas yield. The TS and VS reduction was comparatively high. Significant COD removal was also observed during the digestion (Table 3). At this proportion of the substrates, the biogas composition was determined. The average CH$_4$ and CO$_2$ content was 70.5 % and 17.5 %, respectively. During the process the concentration of VFA ranged from 0.34 to 1.02 g dm$^{-3}$ with average value of 0.66 g dm$^{-3}$ (Fig. 3).

The microbial community in the anaerobic digester is sensitive to the changes of pH. The initial pH of the substrate was 5.6. In order to prevent the process from significant decrease of pH NaOH was added to the substrate. During the experiment the pH in the reactor ranged from 6.7 to 7.9.

Conclusions

Anaerobic co-digestion of AS, WC and WT has been carried out using laboratory schale reactor. The results obtained during this investigation show that the WC improved the anaerobic digestion of AS. The average biogas production and the solids reduction increased with 75.7 % and 30.1 %, respectively. Nevertheless, the process was characterized with significant fluctuations in the biogas yields. The addition of WT decreased these fluctuations. The experiments will be continued with the enrichment of the mixture with other vegetable and fruit wastes.

Acknowledgment

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REFERENCES