Microbiology of food waste digestion & effects of trace element additions

Charles Banks
Collected food waste
Food waste preparation
Commercial garbage grinder – no water added
Process flow diagram

Domestic kitchen food waste
Restaurant waste

Macerator pump
Buffer storage tank
Digester
Digestate storage tank

Gas collector

Biogas

Digestate
Digesters used early study
SURVIVAL OF SALMONELLA IN THE ANAEROBIC DIGESTION OF KITCHEN WASTE

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SUMMARY: The research considered whether the anaerobic digestion of kitchen waste would enable the essential to be reared where the digester would be suitable for spreading on arable land, or whether a posttreatment stage would also be required. Two pilot-scale anaerobic digesters were operated at 36.7°C, the other at 50°C. High concentrations of pathogenic bacteria were found in the collected food waste samples, with an average of 3.1 MPN g⁻¹ Salmonella. The number of Salmonella was significantly reduced in the mesophilic digester and, after the introduction of hygiene measures to prevent bypass, was generally absent in the thermophilic digester. The results are discussed in relation to changes in pH, volatile fatty acids and temperature during the digestion process. The requirement for posttreatment of the mesophilic and thermophilic digesters prior to spreading on arable land is presented as one of recent changes to European regulations.

A pilot-scale comparison of mesophilic and thermophilic digestion of source segregated domestic food waste

Charles J. Banks, Michael Chesher and Anne Stringfellow

ABSTRACT

Source segregated food waste was collected from domestic properties and its composition determined together with the average weight produced per household, which was 2.17 kg per week. This waste was fed over a trial period lasting 50 weeks to an identical pair of 1.5 m³ anaerobic digesters, one at a mesophilic (36.7°C) and the other at a thermophilic temperature (50°C). The digesters were monitored daily for gas production, solids destruction and for digestion characteristics including alkanes, CO₂, volatile fatty acids (VFA) and ammonia concentrations. Both digesters showed high VFA concentrations, but in the mesophilic digester the pH remained stable at around 7.0, buffered by a high alkalinity of 12,000 mg L⁻¹ KOH whereas in the thermophilic digester VFA levels reached 15,000 mg L⁻¹ causing a drop in pH and digester instability. In the mesophilic digester volatile solids (VS) destruction and specific gas yields were favourable, with 87% of the organic solids being converted to biogas at a methane content of 69% giving a biogas yield of 12.3 m³ kg⁻¹ VS inorganic. Digestion under thermophilic conditions showed potentially better VS destruction at 70% VS and a biogas yield of 12.8 m³ kg⁻¹ VS inorganic. But the shifts in alkalinity and the high VFA concentrations required a reduced loading to be applied. The maximum beneficial loading that could be achieved in the mesophilic digester was 4 kgCOD m⁻³ d⁻¹.

Key words: food waste, kitchen waste, mesophilic, thermophilic, volatile fatty acids

Biodigestion of kitchen waste

A comparative evaluation of mesophilic and thermophilic biodigestion for the stabilization and valorization of kitchen waste

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Water Science & Technology
Demonstration plant
<table>
<thead>
<tr>
<th><strong>Facts, speculation and interpretation</strong></th>
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<tbody>
<tr>
<td><strong>Accumulation of VFA after extended period of time</strong></td>
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<tr>
<td><strong>Acetic acid peak replaced by propionic acid peak</strong></td>
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<tr>
<td><strong>Accumulation of ammonia</strong></td>
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<tr>
<td><strong>Can carbon flow to methane in the absence of acetoclastic methanogens?</strong></td>
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<tr>
<td><strong>Why does propionic acid accumulate?</strong></td>
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<tr>
<td><strong>What is the significance of formic acid?</strong></td>
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<td><strong>Formic acid can only be used by hydrogenotrophic methanogens</strong></td>
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<tr>
<td><strong>Selenium and Tungsten possibly essential trace elements for formate reductase enzyme system</strong></td>
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<td><strong>Can we prove the theory</strong></td>
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### Fractional factorial design

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<td>Zn</td>
<td>Cu</td>
<td>Mn</td>
<td>Al</td>
<td>B</td>
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</table>
Acetic and Propionic acids degradation profiles

- Control
- Se, Mo
- Fe, Ni
- Se, Mo, Co, W, Fe, Ni, Zn, Cu, Mn, Al, B
- Se, Mo, Co, W
- Co, W
75-litre digesters
Organic loading rate (OLR)

OLR (kg VS m\(^{-3}\) digester day\(^{-1}\))

- Control OLR=2
- Control OLR=3
- Se, Mo
- Se, Mo, Co, W
- Se, Mo, Co, W, Fe, Ni (supplementation ceased from day 112 onwards)
- Se, Mo, Co, W, Fe, Ni, Zn, Cu, Mn, Al, B

Time (days)
Volatile fatty acids profiles

- Control OLR=2
- Control OLR=3
- Se, Mo
- Se, Mo, Co, W
- Se, Mo, Co, W, Fe, Ni
- Se, Mo, Co, W, Fe, Ni, Zn, Cu, Mn, Al, B

- Trace element supplementation started with Se, Co & Ni
- Se supplemented accidentally
- Double Se supplementation concentration
- Trace element supplementation stopped in Se, Mo, Co, W, Fe & Ni
- Returned the Se supplementation strength to original concentration
- Started supplementation with Co as well
Specific biogas production (SBP)

Volumetric biogas production (VBP)

Digestion efficiency

Specific biogas production (SBP)

Volumetric biogas production (VBP)
Other digester parameters

**pH**
- Control OLR=2
- Control OLR=3
- Se, Mo
- Se, Mo, Co, W
- Se, Mo, Co, W, Fe, Ni
- Se, Mo, Co, W, Fe, Ni, Zn, Cu, Mn, Al, B

**Intermediate alkalinity (IA) : partial alkalinity (PA)**

**Total Ammonia nitrogen (TAN)**
- Control OLR=2
- Control OLR=3
- Se, Mo
- Se, Mo, Co, W
- Se, Mo, Co, W, Fe, Ni
- Se, Mo, Co, W, Fe, Ni, Zn, Cu, Mn, Al, B

**Methane percentage**
Trace element washout – estimating the critical dose
## TE required vs TE in the food waste

<table>
<thead>
<tr>
<th>TE</th>
<th>Minimum requirement at a moderate loading rate</th>
<th>Hackney, London</th>
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<th>Ludlow, Shropshire</th>
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<td>Co</td>
<td>0.22</td>
<td>0.090±0.049</td>
<td>0.017±0.002</td>
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<td>Se</td>
<td>0.16</td>
<td>0.10±0.08</td>
<td>0.28±0.14</td>
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<td>8100</td>
<td>7400</td>
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Unit: mg kg\(^{-1}\) fresh matter
Density gradient centrifugation – SEM images
### FISH images

**Methanomicrobiales** (food waste digestion)  
**Methanosarcinaceae** (vegetable waste digestion)

<table>
<thead>
<tr>
<th>Probe name</th>
<th>Target group</th>
<th>Probe sequence (5’-3’)</th>
<th>Fluorescent dye</th>
<th>Fluorescent colour</th>
<th>Formamide (%)</th>
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<td>EUB338</td>
<td><em>Bacteria</em></td>
<td>GCTGCCCTCCGTAGGAGT</td>
<td>Cy5</td>
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<td>20~50</td>
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<td>ARC915</td>
<td><em>Archaea</em></td>
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<td>6-Fam</td>
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<td><em>Methanosarcinales</em></td>
<td>GGCTCGCTTCACGGCTTCCT</td>
<td>Cy5</td>
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</table>
Conclusions (trace elements)

• Selenium and cobalt are the key trace elements needed for the long-term stability of food waste digesters, but are likely to be lacking in the food waste.

• The minimum concentrations recommended in food waste digesters for selenium, cobalt are around 0.16, 0.22 mg l$^{-1}$ respectively, when running at a moderate organic loading rate.

• A total selenium concentration greater than 1.5 mg l$^{-1}$ is likely to be toxic to the microbial consortium in the digester.

• Food waste is likely to have sufficient Al, B, Cu, Fe, Mn, and Zn. We are still not sure about Ni, Mo and W.
Conclusions (Digester operation)

• Following proper trace element supplementation strategy, food waste digesters can be operated stably with low VFA concentrations at an organic loading rate of 5 kg VS m\(^{-3}\) d\(^{-1}\) with a volumetric biogas production of 3.8 STP m\(^3\) m\(^{-3}\) d\(^{-1}\) and specific biogas production of 0.76 STP m\(^3\) kg\(^{-1}\) VS.

• Prevention of VFA accumulation in the digester by trace element supplementation is necessary, as recovery of a severely VFA-laden digester is not a rapid process even when supplements are added.
Commercial scale
Thanks to DEFRA WR1208

Dr Yue Zhang, Biogen-Greenfinch

...and to EU FP7 VALORGAS for continuing support to take this work forward