Lab scale studies to troubleshoot instability issues in food waste digesters

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Source-segregated food waste from household

- Uncooked fruit and veg: 60%
- Cooked fruit and veg: 7%
- Teabags: 10%
- Bread: 7%
- Eggs: 1%
- Cheese: 1%
- Paper: 1%
- Cooked meat: 12%
- Uncooked meat: 1%

Biffaward
Investing in the environment

Defra
Department for Environment, Food and Rural Affairs

ValorGas
Digesters used in the Burford study
Volatile fatty acid (VFA) concentrations

Mesophilic digester

Thermophilic digester
Ludlow demonstration plant
Volatile fatty acid (VFA) concentrations

- Acetic acid peak
- Accumulation of propionate acid
Biogas production

![Biogas Production Graph]

- **Weekly gas production m³**
  - **biogas**
  - **CH4**
  - **CO2**

**Day**

**Biogas production**
Collected food waste
Laboratory digesters

CSTR-type digesters:
2-litre
5-litre
40-litre
100-litre
Long chain fatty acids (LCFA) accumulation

X-ray diffraction analysis

Melon seeds
Instability

- **Negative response**
  - accumulation of long chain and volatile fatty acids

- **Loading limit**
  - less than 2 kg VS m$^3$ day$^{-1}$

**Sub-healthy**
Anaerobic conversion of biosolids to methane

Biosolids (Carbohydrates, Proteins, Lipids, fibres) → Hydrolysis → Sugars, Amino acids, Long chain fatty acids → Acidogenesis → Volatile fatty acids (VFA) with C>2 Propionate, Butyrate, Valerate → Acetogenesis → Acetate → Acetotrophic Methanogenesis (70%) → CH₄, CO₂ → Acetotrophic Hydrogenotrophic Methanogens (30%) → H₂, CO₂, formate → Hydrolytic-fermentative bacteria

Syntrophic oxidising bacteria → Methanogens
Possible reasons

- **Ammonia toxicity**: 5000~7000 mg N l⁻¹
- **Trace elements deficiency**: Co, Ni, Fe, Se, Mo, W, Zn, Cu, Mn, Al, B

![Corrinoid](image1.png)

![Cofactor F430](image2.png)
### Batch experiments - fractional factorial design

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<th>Run</th>
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<th>Ni</th>
<th>Mo</th>
<th>Se</th>
<th>Fe</th>
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<td>Cu</td>
<td>Mn</td>
<td>Al</td>
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</table>
VFA degradation profiles

- **Control**
- **Se, Mo**
- **Fe, Ni**
- **Se, Mo, Co, W, Fe, Ni, Zn, Cu, Mn, Al, B**
- **Se, Mo, Co, W**
- **Co, W**

Each graph shows the degradation of VFA (volatile fatty acids) over time (days), with different elements affecting the degradation rates.
Digester trials
Organic loading rate (OLR)

Supplementation with Se, Co, Ni from day 427

Se, Mo, Co, W, Fe and Ni supplement stopped in that pair with OLR of 3 kg VS m⁻³ d⁻¹ from day 112
Volatile fatty acids (VFA) profiles

No trace element addition

Se accidentally added

TE supplementation stopped in Se, Mo, Co, W, Fe and Ni

Double Se supplementation concentration

Started supplementation with Se, Co and Ni

Started supplementation with Co as well. Returned the Se supplementation strength to original concentration

Volatile fatty acids (VFA) profiles
Co and Se dilute-out curves – VFA profile

Se: 0.16 mg l\(^{-1}\) = 0.16 g m\(^{-3}\) = 10\(^{21}\) Se m\(^{-3}\)

Microorganisms: 10\(^{16}\) m\(^{-3}\)
## TE required vs TE in the UK food waste

<table>
<thead>
<tr>
<th>Minimum requirement at a moderate loading rate</th>
<th>Hackney, London</th>
<th>Eastleigh, Hampshire</th>
<th>Luton, South Bedfordshire</th>
<th>Ludlow, Shropshire</th>
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<tbody>
<tr>
<td>Cobalt (Co)</td>
<td>0.22</td>
<td>0.09 ± 0.05</td>
<td>0.02 ± 0.01</td>
<td>0.02 ± 0.00</td>
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<tr>
<td>Selenium (Se)</td>
<td>0.16</td>
<td>0.10 ± 0.08</td>
<td>0.03 ± 0.00</td>
<td>0.28 ± 0.14</td>
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<tr>
<td>Total Kjeldahl Nitrogen (TKN)</td>
<td></td>
<td>8100</td>
<td>7500</td>
<td>7400</td>
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</table>

Unit: mg kg\(^{-1}\) fresh matter
Digestion efficiency

Specific biogas production (SBP)

Volumetric biogas production (VBP)
Total ammoniacal nitrogen (TAN)

![Graph showing TAN (mg NH₃-N l⁻¹) over time (days) for different treatments and control. The y-axis represents TAN levels ranging from 0 to 7000, while the x-axis represents time in days ranging from 0 to 600. The graph compares Control OLR=2, Control OLR=3, Se, Mo, Se, Mo, Co, W, Se, Mo, Co, W, Fe, Ni, and Se, Mo, Co, W, Fe, Ni, Zn, Cu, Mn, Al, B, with each treatment line marked differently. The graph highlights biological fixed nitrogen changes over time.]
# Classification of Methanogen

<table>
<thead>
<tr>
<th>Methanogen</th>
<th>Carbon source</th>
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<tbody>
<tr>
<td>Methanobacteriales</td>
<td>CO$_2$ / formate</td>
</tr>
<tr>
<td>Methanococcales</td>
<td>CO$_2$ / formate</td>
</tr>
<tr>
<td>Methanomicrobiales</td>
<td>CO$_2$ / formate</td>
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<td><strong>Methanosarcinales</strong></td>
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<tr>
<td>Methanosarcinaceae</td>
<td>CO$_2$</td>
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<td></td>
<td>Acetate</td>
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<tr>
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<tr>
<td>Methanosaetaceae</td>
<td>Acetate</td>
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</table>
Density gradient centrifugation – SEM images

Separated microbial biomass

Food waste residues
Fluorescence in-situ hybridisation (FISH)

<table>
<thead>
<tr>
<th>Probe name</th>
<th>Target group</th>
<th>Fluorochrome</th>
<th>Formamide (%)</th>
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<tr>
<td>EUB338</td>
<td><em>Bacteria (most)</em></td>
<td>Cy5</td>
<td>20–50</td>
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<td>EUB338+</td>
<td><em>Bacteria (remaining)</em></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><em>Methanococcales</em></td>
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</table>

Inoculum - *Methanosphaerae*
Fluorescence in-situ hybridisation (FISH)

After 3 months - *Methanosarcinaceae*

After 1.5 years - *Methanomicrobiales*

After 3 years?
FISH images on another digestate sample

Inoculum

Vegetable waste digestate
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
Application of research finding
Acknowledgements

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