Cambi Thermal Hydrolysis
Theory, market and the future

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Background and theory of thermal hydrolysis
Pressure Cooking

- Approx 330 °F
- 94 psi
- 20 – 30 minutes

Pressure Cooking of Sludge

- Primary WAS
- Thickening
- Anaerobic Digestion
- Dewatering
- Class B Cake
- Liquors
Standard thermal hydrolysis

- Primary WAS
- Dewatering
- Thermal Hydrolysis
- Anaerobic Digestion
- Dewatering
- Class A Cake
- Biogas
- Liquors
- NH₃ Liquors

Rheology is fundamentally changed by processing with heat.
Rheology change is temperature dependent

The original use of thermal hydrolysis


The potential advantages of a mechanical sludge dewatering process over atmospheric drying include an undependence on uncontrollable climatic conditions, ability to maintain sludge disposal to regular schedule in all seasons of the year, and small land area requirements.

Conditioning of sludge, prior to filtration, has usually been used. This paper describes the operation of a plant at Halifax, England, which, over a 10-year period, has conditioned sludge, by heating the sludge mixture with live steam, to temperatures from 290° to 370° F. for 0.5 hr.

The process has involved the use of live steam in pressure vessels. Heat exchange apparatus is incorporated.

<table>
<thead>
<tr>
<th>Conditioning Agent</th>
<th>Primary Sludge</th>
<th>Sec. Sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>Aluminum sulfate</td>
<td>200</td>
<td>10</td>
</tr>
<tr>
<td>Ferric sulfate</td>
<td>300</td>
<td>15</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>400</td>
<td>20</td>
</tr>
<tr>
<td>Lime</td>
<td>1,000</td>
<td>80</td>
</tr>
<tr>
<td>Heat treatment</td>
<td>6,000</td>
<td>1,000</td>
</tr>
</tbody>
</table>

1 Mixed humus and activated sludge.
2 At optimum H value.
3 At optimum dosage.
4 1 hr. at 300°F.

The average moisture content of the raw sludge is 95.1 per cent, of the thickened sludge after heat treatment and decantation, 89.9 per cent, and of the cake from the filters, 48.0 per cent.
Heating sewage sludge

- Initial solubilisation of material in bulk phase
- Release of polysaccharides from loosely bound extra-cellular polymers (ECP)
- Destruction of tightly bound ECP further releasing polysaccharides
- Degradation of cell walls causing a collapse of cell turgor pressure causing cell rupture releasing intracellular proteins and cell wall debris
- Polysaccharides interact with each other and also the newly released proteins to make higher molecular weight Maillard and Andoni products which are non-biodegradable

Increasing reaction temperature

- Improving dewaterability
- Improving biogas production
- Destroys extracellular polymers
- Destroys Gordonia-like and similar organisms
- Sterilises sludge
- Decreases Particle size
- Increases solubility
- Decreases Viscosity
- Allows higher loading rates → reduces digestion size
- Improves dewatering
- Improves digestion
- Destroys foam and minimizes foam potential
- Meets advanced levels of treatment

What it does
Biogas Production Increase

- Pre-treatment technology does not increase the biogas yield
  - This is fixed by stoichiometry
- However, thermal hydrolysis increases biogas rate
  - Better suited to lower retention times
    - 20 day HRT (approx. 25% increased biogas dependent on sludge type)
    - MAD after thermal hydrolysis is actually better suited at lower HRT
  - 90%+ of 20 day biogas yield within 10 days HRT
  - Is a further 10 days HRT worth the extra 5 – 10% biogas?
  - Text books do not account for TH

Typical energy generation from sludge digestion*

- MAD = 514 kWhr e/TDS digested
- Acid phase = 670 kWhr e/TDS digested
- Thermal hydrolysis = 980 kWhr e/TDS digested

* From DECC document

Typical Mass Balance

- Sludge composition of 60:40; primary:WAS; 10,000 metric tonne DS
- 10,000 metric tonnes DS
- Sludge composition of 60:40; primary:WAS
- Processing all primary and WAS
- IC Engine

**Typical Energy Balance**

- 0 kW Excess high grade heat
- 776 kW High Grade Heat
- 498 kW Low Grade Heat
- 108 kW Electricity Generation
- 57 kW Condensation Losses

**Influence on thermal systems**

- **No digestion**
  - Less cake to dry
  - 25% less energy required than raw

- **MAD**
  - Even less cake to dry
  - Which also has less water in it per unit volume
  - 60%+ less energy required than raw
  - 50% less energy required than digested

- **TH + MAD**
  - Evaporated Water: 2.107 tonnes
  - Water: 0.111 tonnes
  - Sludge Solids: 0.663 tonnes
  - Energy Required: 184.266 kWh
  - Latent Heat: 1325.385 kWh

- **Evaporated Water: 2.107 tonnes**
  - Water: 0.15 tonnes
  - Sludge Solids: 1 tonne
  - Energy Required: 249.375 kWh
  - Latent Heat: 1792.729 kWh

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Thermal hydrolysis of sewage sludge has been found to provide greatest carbon footprint savings regardless of endpoint of sludge:

- Increased production of renewable energy
- Better volatile solids destruction resulting in less biosolids downstream for transport and further processing
- Better dewatering which further reduces biosolids for downstream processing. Also significant reduction in fossil fuel requirements for downstream drying
- Higher dewaterability increases energy content in cake which provides greater energy recovery benefit in downstream incineration, whilst improved volatile solids destruction reduces the quantity of material which needs to be incinerated
- Higher grade of biosolids means more landbank is opened up which reduces transport of biosolids
- Higher loading rates in digestion so less material used in construction which reduces embodied carbon impact

Example: 100 t DS/d

Smallest Contributions to carbon impact

Greatest benefits to carbon impact
Cambi thermal hydrolysis and carbon footprint
Example: 100 t DS/d

CambiTHP™
THE ENERGY EFFICIENT AND RELIABLE STEAM EXPLOSION PROCESS SINCE 1996

215 °F 330 °F 206 °F
**Cambi Plant Sizes**

<table>
<thead>
<tr>
<th>B – 2 (2 m³ reactor)</th>
<th>B – 6 (6 m³ reactor)</th>
<th>B – 12 (12 m³ reactor)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>Small size projects</td>
<td>Medium-large size projects</td>
<td>Extra large size projects</td>
</tr>
<tr>
<td>- Standardised package unit</td>
<td>- Standardised package unit</td>
<td>- custom-made</td>
</tr>
<tr>
<td>- pre-assembled &amp; pre-tested</td>
<td>- Pre-assembled skids</td>
<td>- on-site construction</td>
</tr>
<tr>
<td>- containerized unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 – 20 tDS/day</td>
<td>20 – 80 tDS/day</td>
<td>60 – 500 tDS/day</td>
</tr>
</tbody>
</table>

**Thermal Hydrolysis Market**

- Cambi - recycling energy
CAMBI experience

- Since 1995 Cambi have built 40 plants and have 16 plants under construction, in 21 countries
- Total capacity to treat sludge and food waste from >53 mill. people, 1.55 million tons DS/year

- Multiple repeat customers

- 2 plants owned and operated by Veolia Water
  - Bruxelles Nord
  - Seafield Edinburgh


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Thermal Hydrolysis Market

By plant number

By capacity

- Cambi 71%
- Other 1%
- Other 3%
- Other 6%
- Other 9%
- Other 3%
- Other 0%
- Other 1%
- Other 5%
- Cambi 87%
CAMBI SERVES A POPULATION OF MORE THAN 50 MILLION PEOPLE WORLD WIDE

SEOUL – DUBLIN – OSLO – BRUSSELS – ATHENS
SANTIAGO DE CHILE – EDINBURGH – CARDIFF – AND 20+ OTHER CITIES

* = operating, ** = operating & expanded, (*) = closed down (pilot/commissioned), **) = uncertain operating status. All other under design/construction
Cambi THP® IN UK

- UK Water Industry has strict financial regulator - OFWAT
- Privatised companies on stock exchange
- United Utilities (last year $1000M spent in infrastructure)
- Revenue $2200M, of which $755M profit
- CambiTHP® treats >30% of UK's sewage sludge.
- Standard unit operation

Highest renewable energy producers in UK Water Industry

<table>
<thead>
<tr>
<th>Site</th>
<th>Pre-treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Davyhulme</td>
<td>Thermal Hydrolysis</td>
</tr>
<tr>
<td>2 Minworth</td>
<td>Thermal Hydrolysis*</td>
</tr>
<tr>
<td>3 Great Billing</td>
<td>EH</td>
</tr>
<tr>
<td>4 Mogden</td>
<td>None</td>
</tr>
<tr>
<td>5 Avonmouth</td>
<td>EH</td>
</tr>
<tr>
<td>6 Bran Sands</td>
<td>Thermal Hydrolysis</td>
</tr>
<tr>
<td>7 Cardiff East</td>
<td>Thermal Hydrolysis</td>
</tr>
<tr>
<td>8 Howdon</td>
<td>Thermal Hydrolysis</td>
</tr>
<tr>
<td>9 Longreach</td>
<td>Thermal Hydrolysis</td>
</tr>
<tr>
<td>10 Stoke Bardolph</td>
<td>Co-digestion</td>
</tr>
</tbody>
</table>

* Cambi recently awarded contract to upgrade from MAD to thermal hydrolysis
Blue Plains

- 280 – 300 tDS/d processed
- VS destruction 62 – 65%
- 9 MWe generation
- Cake dewatering on belt press 32% DS
- Poly consumption approx. 14 lbs/TDS
- Energy for thermal hydrolysis met by co-gen plant
- Ongoing work to make biosolids products

Further processing

- Biosolids exceeds composting requirements for all parameters except dry solids
- Better product qualities when compared with composted biosolids

Davyhulme – United Utilities

Key performance parameters from a years operation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Target</th>
<th>Measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickening Polymer usage</td>
<td>kg/tds</td>
<td>&lt;10.0</td>
<td>5.96</td>
</tr>
<tr>
<td>Dewatering polymer usage</td>
<td>kg/tds</td>
<td>&lt;10.0</td>
<td>8.07</td>
</tr>
<tr>
<td>Throughput</td>
<td>tds/day</td>
<td>275</td>
<td>225</td>
</tr>
<tr>
<td>Specific power consumption</td>
<td>kWh/tds</td>
<td>197</td>
<td>152</td>
</tr>
<tr>
<td>Renewable energy performance</td>
<td>kWh/tds</td>
<td>800</td>
<td>Up to 920</td>
</tr>
<tr>
<td>Cake dry solids</td>
<td>% DS</td>
<td>&gt;28.5</td>
<td>31.3</td>
</tr>
<tr>
<td>Specific methane production</td>
<td>Nm³/tds</td>
<td>&gt;257</td>
<td>259</td>
</tr>
<tr>
<td>Specific biogas production</td>
<td>Nm³/tds</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Sludge status</td>
<td>Product status</td>
<td>Pass/Fail</td>
<td>Enhanced</td>
</tr>
<tr>
<td>Biogas utilisation to boilers</td>
<td>%</td>
<td>8</td>
<td>4.1</td>
</tr>
<tr>
<td>Volatile solids destruction rate</td>
<td>%</td>
<td>60</td>
<td>58 – 64</td>
</tr>
<tr>
<td>CHP Biogas use</td>
<td>%</td>
<td>91.2</td>
<td>94.3</td>
</tr>
</tbody>
</table>

We have seen good gas utilisation reducing the gas used as fuel in the boilers below 4% (target 8%) initially 12%

Energy generation per tds treated sludge has outperformed expectations peaking at 920KWh/tds

Energy neutral – UU are approximately 96% energy self sufficient at times neutral. We also power UU’s data centre and site vehicles

Highest producer of renewable energy from sludge in UK

9 – 10 MWe generated
Future Developments

Standard thermal hydrolysis

- Primary
- WAS
- Dewatering
- Thermal Hydrolysis
- Anaerobic Digestion
- Biogas
- Liquors
- NH₃ Liquors
- Dewatering
- Class A Cake
WAS only thermal hydrolysis

- Lower capex and steam consumption than full Cambi
- Contributes to digester heating/less cooling required
- Integrates will with CHP to make system run completely on waste heat
- Where there is no need for Class A biosolids:
  - Upgrade digester VS loading by about 30% and avoids digester construction
- 80% of the dewatering benefit for 50% capex
Typical Energy Balance – full THP

- 10,000 metric tonnes DS
- Sludge composition of 60:40; primary:WAS
- Processing all primary and WAS
- IC Engine

Typical Energy Balance – WAS only THP

- 10,000 metric tonnes DS
- Sludge composition of 60:40; primary:WAS
- Processing all primary and WAS
- IC Engine
**Intermittent Thermal Hydrolysis (ITHP)**

- **Primary**
- **WAS**
- **Dewatering**
- **Anaerobic Digestion**
- **Thermal Hydrolysis**
- **Anaerobic Digestion**
- **Biogas**
- **Class A Cake**
- **Liquors**
- **NH₃ Liquors**

### Second Generation THP - Summary of performance by Thames Water

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Conv AD</th>
<th>THP</th>
<th>WAS only THP</th>
<th>I-THP</th>
</tr>
</thead>
<tbody>
<tr>
<td>VSR</td>
<td>%</td>
<td>44%</td>
<td>59%</td>
<td>55%</td>
<td>65%</td>
</tr>
<tr>
<td>Gas Yield</td>
<td>scf/TDS</td>
<td>13183</td>
<td>17656</td>
<td>16372</td>
<td>19561</td>
</tr>
<tr>
<td>Gas yield</td>
<td>MMBTU/TDS</td>
<td>7.37</td>
<td>9.89</td>
<td>9.18</td>
<td>10.95</td>
</tr>
<tr>
<td>Elec Efficiency (gross)</td>
<td>%</td>
<td>15.30%</td>
<td>20.60%</td>
<td>19.10%</td>
<td>22.80%</td>
</tr>
<tr>
<td>Elec Efficiency (net)</td>
<td>%</td>
<td>12.30%</td>
<td>14.40%</td>
<td>12.90%</td>
<td>16.60%</td>
</tr>
<tr>
<td>Electrical Output</td>
<td>MWhr/TDS</td>
<td>0.72</td>
<td>0.97</td>
<td>0.90</td>
<td>1.07</td>
</tr>
<tr>
<td>Support Fuel</td>
<td>MWhr/TDS</td>
<td>-</td>
<td>0.28</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Digester volume</td>
<td>gallons</td>
<td>12,236,400</td>
<td>3,775,200</td>
<td>6,930,000</td>
<td>7,656,000</td>
</tr>
<tr>
<td>THP Size</td>
<td>%</td>
<td>-</td>
<td>100%</td>
<td>40%</td>
<td>60%</td>
</tr>
<tr>
<td>Dewaterability (min/max)</td>
<td>%DS</td>
<td>21 \ 30</td>
<td>32 \ 45</td>
<td>28 \ 35</td>
<td>34 \ 48</td>
</tr>
</tbody>
</table>

**Basis:**
- 100 tDS.d
- Primary: 60%
- WAS: 40%
SolidStream – Process description

- Dewatered, digested sludge is fed to SolidStream process at 16% DS
- Sludge is treated at high Temp & Pressure in **pumpless process**
- Hydrolysed sludge is dewatered at elevated temperature
  (220 °F; drops to 185>°F with polymer)
- Dry sludge cake is cooled with air
- Cooling air is scrubbed to remove odor components
- Dewatering centrate & process gas are returned for biogas production
- **No cooler required**, Hot centrate heats up input sludge to digester temperature
- Can dewater to 35% DS **with no polymer**
- Plant is approximately **40% smaller compared to standard thermal hydrolysis**
AmperVerband

- 5100 t US/DS; 83% VS
  - 14 tDS.d
- 62% primary, 38% WAS
- MAD 22 day HRT
- 50% VSR
- 20 – 23% DS cake
- 14,330 wet ton/year
Demonstration plant in AmperVerband

Base Case, conventional

- 5100 t US DS/yr
- 83% VS
- 62% Primary
- 38% Secondary
- To WWTP inlet
- VSR = 50%
- 20 - 23% DS
- 14 330 t/yr Cake
Demonstration plant in AmperVerband

SolidStream case, actual numbers 2016

- 5100 t USDS/yr
- 83% VS
- 62% Primary
- 38% Secondary
- +61% Biogas
- COD rich centrate
- 70% reduced wet ton cake
- 61% increased biogas
- High quality cake
- Input Dry tons x 0.9
  Output = Wet tons

Biosolids cake

Different to thermally hydrolyzed biosolids

- No odor
- Very crumbly – falls apart on squeezing
- Further drying in storage
Conclusions

- Thermal hydrolysis is a mature process
  - Standard technology – business as usual
  - Multiple suppliers
- Cambi processes over 30% of the UK sludge market – driver is financial
- Main market for TH is to process all sludge prior to digestion however other applications are gaining traction
  - Partial THP and intermittent to reduce steam demand
- SolidStream, 40+% DS cake, 75% VSR
  - Option for existing digestion plants which have sufficient digestion capacity rather than need to increase capacity or reduce digestion requirement
  - Ongoing research with different materials and configurations
Thank you: bill.barber@cambi.com