Energy Recovery from Brewery Waste by Utilizing Anaerobic Digestion of Brewery Spent Grain in a Two Stage Reactor System

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The Brewery Project

• SLO brewing industry - 2 breweries, each approx. 100,000,000 L of brew annually.

• The goal in 2006: achieving and surpassing 20% renewable by 2015, several directions:
  • Solar photovoltaic, solar thermal,
  • Biogas from waste.

  • Economic sustainability!
  • 10 years of research
The Starting Conditions

• Efficient treatment of brewery wastewater since 2006 (approx. 400,000 m³ annually).
  • Usual No. 10-20 % recovery from wastewater.

• Available waste for biogas production:
  • Waste yeast (quantity approx 3000 t (m³) annually), resolved since 2012, additional 6 % recovery
  • Spent brewery grain (quantity 17,000 t annually), concept confirmed in 2015, potential recovery additional 50 %

• Conventional management:
  • Yeast: drying and sold as a food supplement 1¢/L
  • Spent brewery grain: livestock feed 13 €/ton
BSG Biogas Potential

- Brewery Spent Grains → \(120-130\ \text{m}^3/\text{ton}\)
Conventional treatment 2007

• Conventional anaerobic digestion:
  • Mixture yeast-grain in according ratio as well as separate,
  • COD approx 300,000 mg/kg,
  • Total N approx 12,000 mg/kg, C-N = 3.

• Low OLR (max 2.0 kg/m³/day), HRT 30 days

• After 30 days of digestion – ammonia inhibition
Lubljana, 12. 9. 2016.
Workshop on "Bio-energy and by-product recovery in integrated water and biosolids management"
Adaptation of digestion 2008-2011

- Separate study of yeast and spent grain
- Spent grain - dilution of mixture 1:2 with brewery wastewater
- Pretreatment - hydrolisys of spent grain.
- Mechanical:
  - Griding with ultraturrax @ 12,000 RPM.
- Thermal – Chemical:
  - Using acid or alkaline with temperature to degrade ligno-cellulosic compounds.
- Inhibition with intermediate degradation phenolic compounds
Pre-treatment data

- $160^\circ C \rightarrow 2 \text{ h}$
- $140^\circ C \rightarrow 2 \text{ h}$
- $120^\circ C \rightarrow 3 \text{ h}$
- $95^\circ C \rightarrow 4 \text{ h}$
- $70^\circ C \rightarrow 48 \text{ h}$
Experimental Setup
Results

Conventional digestion - conclusions

- Conventional digestion does not achieve desired goals.
- Ammonia problem → resolved
- Phenolic degradation products → inhibition at day 100-120 (200 mg/L)
- New solutions needed → using available infrastructure & appropriate pretreatment of available substrates
Spent grain treatment 2010 - 2011

• Hydrolysis with acid and temperature:
• Mixture of spent grain & wastewater 1:2
• pH=2, tCOD ≈100,000 mg/kg
• After treatment separation solid – liquid on 0.25 mm filter, liquid COD ≈ 70,000 mg/kg
• Liquid neutralized, mixed with wastewater and treated in UASB reactor
• Efficiency of liquid COD extraction ≈ 55 %
• Ligno-cellulosic biomass degradation ≈90%
Treatment in UASB

• Idea: phenolic compounds degraded with granular biomass (Chen et al., 2008; Levén and Schnürer, 2012) in concentrations of 1 g/L

• Inclusion of existing reactor for WWTP and yeast treatment.

• Wastewater, yeast and liquid phase of spent grain.

• Slow adaptation over 3 months, increasing the percentage of spent grain liquid to maximum which is approx. 10% at constant COD loading rate.

• Problems: increasing solids content in treated wastewater ≈ 7 g/L, which are degraded only at lower loading rates.
UASB Results

- Solids degradation at OLR less than 6
- Partial degradation between 6 and 10
- Solids flush out between 10 and 15
- Process failure at more than 16
Workshop on "Bio-energy and by-product recovery in integrated water and biosolids management"

Lubljana, 12. 9. 2016.
Digestion setup using infrastructure 2012-2014

SS-AD - Solid State Anaerobic Digestion
Experimental setup SS-AD
### Results

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Residence – cycle time (day)</th>
<th>Biodegradability (% TS)</th>
<th>Biogas production (m³/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle 1</td>
<td>30</td>
<td>77.7</td>
<td>91.9</td>
</tr>
<tr>
<td>Cycle 2</td>
<td>37</td>
<td>73.6</td>
<td>103</td>
</tr>
<tr>
<td>Cycle 3</td>
<td>31</td>
<td>76.3</td>
<td>93.2</td>
</tr>
<tr>
<td>Cycle 4</td>
<td>43</td>
<td>76.5</td>
<td>107</td>
</tr>
<tr>
<td>Cycle 5</td>
<td>26</td>
<td>80.4</td>
<td>102</td>
</tr>
<tr>
<td>Cycle 6</td>
<td>29</td>
<td>75.0</td>
<td>90.4</td>
</tr>
<tr>
<td>Median</td>
<td>30.6</td>
<td>76.6</td>
<td>98.0</td>
</tr>
</tbody>
</table>

- Operated for 6 cycles, average cycle finished in approx. 30 days
- Up to 80 % degradation
- Up to 60 m³ of methane per tonne
- Very good synergy in two stage system

- Problems @ day 100-110 increase in p-cresol concentration (45 mg/L)
- Still too slow, @ 30 days cycle reactors too large, biogas productivity @ 60 % conventional

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Enhanced SS-AD 2014 - 2015

Reduction of residence time 30 → 18 days
Enhanced biodegradability → over 90 %
Almost biogas potential → up to 119,8 m³/kg biogas
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<th>Biodegradability (% TS)</th>
<th>Biogas production (m³/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22</td>
<td>88,9</td>
<td>108,0</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>88,6</td>
<td>97,00</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>92,2</td>
<td>113,4</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>90,0</td>
<td>98,17</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>89,5</td>
<td>105,1</td>
</tr>
<tr>
<td>6</td>
<td>18</td>
<td>91,4</td>
<td>108,1</td>
</tr>
<tr>
<td>7</td>
<td>21</td>
<td>95,0</td>
<td>119,1</td>
</tr>
<tr>
<td>8</td>
<td>28</td>
<td>90,8</td>
<td>109,2</td>
</tr>
<tr>
<td>9</td>
<td>28</td>
<td>93,1</td>
<td>115,2</td>
</tr>
<tr>
<td>10</td>
<td>17</td>
<td>87,4</td>
<td>119,2</td>
</tr>
<tr>
<td>11</td>
<td>18</td>
<td>90,3</td>
<td>111,2</td>
</tr>
<tr>
<td>12</td>
<td>24</td>
<td>90,0</td>
<td>119,8</td>
</tr>
<tr>
<td>13</td>
<td>42</td>
<td>95,7</td>
<td>116,8</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td><strong>18,1</strong></td>
<td><strong>91,0</strong></td>
<td><strong>110,8</strong></td>
</tr>
</tbody>
</table>
Pilot Plant – BSG Digestion
IMPACT - BSG digestion

- Average substitite ratio close to 70%
- In brewery full operation summer months substitute over 90%
- To achieve total renewable optimization of brewing process neccessary
IMPACT - BSG digestion

• Current value BSG 13 €/tonne
• Gross value of BSG as renewable fuel 36 €/tonne (@ total natural gas price of 0,4 €/m³)
• Net value in range 22 – 24 €/tonne (with investment & operation estimation)
  • Additional considerations – digestion residues!
• Necessary integration in wastewater treatment and brewing process (chemicals such as NaOH and HCl already present);
• Production – demand; Parasitic heat losses
• Heavily dependent on natural gas price
## BSG AD Residue

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>SS-AD</th>
<th>Enhanced SS-AD</th>
<th>MDK (according to NN 09/14)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total chromium</strong></td>
<td>mg kg⁻¹ TS</td>
<td>12,7</td>
<td>5,15</td>
<td>40 - 80</td>
</tr>
<tr>
<td><strong>Copper</strong></td>
<td>mg kg⁻¹ TS</td>
<td>54,8</td>
<td>14,4</td>
<td>60 - 90</td>
</tr>
<tr>
<td><strong>Zinc</strong></td>
<td>mg kg⁻¹ TS</td>
<td>70</td>
<td>130</td>
<td>60 - 150</td>
</tr>
<tr>
<td><strong>Nickel</strong></td>
<td>mg kg⁻¹ TS</td>
<td>33,8</td>
<td>2,6</td>
<td>30 - 50</td>
</tr>
<tr>
<td><strong>Lead</strong></td>
<td>mg kg⁻¹ TS</td>
<td>3,67</td>
<td>0,59</td>
<td>50 - 100</td>
</tr>
<tr>
<td><strong>Cadmium</strong></td>
<td>mg kg⁻¹ TS</td>
<td>0,217</td>
<td>&lt; 0,1</td>
<td>0,5 - 1,0</td>
</tr>
<tr>
<td><strong>Mercury</strong></td>
<td>mg kg⁻¹ sTS</td>
<td>0,062</td>
<td>&lt; 0,05</td>
<td>0,5 - 1,0</td>
</tr>
</tbody>
</table>

### Parameter Table

<table>
<thead>
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<th>SS-AD</th>
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</thead>
<tbody>
<tr>
<td><strong>HCH</strong></td>
<td>mg kg⁻¹ TS</td>
<td>&lt; 0,05</td>
<td>&lt; 0,05</td>
<td>0,1</td>
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<tr>
<td><strong>HCB</strong></td>
<td>mg kg⁻¹ TS</td>
<td>&lt; 0,05</td>
<td>&lt; 0,05</td>
<td>0,1</td>
</tr>
<tr>
<td><strong>Lindan</strong></td>
<td>mg kg⁻¹ TS</td>
<td>&lt; 0,1</td>
<td>&lt; 0,1</td>
<td></td>
</tr>
<tr>
<td><strong>Heptaklor</strong></td>
<td>mg kg⁻¹ TS</td>
<td>&lt; 0,05</td>
<td>&lt; 0,05</td>
<td>0,1</td>
</tr>
<tr>
<td><strong>Aldrini</strong></td>
<td>mg kg⁻¹ TS</td>
<td>&lt; 0,05</td>
<td>&lt; 0,05</td>
<td>0,1</td>
</tr>
<tr>
<td><strong>Endrine</strong></td>
<td>mg kg⁻¹ TS</td>
<td>&lt; 0,05</td>
<td>&lt; 0,05</td>
<td>0,1</td>
</tr>
<tr>
<td><strong>DDT i derivati</strong></td>
<td>mg kg⁻¹ sTS</td>
<td>&lt; 0,5</td>
<td>&lt; 0,5</td>
<td>0,1</td>
</tr>
<tr>
<td>2,4,4'– triklorbifenil</td>
<td>mg kg⁻¹ TS</td>
<td>&lt; 0,2</td>
<td>&lt; 0,2</td>
<td>0,2</td>
</tr>
<tr>
<td>2,2',5,5'– tetraklorbifenil</td>
<td>mg kg⁻¹ TS</td>
<td>&lt; 0,2</td>
<td>&lt; 0,2</td>
<td>0,2</td>
</tr>
<tr>
<td>2,2',4,5,5'– pentaklorbifenil</td>
<td>mg kg⁻¹ TS</td>
<td>&lt; 0,2</td>
<td>&lt; 0,2</td>
<td>0,2</td>
</tr>
<tr>
<td>2,2',3,4,5,5'– heksaklorbifenil</td>
<td>mg kg⁻¹ TS</td>
<td>&lt; 0,2</td>
<td>&lt; 0,2</td>
<td>0,2</td>
</tr>
</tbody>
</table>

**Note:** The values in the MDK column are based on the MDK (Ministry of the Environment) standards.
CONCLUSIONS

After long years of research......

• BSG digestion utilising SS-AD and GBR can be successful
  • Over 80 % degradation
  • Up to 90 m³ per tonne of methane produced
  • Concerns (heating demands; synchronization)

• Integrated into brewery system approx. 90 % of natural gas can be substituted

• Added value up to 0,5 euro cent per L of brew

• Although heavily dependent of natural gas price, it can be sustainable

• Self sustainable brewery – future goal
Thanx for attention!

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