“Design & Analysis of an Anaerobic Digester to Feed a Biogas Fuelled Boiler for a Medium Sized Industrial Enterprise”

Matthew Butcher
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Supervisors: Dr Yaodong Wang, Professor Tony Roskilly, Dr Barbara Sturm
Contents

• Introduction
• Objectives
• Literature Review
• Audit
• Digester System Design
• NNFCC
• Micro Analysis
• ECLIPSE
• Analysis
• Financial
• Conclusions
• Recommendations
Introduction

• The Brewery
• Reduce emissions, waste and expenditure
• Energy intensive process
  – Heat (Oil)
  – Cooling (Electrical)
  – Electricity
• By products not utilised
• Anaerobic digester
  – Use waste products
  – Biogas to fuel boiler
  – Maybe excess to sell or use elsewhere
• Explore the potential of on-site digester
Objectives

• Understanding and analysis of industrial brewing processes (With colleagues)
• Audit of current heating, cooling and electricity usage (With colleagues)
• Literature review of current anaerobic digester technology
• Design and analysis of an onsite anaerobic digester and storage system suitable for biogas production to fuel a boiler using NNFCC & ECLIPSE software
Literature Review

- Industrial brewing process
- Anaerobic digestion process and variables
- Technology and equipment
- Feedstock
- Anaerobic digestion products
- Biogas properties and uses
Production Process
Audit

• Investigate current usage
  – Heat
    • Heat water in hot liquor tank and heat wort in copper
    • Steam from Fulton 200 kW boiler
    • Required boiler rating
      – Based on firing rate - 198 kW (used for biogas requirement)
      – Based on 1568 L oil/month - 131 kW
      – Audit demand - 91 kW
    • Indicates ~ 70 % efficiency (91/130)
  – Cooling
    • Chill cold liquor tank, conditioning vessels, rooms
    • 23.7 kW installed rating
    • 7.6 kW theoretically required
    • 32 % of capacity theoretically used
    • Thermal losses
 Audit

- **Electricity**
  - Cooling equipment, pumps, motors, etc
  - Meter readings 242 kWh/day
  - 19.8 kW rating required
  - 0.2 % difference in meter and audit
  - 62 % of electricity used for cooling

- **Boiler Conversion**
  - 23 m$^3$ natural gas/hr
  - Biogas lower CV (1.9x lower)
  - 44.1 m$^3$ biogas/hr required
  - 220 m$^3$ biogas/day required
  - 57,304 m$^3$ biogas/yr
• Initial thought of slurry pit, but then separate digester
• Approx 1300 kg grain/day, 130 kg hops/day (1450 kg/day)
• 16 % volatile solids so 243 kg/day
• 220 m$^3$ biogas/day required
• 4.1 m$^3$/m$^3$ digester
• Therefore 54 m$^3$ digester required
• 7 m diameter, 1.5 m height
• 5.7 kg/m$^3$ digester feed rate
• More feed needed – slurry
• 600 kg/day ‘raw’ slurry needed
• Storage needed for weekend
Digester System Design

- Complete system
- 21 kWh/day lost through digester walls
NNFCC

- Biogas Calculator by National Non Food Crops Centre
- Max biogas production
- 5 scenarios explored
  - Actual capacity
  - Required feedstock
  - Extra brew
  - Over capacity (x2)
- CHP design
  - Need 498 m³ biogas

<table>
<thead>
<tr>
<th></th>
<th>Actual Cap</th>
<th>Required</th>
<th>1 Extra Brew</th>
<th>Over Cap 1</th>
<th>Over Cap 2</th>
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<tbody>
<tr>
<td>Dairy Cow Slurry (t/yr)</td>
<td>0</td>
<td>500</td>
<td>600</td>
<td>1900</td>
<td>4500</td>
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<tr>
<td>Brewers Waste (t/yr)</td>
<td>377.5</td>
<td>377.5</td>
<td>453</td>
<td>377.5</td>
<td>377.5</td>
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<tr>
<td>Total Biogas/yr (m³)</td>
<td>45,240</td>
<td>57,884</td>
<td>69,553</td>
<td>93,286</td>
<td>159,034</td>
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<tr>
<td>Biogas per Brewing Day (m³)</td>
<td>174</td>
<td>222.63</td>
<td>222.93</td>
<td>358.79</td>
<td>611.67</td>
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<tr>
<td>Biogas/t Feedstock (m³)</td>
<td>120</td>
<td>66</td>
<td>66</td>
<td>41</td>
<td>32.6</td>
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<tr>
<td>Max Retention Period (days)</td>
<td>88/176</td>
<td>37/75</td>
<td>31/63</td>
<td>14/29</td>
<td>14/27</td>
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<tr>
<td>Irregular Feed (%)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
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<tr>
<td>Min Digester Capacity (m³)</td>
<td>100/200</td>
<td>100/200</td>
<td>100/200</td>
<td>100/200</td>
<td>300/400</td>
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Micro Analysis

- Needed elemental analysis for ECLIPSE
- Samples taken, dried and crushed
- Run through analyser twice
- Get C, H, N and O

<table>
<thead>
<tr>
<th>Sample</th>
<th>Test</th>
<th>N (%)</th>
<th>C (%)</th>
<th>H (%)</th>
<th>O (%)</th>
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<tr>
<td>Hops</td>
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<td>5.41</td>
<td>47.25</td>
<td>7.48</td>
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<td>2</td>
<td>5.54</td>
<td>47.15</td>
<td>7.84</td>
<td>39.47</td>
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<tr>
<td><strong>AV</strong></td>
<td></td>
<td><strong>5.475</strong></td>
<td><strong>47.20</strong></td>
<td><strong>7.66</strong></td>
<td><strong>39.665</strong></td>
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<tr>
<td>Malted Barley</td>
<td>1</td>
<td>4.33</td>
<td>46.69</td>
<td>7.71</td>
<td>41.27</td>
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<tr>
<td></td>
<td>2</td>
<td>3.20</td>
<td>46.15</td>
<td>8.07</td>
<td>42.58</td>
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<td><strong>AV</strong></td>
<td></td>
<td><strong>3.765</strong></td>
<td><strong>46.42</strong></td>
<td><strong>7.89</strong></td>
<td><strong>41.925</strong></td>
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<tr>
<td>Dairy Cow Slurry</td>
<td>1</td>
<td>2.81</td>
<td>40.23</td>
<td>5.09</td>
<td>51.87</td>
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<tr>
<td></td>
<td>2</td>
<td>2.45</td>
<td>35.56</td>
<td>4.66</td>
<td>57.33</td>
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<td><strong>AV</strong></td>
<td></td>
<td><strong>2.63</strong></td>
<td><strong>37.895</strong></td>
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<td><strong>54.6</strong></td>
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ECLIPSE

- Used for two purposes
  - Explore biogas production (as with NNFCC)
  - Investigate heat transfer for production processes (x2)
- Elemental analysis results entered into compound database
- Three flow diagrams constructed
- Technical data entered
- Mass & energy balances completed
- Results gained
**ECLIPSE Results**

- 3 scenarios explored for comparison with NNFCC
  - Actual capacity
  - Required feedstock
  - Over production
- Base model heat transfer
- Biogas model heat transfer

### Scenario 1 Overall Gas Composition

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>39.93%</td>
</tr>
<tr>
<td>CH₄</td>
<td>56.01%</td>
</tr>
<tr>
<td>N₂</td>
<td>4.05%</td>
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<tr>
<td>O₂</td>
<td>0.01%</td>
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</table>

| Volume (m³) | 90.73 |

### Scenario 2 Overall Gas Composition

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>45.35%</td>
</tr>
<tr>
<td>CH₄</td>
<td>50.97%</td>
</tr>
<tr>
<td>N₂</td>
<td>3.66%</td>
</tr>
<tr>
<td>O₂</td>
<td>0.01%</td>
</tr>
</tbody>
</table>

| Volume (m³) | 220.48 |

### Scenario 3 Overall Gas Composition

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>45.35%</td>
</tr>
<tr>
<td>CH₄</td>
<td>50.98%</td>
</tr>
<tr>
<td>N₂</td>
<td>3.66%</td>
</tr>
<tr>
<td>O₂</td>
<td>0.01%</td>
</tr>
</tbody>
</table>

| Volume (m³) | 411.54 |

<table>
<thead>
<tr>
<th>Heat Exchanger</th>
<th>Heat Transfer (kW)</th>
<th>Audit Requirement (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss H</td>
<td>265</td>
<td></td>
</tr>
<tr>
<td>Exhaust H</td>
<td>50 (Copper) / 41 (HLT)</td>
<td></td>
</tr>
<tr>
<td>Boiler</td>
<td>205 (Copper) / 213 (HLT)</td>
<td>200</td>
</tr>
<tr>
<td>Copper</td>
<td>175</td>
<td>173</td>
</tr>
<tr>
<td>HLT</td>
<td>196</td>
<td>193</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heat Exchanger</th>
<th>Heat Transfer (kW)</th>
<th>Audit Requirement (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss H</td>
<td>263</td>
<td></td>
</tr>
<tr>
<td>Exhaust H</td>
<td>52 (Copper) / 51 (HLT)</td>
<td></td>
</tr>
<tr>
<td>Boiler</td>
<td>201 (Copper) / 200 (HLT)</td>
<td>200</td>
</tr>
<tr>
<td>Copper</td>
<td>174</td>
<td>173</td>
</tr>
<tr>
<td>HLT</td>
<td>193</td>
<td>193</td>
</tr>
</tbody>
</table>
Analysis – Production

- Both methods produce enough biogas
- NNFCC calculator higher estimation for all cases
  - 174 m³ compared to 91 m³
  - 500 T compared to 1820 T of extra slurry
  - 611 m³ compared to 411 m³ (67% of NNFCC)
- NNFCC uses fixed moisture content and ‘standard’ feedstock
- ECLIPSE takes these into account
- NNFCC represents absolute maximum
- ECLIPSE represents likely biogas production
Analysis – Transfer

• Both models satisfy the heat transfer requirements
• Base model
  – 265 kW from combustion
  – 50-60 kW lost as heat (mostly in exhaust)
  – Boiler efficiency 77-80 %
• Biogas model
  – 263 kW from combustion
  – Very similar losses as with base model
  – Overall efficiency around 76 %
• Large losses in exhaust as expected from visits and audit
Financial

- Initial capital cost likely to be £50,000-100,000
- Minimum RHI income of £6,697 per annum
- Saving in oil purchases of around £8,844 per annum
- Based on £100,000 capital cost, 6.5 year payback
- Then 3.5 further years of £6,697 income and lifetime of digester savings of £8,844 per annum
- Represents a good return on the initial investment
- Excess biogas could bring further income
Conclusions

• Audit
  – High use of thermal energy
  – Not used efficiently
  – Results in unnecessary cooling

• Digestion system capable of providing biogas requirements
  – Shown with basic calculations
  – Proven with two pieces of software
  – Both show an over-production

• Heat transfer required can be provided by new system
  – Proven with two ECLIPSE models
  – Minimal impact to boiler efficiency

• Financially viable, even attractive
• Lower fossil fuel use and reduce running costs
Recommendations

• Accurate fuel metering
  – Give more detail on ‘actual’ fuel use

• Detailed digester design and costing
  – Exact equipment required and costs

• Detailed financial outline
  – Look into total capital costs, payback periods, potential income

• Heat recovery from boiler
  – Heat exchanger on exhaust to pre-heat water in HLT
  – Increase overall system efficiency
Thank You For Listening
Any Questions?