Techno-economic analysis for bio-methane production from agriculture and food industry waste.

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Aims and objectives

✓ Analysis of bio-gas to bio-methane upgrading technologies.

✓ Process design of sorbent and solvent based gas separation units.

✓ Comparative techno-economic assessment of studied processes.
Anaerobic Digestion and potential uses of bio-gas and digestate
**Bio-gas composition, flow-rate and need of upgrading**

**CH₄ mole fraction larger than 95%** is required for bio-methane injection to the grid.

<table>
<thead>
<tr>
<th></th>
<th>Dairy cows</th>
<th>Waste per cow per day (kg/cow day)</th>
<th>kg VS/kg waste</th>
<th>Bio-gas (Nm³/kg VS)</th>
<th>Bio-gas (Nm³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₃</td>
<td>1.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂S</td>
<td>0.2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>40.9%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH₄</td>
<td>57.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bio-gas composition:
- NH₃: 1.5%
- H₂S: 0.2%
- CO₂: 40.9%
- CH₄: 57.4%

Bio-gas flow-rate and need of upgrading:
- CH₄ mole fraction larger than 95% is required for bio-methane injection to the grid.
**Bio-gas upgrading technologies**

**Separation processes**

- **Physically driven**
  - CO₂ is retained in the separation agent (adsorption, membranes).

- **Chemically driven**
  - CO₂ chemically reacts with the separation agent (absorption using amines).
Pressure swing adsorption cycles

In PSA processes, gas mixtures are separated by cyclic adsorption and desorption steps driven by cyclic pressure swings.

CO$_2$ is retained in the pores of the adsorbent during the adsorption step. Sorbent regeneration occurs during purge. Power consumption occurs for compression and vacuum.
Pressure swing adsorption: optimisation

Cycle configuration and operating conditions must be selected to reach the separation targets with the lowest energy consumption.

- Adsorption step time.
- Adsorption pressure.
- Purge pressure.
- Purge and feed ratio.

\[ CH_4_{\text{recovery}} = \frac{\int_0^{t_{\text{feed}}} c_{CH_4}(z = L) \, dt}{\int_0^{t_{\text{feed}}+t_{\text{press}}} c_{CH_4}(z = 0) \, dt} \]

\[ CH_4_{\text{purity}} = \frac{\int_0^{t_{\text{feed}}} c_{CH_4}(z = L) \, dt}{\int_0^{t_{\text{feed}}} c(z = L) \, dt} \]

\[ \text{power}_{\text{specific}} = \frac{\int_0^{t_{\text{feed}}+t_{\text{press}}} \text{power}_{\text{blower}} \, dt + \int_0^{t_{\text{blowdown}}+t_{\text{purge}}} \text{power}_{\text{vacuum pump}} \, dt}{\int_0^{t_{\text{feed}}} c_{CH_4}(z = L) \, dt} \]
Two stage PSA unit
## Column design and operating conditions

<table>
<thead>
<tr>
<th></th>
<th>First stage</th>
<th>Second stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_c ) (m)</td>
<td>3.0</td>
<td>2.6</td>
</tr>
<tr>
<td>( D_c ) (m)</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>( P_{ads} ) (bar)</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>( P_{vac} ) (bar)</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>P/F (%)</td>
<td>3.0</td>
<td>1.0</td>
</tr>
<tr>
<td>( t_{ads} = t_{purge} )</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>( t_{press} = t_{blow} )</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>
Amine based process (30% w/w MEA)

\[ \text{CO}_2 \text{ chemically reacts with the solvent in the absorber and the separation agent is thermally regenerated in the stripper.} \]
Solvent based units: optimisation

Key variables influence on the separation performance and the energy consumption for this kind of processes.

- Solvent (amine loading).
- Absorber pressure.
- Feed temperature.
- Stripper pressure.
- Amine degradation (max. temperature).
- Column length.
- Packing.

\[ CH_4 \text{ purity} \]

\[ CH_4 \text{ recovery} \]

\[ \text{Reboiler duty} \]

\[ \text{Power consumption in pumps} \]
# MEA based process

<table>
<thead>
<tr>
<th></th>
<th>Absorber</th>
<th>Stripper</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_c$ (m)</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>$D_c$ (m)</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Packing</td>
<td>Flexipac 250 Y</td>
<td>IMTP#40</td>
</tr>
<tr>
<td>$P_{abs}$ (bar)</td>
<td>1.3</td>
<td>$P_{stripper}$ (bar)</td>
</tr>
<tr>
<td>Inlet temperature (C)</td>
<td>44</td>
<td>Inlet temperature (C)</td>
</tr>
<tr>
<td>Blower power (kW)</td>
<td>0.6</td>
<td>Reboiler (kW)</td>
</tr>
<tr>
<td>Pump rich amine (kW)</td>
<td>0.005</td>
<td>Condenser (kW)</td>
</tr>
<tr>
<td>Heat rich and lean amine (kW)</td>
<td>13.6</td>
<td>Pump lean amine (kW)</td>
</tr>
</tbody>
</table>
Comparative technical and economic performance indicators

\[ NBM_{k g \, VS} = \frac{BMFR}{MSL \times \frac{VS \, (\%)}{100}} \]

NBM: Net bio-methane flow-rate per kg VS
BMFR: Bio-methane flow rate
MSL: Mass of slurry

\[ ALTCBM = \frac{\sum_n CIC + O&M}{(1 + r)^n} \times \frac{\sum_n BMFR}{(1 + r)^n} \]

ALTCBM: Average life-time cost of bio-methane
CIC: Capital investment cost
r: Discount rate
n: number of years
Energy for the separation unit is supplied using part of the bio-gas in the solvent based process whilst electricity from the grid is employed for the PVSA cycles. Exergy associated with the heat in the reboiler is twice the times the exergy related to electricity consumption in the PVSA cycles.
Economic analysis results
✓ Larger values for the capital investment cost for the solvent based units in addition to a lower bio-methane production output leads to larger values for the average life-time cost of bio-methane compared to the plant with PVSA cycles.

✓ Heat production in both plants enable a reduction of propane consumption leading to cost savings.

✓ Average cost of bio-methane for AD plants with PVSA cycles and MEA solvent based units are considerably lower than the revenues paid in the UK (3.89 p/kWh ).
Conclusions

✔ Bio-gas from anaerobic digestion of food and farm waste enables the production of heat, electricity and bio-methane.

✔ Bio-gas must be upgraded (acid gas removal) to be injected into the gas network as bio-methane. Both sorbent (PVSA cycles) and solvent based gas separation technologies (using aqueous solution of MEA 30% w/w) could be employed.

✔ PVSA cycles have lower capital investment and average bio-methane life cycle cost compared to the solvent based units.

✔ Considering currently paid feed in incentives in the UK, the deployment of bio-gas upgrading technologies in farms may make a good business proposition.
Thanks for your attention

Questions?