Straw Fermentation Technology Sharing

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SF-Soepenberg GmbH

- Produces more than 300,000 t/a fertilizers from waste
- Produces customized organic and mineral fertilizers
- Operates a waste water treatment facility with industrial biogas plant and nutrient recovery for more than 3,000 t Struvite (P) and K per year.
Nutrient Management Plans

required area (mu) for digestate from a biogas plant producing 10,000 m³ CH₄/d

Base of calculation: Demand of nutrients: 22.5 kg N/(mu a)**; 3.7 kg P/(mu a)**; 12.800 LU produce 1,400 kg DM/(LU a)*; 1 kg DM produces 12 m³ CH₄ ***; 1 LU= 500 kg, P-removal 80%, N removal 50%, (Data from Schuchard et al. 2012*, according to Roelcke 2016**, database Lfl***)
What is to share?

- The European biogas sector is only beginning to use pure straw as feedstock for biogas plants.
- So far straw has not played a role with the exception as cosubstrate in Farm Yard Manure and liquid animal manure.
Full Scale Pretreatment in China
Alkaline Pretreatment

- NaOH-pretreatment
- CSTR-technology
- Designed capacity: 10,000 m³ CH₄/d

http://yuanyibiogas.com/
Challenges for Straw

Challenges

• Technical
  – Harvesting
  – Pretreatment
  – Mixing in the fermenter

• Biological
  – Additional nutrients

• Financial
  – Price (60-120 €/t FM)

Advantages

• Additional energetic value from arable land in Germany:
  8-13.2 Mio t/a

• Energetic use via biogas is a low emission technology

http://www.proplanta.de/Markt-und-Preis/Agrarmarkt-Berichte/Aktuelle-Strohpreise-und-Heupreise-2016-KW-42_notierungsn1476799985.html
Straw in China
Straw in China (data from 1,076 samples)

Niu et al. 2016
Straw in China

The equation used to calculate BMP needs perhaps adjustments
Pretreatment technologies

• “Pretreatment of feedstock for enhanced biogas production”
  – Published by: International Energy Agency Bioenergy 2014

• In general, all pretreatment technologies aim to use a CSTR for AD

• Following technologies can be used alone or combined for pretreatment
<table>
<thead>
<tr>
<th>Method</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Milling</strong></td>
<td>increases surface area</td>
<td>increased energy demand</td>
</tr>
<tr>
<td></td>
<td>makes substrate easier to handle</td>
<td>high maintenance costs / sensitive to stones etc.</td>
</tr>
<tr>
<td></td>
<td>often improves fluidity in digester</td>
<td></td>
</tr>
<tr>
<td><strong>Hot water</strong></td>
<td>increases the enzyme accessibility</td>
<td>high heat demand</td>
</tr>
<tr>
<td><em>(TDH)</em></td>
<td></td>
<td>only effective up to certain temperature</td>
</tr>
<tr>
<td><strong>Alkali</strong></td>
<td>breaks down lignin</td>
<td>high alkali concentration in digester</td>
</tr>
<tr>
<td></td>
<td></td>
<td>high cost of chemical</td>
</tr>
<tr>
<td><strong>Acid</strong></td>
<td>solubilises hemicellulose</td>
<td>high cost of acid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>corrosion problems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>formation of inhibitors, particularly with heat</td>
</tr>
<tr>
<td><strong>Microbial</strong></td>
<td>low energy consumption</td>
<td>slow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>no lignin breakdown (?)</td>
</tr>
<tr>
<td><strong>Enzymatic</strong></td>
<td>low energy consumption</td>
<td>continuous addition required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>high cost of enzymes</td>
</tr>
<tr>
<td><strong>Steam</strong></td>
<td>breaks down lignin</td>
<td>high heat and electricity demand</td>
</tr>
<tr>
<td><strong>explosion</strong></td>
<td>solubilises hemicellulose</td>
<td></td>
</tr>
<tr>
<td><strong>Extrusion</strong></td>
<td>increases surface area</td>
<td>high maintenance costs / sensitive to stones etc.</td>
</tr>
</tbody>
</table>

Adapted from IEA, 2014
Milling

- milled wheat straw 0.13 mm
- 630 days continuous operation of a lab fermenter

<table>
<thead>
<tr>
<th>Method</th>
<th>CH$_4$/kg VS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch-Test</td>
<td>271</td>
</tr>
<tr>
<td>contin. 41°C, OLR 7.5, HRT 10, no trace elements</td>
<td>143</td>
</tr>
<tr>
<td>contin. 41°C, OLR 7.5, HRT 10, trace elements</td>
<td>220</td>
</tr>
<tr>
<td>contin. 58°C, OLR 7.5, HRT 10, no trace elements</td>
<td>124</td>
</tr>
<tr>
<td>contin. 58°C, OLR 7.5, HRT 10, trace elements</td>
<td>162</td>
</tr>
</tbody>
</table>

(Antonczyk et al., 2016)
Hot water (Thermo Druck Hydrolyse)

- Plant from Verbio AG in Schwedt, Germany
  - from 2019 on
  - 40,000 t of straw per year*
  - 120-140 GWh biomethan*
  - Biomethane Yield: 300 m³ CH₄/t straw (or some additional substrate)
  - Around 37,000 m³ CH₄/d

*www.verbio.de
Simplified, according to patent DE102012112898A1
Verbio Straw Process?

Simplified, according to patent DE102012112898A1

- Straw
- Water
- Steam
- Nutrients

1. Conditioning (70-85°C)
2. Shredder < 20 mm
3. Steam (150-180°C for 10-30 minutes)
4. Cooling
5. Fermentation
6. Separation

Outputs:
- Biogas
- Organic fertilizer
Microbial Pretreatment of Straw

- BMT-System from MWK Bionic GmbH operates a pilot system
- Separated liquid digestate is heated
- Additive is used
- Straw is added
- After reaction the material is pumped to the fermenter

www.mwk-bionik.de/de/systeme/bmt.html
Steam Explosion

- ECONOMIZER SE from BIOGAS SYSTEMS GmbH
- Material is heated up to 180°C in two steps
- Pressure up to 1 MPa
- Final rapid pressure drop disintegrates material

- large scale pilot plant in operation since 2014
- capacity: up to 1 ton straw / hour
- first client projects under realisation

(www.biogas-systems.com)
Extrusion

- Extrusion is a process where material is subjected mechanically to high shear, temperature, pressure and desintegration.

- „Bioextruder“ from Lehmann-UMT GmbH combines short time-hydrolysis & extrusion: 5-12 kWh/t material, low maintenance

- Installed at different plants, but non for monofermentation of straw

Data from Lehmann & Friedrich 2012, picture from Lehmann-UMT GmbH
New Reactor Design for Straw?

• IEA Bioenergy:
  “Current pretreatment systems are useful to transform a very fibrous substrate into something resembling manure or maize. This allows lignocellulosic substrates to be used in existing (CSTR) reactors. However, ...., there is much evidence that a different reactor design may be more suitable for lignocellulosic substrates.”

• The Vertical Plug Flow Reactor used in China...?
Vertical Plug Flow Fermenter for Straw Digestion in China

Pictures from 2012
Vertical Plug Flow Fermenter for Straw Digestion in China

• Straw forms swimming layer
• Digested material settles down and can be removed
• Straw surface is rewetted with digestate pumped from the bottom to the top

• Design/operating considerations:
  – Is it possible to supply the swimming layer with enough nutrients and water?
  – Is the gas sufficiently released to the top of the fermenter?
  – A too thick swimming layer is not favorable
  – The ratio of surface area to volume should be rather high
A CSTR/VPF-like fermentation system

- No agitator & no heating system in the fermenter
- Operation as CSTR or as Vertical Plug Flow Reactor
Nozzle System

• Heat and mass transfer by a pump/nozzle system
• Three nozzles that can be turned for 120°
• By electronic frequency converter the nozzle can splatter digestate from the fermenter wall to the center
• The digestate is pumped from the bottom to the nozzle.

www.ecogas-gmbh.de
Characteristics of the CSTR/VPF system

• Little maintenance
• 11 plants up to 7,200 m³ CH₄/d or 1.2 MWₑᵢₑ)
• Operating hours more than 95% in a year
• Electricity consumption of the plant:
  < 5% of the produced electricity
• System is suited for earth basin fermenter

www.ecogas-gmbh.de
Conclusions

• Various technologies for straw pretreatment exist.
• In Europe the straw fermentation is about to start.
• The only running biogas plants for straw fermentation are in China: CSTRs with pretreatment and Vertical Plug Flow Fermenter
• Without pretreatment CSTRs may not be the first choice of reactor design
• So far a sound analysis of the methane yield and mass balance from full scale plants is missing.
Thank you for your attention