Gasification of digestates and nutrient recycling

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DI Mag. Kerstin Schopf
Introduction

Trend of development of biogas plants in Germany

Today in Germany:
- around 75,000,000 t p.a. of biogas-digestates (10% dry-matter)

Potential?
- Biogas-digestates: $7.5 \text{ Mtdry} \cdot 15 \frac{\text{MJ}}{\text{kg}} \approx 31 \text{ TWh}$

At 8000 h of operation:
- 3.9 GW for Biogas-digestates
Today’s use of digestates?

- Mostly local use as ecological fertilizer
- But...

1. Local Oversupply

Transportation costs exceed fertilizer value if distance is above 10km

2. Disposal bans

in overfertilized regions (NO$_3^-$ - problem)

3. Poor conversion-efficiency of digestion-processes

- only around 50% of feed’s calorific-value gets converted in digestion
- Most nutrients remain in the ash, also after subsequent thermal conversion

Potential?

- Biogas-digestates: $7.5 \text{Mtdry} \cdot 15 \frac{\text{MJ}}{\text{kg}} \approx 31 \text{TWh}$

At 8000 h of operation:

- 3,9 GW for Biogas-digestates
Fuel preparation: for economic use drying and dewatering is necessary. Due to low-calorific-values: drying to 10% Water-content

- Thickening: 5-8% dry
- Dewatering: 20-45% dry
- Drying: >45% dry

<table>
<thead>
<tr>
<th>Water content (%)</th>
<th>Ash content (%)</th>
<th>Calorific Value [MJ/kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gross</td>
<td>Net</td>
</tr>
<tr>
<td>Biogas-digestate 1</td>
<td>9.2</td>
<td>18.3</td>
</tr>
<tr>
<td>Biogas-digestate 2</td>
<td>9.9</td>
<td>14.6</td>
</tr>
<tr>
<td>Pinewood (with bark)</td>
<td>12.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Source: Kratzeisen et al (2010)

- Energetic point of view (of dry digestates): Net Calorific values of biogas-digestates can be compared with wood.
- High ash-contents: Digestates require challenging ash-handling
Ash characteristics

<table>
<thead>
<tr>
<th></th>
<th>Softening</th>
<th>Hemisphere</th>
<th>Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas-digestate 1</td>
<td>1.090</td>
<td>1.290</td>
<td>1.320</td>
</tr>
<tr>
<td>Biogas-digestate 2</td>
<td>1.110</td>
<td>1.150</td>
<td>1.390</td>
</tr>
<tr>
<td>Pinewood (with bark)</td>
<td>1.430</td>
<td>1.600</td>
<td>1.600</td>
</tr>
</tbody>
</table>

**Thermal-Conversion-Requirement:** Combustion- respectively Gasification-temperatures *NOT higher than 1000°C*

- Inhomogeneous fuels: Compositions vary widely

Source: Kratzeisen et al (2010)
Motivation for Gasification:
In comparison to combustion plants:
- Lower investment-costs
- Higher electrical efficiencies

Dried Biogas-digestates

plant sizes
- some 100 kW for on-site gasification
- Low MW-range for plants with digestate-logistics

Major hurdle
- Reaching low tar-contents at the low gasification temperatures needed to avoid ash-slagging.

Also challenging
- Ash-stream handling...
- Gas-cleaning
- Corrosion related issues
Solution: BFB-Gasification?

Optimal temperature-control possible, but...

Major hurdle

- Reaching low tar-contents at the low gasification temperatures needed to avoid ash-slagging.

Also challenging

- Ash-stream handling...
- Gas-cleaning
- Corrosion related issues
**Solution: Staged-Gasification?**

Oxidation of low-temperature pyrolysis-products, Char-coal reduction below ash-melting temperatures

**Major hurdle**
- Reaching low tar-contents at the low gasification temperatures needed to avoid ash-slagging.

**Also challenging**
- Ash-stream handling...
- Gas-cleaning
- Corrosion related issues

*Challenging in terms of plant-design, but... Why not?*
Staged gasification of biogas-digestates

Syncraft → CraftWERK
- screw-pyrolysis → pyrolysis gas oxidation → char reduction in expanded bed reactor
- Fuel: pelletized biogas-digestates → 2014, positive tests, Craftwerk700 fits to 500 kW biogas-plant
Staged gasification of sewage-sludge

Kopf SynGas-plant in Koblenz (D)

- New concept: screw-pyrolysis → pyrolysis gas oxidation → char reduction in ash-bed
  aim: Low-tar contents.
- 4000 t$_{\text{Dry}}$ p.a. → around 1 MW nominal fuel capacity → around 350 kW$_{\text{el}}$
- Concept can be adapted for the use of biogas-digestates also
Nutritional requirements

- **Introduction**
- **Fuel Assessment**
- **Gasification**
- **Nutrient recycling**
- **Summary**

These basic nutrients are generally available to plants in sufficient quantities simply through air, soil, & water.

Primary macronutrients (NPK’s) are the primary foci of most traditional fertilizer application programs.

Secondary macronutrients and micronutrients are often grouped together for classification and identification. While they are not generally the foci of fertilization programs, they are absolutely essential for successful and healthy plant growth.

While not widely considered to be essential components of plant nutrition, these elements are known to be required by certain plant types in certain environmental circumstances.

**BASIC NUTRIENTS**
- C: Carbon
- H: Hydrogen
- O: Oxygen

**PRIMARY MACRONUTRIENTS**
- N: Nitrogen
- P: Phosphorus
- K: Potassium

**SECONDARY MACRONUTRIENTS**
- Ca: Calcium
- Mg: Magnesium
- S: Sulphur

**MICRONUTRIENTS**
- Fe: Iron
- Mn: Manganese
- Zn: Zinc
- Cu: Copper
- B: Boron
- Mo: Molybdenum
- Cl: Chlorine

**OTHERS**
- Si: Silicon
- Co: Cobalt

Color-Coding Key: Elemental Classifications
- Nonmetals
- Alkali Metals
- Alkaline Earth Metals
- Poor Metals
- Transition Metals

Source: sulvaris, 2016
### Fuel assessment

<table>
<thead>
<tr>
<th>Element</th>
<th>Unit</th>
<th>Biogas-digestate 1</th>
<th>Biogas-digestate 2</th>
<th>Pinewood (with bark)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>wt%</td>
<td>45.3</td>
<td>43.2</td>
<td>49.7</td>
</tr>
<tr>
<td>N</td>
<td>wt%</td>
<td>2.9</td>
<td>1.5</td>
<td>0.13</td>
</tr>
<tr>
<td>O</td>
<td>wt%</td>
<td>28.4</td>
<td>35.9</td>
<td>43.3</td>
</tr>
<tr>
<td>H</td>
<td>wt%</td>
<td>5.2</td>
<td>5.5</td>
<td>6.3</td>
</tr>
<tr>
<td>P</td>
<td>wt%</td>
<td>1.3</td>
<td>1.1</td>
<td>0.03</td>
</tr>
<tr>
<td>S</td>
<td>wt%</td>
<td>0.9</td>
<td>0.3</td>
<td>0.02</td>
</tr>
<tr>
<td>K</td>
<td>wt%</td>
<td>1.4</td>
<td>1.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Cl</td>
<td>wt%</td>
<td>0.84</td>
<td>0.27</td>
<td>0.01</td>
</tr>
<tr>
<td>As</td>
<td>mg/kg</td>
<td>0.93</td>
<td>0.54</td>
<td>0.48</td>
</tr>
<tr>
<td>Cd</td>
<td>mg/kg</td>
<td>0.29</td>
<td>0.15</td>
<td>0.23</td>
</tr>
<tr>
<td>Cr</td>
<td>mg/kg</td>
<td>13.2</td>
<td>21.5</td>
<td>6.8</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/kg</td>
<td>58.8</td>
<td>18.2</td>
<td>3.5</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/kg</td>
<td>4.4</td>
<td>0.78</td>
<td>2.17</td>
</tr>
<tr>
<td>Hg</td>
<td>mg/kg</td>
<td>0.07</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Zn</td>
<td>mg/kg</td>
<td>304</td>
<td>125</td>
<td>35</td>
</tr>
</tbody>
</table>

- Digestates show considerably higher amounts of nutrients in comparison to wood
- ...but also heavy-metals are higher

Source: Kratzeisen et al (2010)
Nutrient recycling

Ash as fertilizer: differences between gasification and combustion

- Differences in elemental concentrations depend mostly on the process-temperature and the systematically high carbon content of gasification Bottom Ashes (ca. 50%)
- Lower P, Mg and K concentration the higher the process-temperatures are
- Both: no Nitrogen

<table>
<thead>
<tr>
<th></th>
<th>Combustion</th>
<th>Gasification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/kg dry</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>130.65</td>
<td>75.57</td>
</tr>
<tr>
<td>Mg</td>
<td>44.13</td>
<td>7.91</td>
</tr>
<tr>
<td>K</td>
<td>129.47</td>
<td>20.33</td>
</tr>
<tr>
<td>P</td>
<td>11.76</td>
<td>2.44</td>
</tr>
<tr>
<td>Mn</td>
<td>12.32</td>
<td>4.20</td>
</tr>
<tr>
<td>B</td>
<td>0.71</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Source: Pan & Eberhardt (2011)

All wood-based data: poor database for digestate-ashes
Nutrient recycling

Ash as fertilizer: elutability of nutrients

- Generally: higher temperatures and pressures in the thermal process decrease short-time plant-availability
- P is very badly elutable
- Biomass-ashes are therefore considered as a long-time soil-conditioner

Source: Oberberger, 1997
**Nutrient recycling**

**Ash as fertilizer: heavy metals**

<table>
<thead>
<tr>
<th></th>
<th>Gasification</th>
<th>German fertilizer act</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/kg dry</td>
<td></td>
</tr>
<tr>
<td>As</td>
<td>10.06</td>
<td>40</td>
</tr>
<tr>
<td>Cd</td>
<td>4.39</td>
<td>4</td>
</tr>
<tr>
<td>Cr</td>
<td>38.51</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>37.25</td>
<td>70</td>
</tr>
<tr>
<td>Ni</td>
<td>47.29</td>
<td>80</td>
</tr>
<tr>
<td>Pb</td>
<td>11.83</td>
<td>150</td>
</tr>
<tr>
<td>Zn</td>
<td>345.45</td>
<td>1,000</td>
</tr>
</tbody>
</table>

- Generally: Fine fly-ashes (bag-filter, E-filter) contain high heavy-metal contents (Zn) and must be deposed.
- Coarse biomass-ash (Bottom-ash) normally is within the limits of national fertilizer acts. High heavy metal input due to local conditions must be taken into account.
- Caution: Plants with highly stressed stainless-steel components can emit ashes with to high concentrations of Ni and Cr.
Summary

- For gasification of digestates, promising concepts, based on staged-gasification, exist. Major hurdle is the high ash-content and the low ash-softening temperature.

- Ashes from the thermal utilization of digestates can be used as fertilizer, but they can only be a part of a total nutrient management strategy.

Pros
- Often high in P and K
- High Ca concentration possible
- Ash can improve the nutrient balance in soils

Cons
- No Nitrogen
- Only minor short-time plant-availability
- Heavy metal contents
- Gasification ash: Carbon and PAH

Thank you for your kind attention.