“Nutrient recovery from biogas digestate in semi-technical scale in Northern Germany”

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Project time: January 2014 – November 2017
Motivation
Biogas plants in Germany

• In 2016 about 31.7 % of electricity consumption in Germany is based on renewable energies, 7 % on biomass energy

• Biogas plants in Germany constantly increased in number and electric capacity

• **9,000 plants with 4,200 MW\(_e\) installed power** (2016)

• Development driven by “German Renewable Energy Sources Act”
**Motivation**

**Biogas plants in Germany**

- In 2011, about 65.5 million m³ of anaerobic sludge from biogas plants was ejected [1]

\[ \text{20000 – 25000 t/a sludge per MW}_e \]

- Nutrients are highly recommended for manuring processes [1]
  - Nitrogen \( 1.2 – 9.1 \text{ kg/t} \)
  - Ammonia \( 1.5 – 6.8 \text{ kg/t} \)
  - Phosphorus \( 0.4 – 2.6 \text{ kg/t} \)
  - Potassium \( 1.2 – 11.5 \text{ kg/t} \)

**But:** Local usage is limited (excess)

**Costs for transport (50-150 km):**
- \( 10 – 17 \text{ €/m}^3 \) digestate (N-Germany)

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- Conclusion and outlook

Fig. 3: Ultrafiltration plant Inwil- Switzerland
Separation technology
Membrane based

Fig. 4: Process scheme of the membrane based total conditioning process

Screw press separator
Decanter centrifuge
Ultrafiltration
Reverse osmosis

Biogas plant
Digestate
Retentate
Liquid fertiliser
Water
Solid fertiliser
Separation technology
Membrane based

Fig. 4: Process scheme of the membrane based total conditioning process

UF: 50 % of invest costs
50-60 % of energy costs

Process targets:

1. Liquid fertiliser:
   particle free, high amount of nitrogen+potassium
2. Solid fertiliser:
   TS > 20 %, org. nitrogen and phosphorus
3. Process water in high quality

1. Energy efficient separation
2. Stable process during unstable condition
3. Transport worthy nutrient production
4. Reduction of transport effort
Experimental set-up Screening

Analysed parameters:

- Viscosity of digestate and centrate (supernatant)
- Density of digestate and centrate
- Polysaccharides and proteins
- FOS/TAC value
- $N_{\text{total}}$, $\text{NH}_4\text{-N}$, $\text{K}^+$, $\text{P}_2\text{O}_5$,
- Membrane performance with 40 nm ultrafiltration (Amicon)
- TS, VS...

digestate, centrate, retentate UF, filtrate UF
Experimental set-up
Biogas plant

Biogas plant Northwest Germany

- 2 MW_{el} and 2 MW_{th} power
- Feed: 50 t/d cattle manure, 50 t/d maize silage, 50 t/d crops
- Digestate output: 35,000 – 45,000 t/a

Problems:

- Local fields are limited
- Nitrate → Groundwater
- Further Phosphorus separation required
Experimental set-up
Separation units

Container decanter centrifuge
- 5-6 m³/h
- Z = 3.500 g

Screw press separator
- 0,5 mm mesh
- 6-7 m³/h

Solid fertiliser
- 0,5-1 t/h
- 0,5 t/h
Experimental set-up
Separation units

Ultrafiltration unit
- Ceramic $\text{Al}_2\text{O}_3$ membranes (50 nm)
- 7.3 m² active membrane area
- High cross-flow velocity 3 – 5 m/s

Fouling control

Reverse osmosis unit
- Polymeric membrane
- 138 m² active membrane area
- 3-stage reverse osmosis for high water quality
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Abb. 4: Ultrafiltrationsanlage in Inwil (Schweiz)
Results Screening

Digestate:

- High viscous, fibre rich, organic material
- TS = 5 – 10 % with ¾ VS
- Water density

Centrifugation

After centrifugation (RZB = 3.500 g):

- Moderate viscous, fibre free, organic material
- TS = 2 – 4 % with 2/3 VS
- Water density but **not** water viscosity

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<td>N = 15</td>
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<tr>
<td>TS</td>
<td>wt%</td>
<td>7.6 ± 2.4</td>
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<td>VS</td>
<td>wt% of TS</td>
<td>71.9 ± 5.0</td>
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<td>Density</td>
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<td>997 ± 28</td>
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<td>pH</td>
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<td>TS</td>
<td>wt%</td>
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<td>VS</td>
<td>wt% of TS</td>
<td>62.6 ± 7.4</td>
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<td>Density</td>
<td>kg·m⁻³</td>
<td>1017 ± 5.0</td>
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<td>pH</td>
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Viscosity-Screening:

- Viscosity after centrifugation is factor 10 – 100 higher than water (Non-Newtonian)
- Water viscosity = 0.001 Pa·s
- Average viscosity after centrifugation (Shear rate = 1000 s⁻¹) → 0.014 Pa·s
- Strong deviation for the analysed samples → feeding strategy is very different

Fig. 7: Viscosity at 20 °C with double-gap rheometer Anton Paar MCR 101
• High viscosities correlate with low ultrafiltration flux (1 – 2 L·m⁻²·h⁻¹)

• Bio-waste digestates are subjected to have higher flux (2.5 – 7.5 L·m⁻²·h⁻¹) → lower TS, lower organic concentration and viscosity
Conclusion

Screening

- 32 samples from agricultural biogas plants and 11 samples from bio-waste biogas plants
- Screening is necessary to understand fluid dynamics and the differences in feed and composition

→ Detailed engineering knowledge of rheological and physical behavior

→ Scale-Up could be possible!

Fig. 9: Correlation of viscosity and organic concentration
Results Scale-Up

Digestate

Solid organic N/P fertiliser

Liquid inorganic N/K fertiliser

Process water

Nutrient concentration in kg t⁻¹

Digestate

Solid organic N/P fertiliser

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**Results Scale-Up**

**Water-Energy Nexus:**

- Production of clean water and total reduction of organic/inorganic residues
- Production of high concentrated nutrients for direct manuring applications (N/P/K)
- Recycling of limited resources (Phosphorus)

**Costs for manuring procedure and transport**
- 10 – 17 €/m³ digestate (Northern Germany)

**Operation costs incl. investment**
- 6 – 10 €/m³ digestate

**MINUS** (3 – 4 €/m³) [3]  
Price for conc. nutrients (equivalents of synth. fertilizer)

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Conclusion and outlook

4 Years of project work…

• 2.5 years of screening and optimisation of digestate and its separated fractions

• 1 year practical tests on site (Northwest Germany)
  • Separation of 1,500 m³ of digestate
  • Process water in very high quality (<15 mg/L COD, 10 mg/L NH₄⁺-N)
  • Concentrated fractions of liquid and solid fertilisers

• Now: 3 months practical tests on side (West Germany)
  • Validating experimental results
  • Optimisation of energy consumption (Target -50% of ultrafiltration unit)

… 2- 3 months for PhD, publication…

🎓
Thank you very much for your kind attention!

Please feel free to ask any questions…