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

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A3 water solutions GmbH

Technische Universität Berlin

Motivation
Biogas plants in Germany

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- 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*"

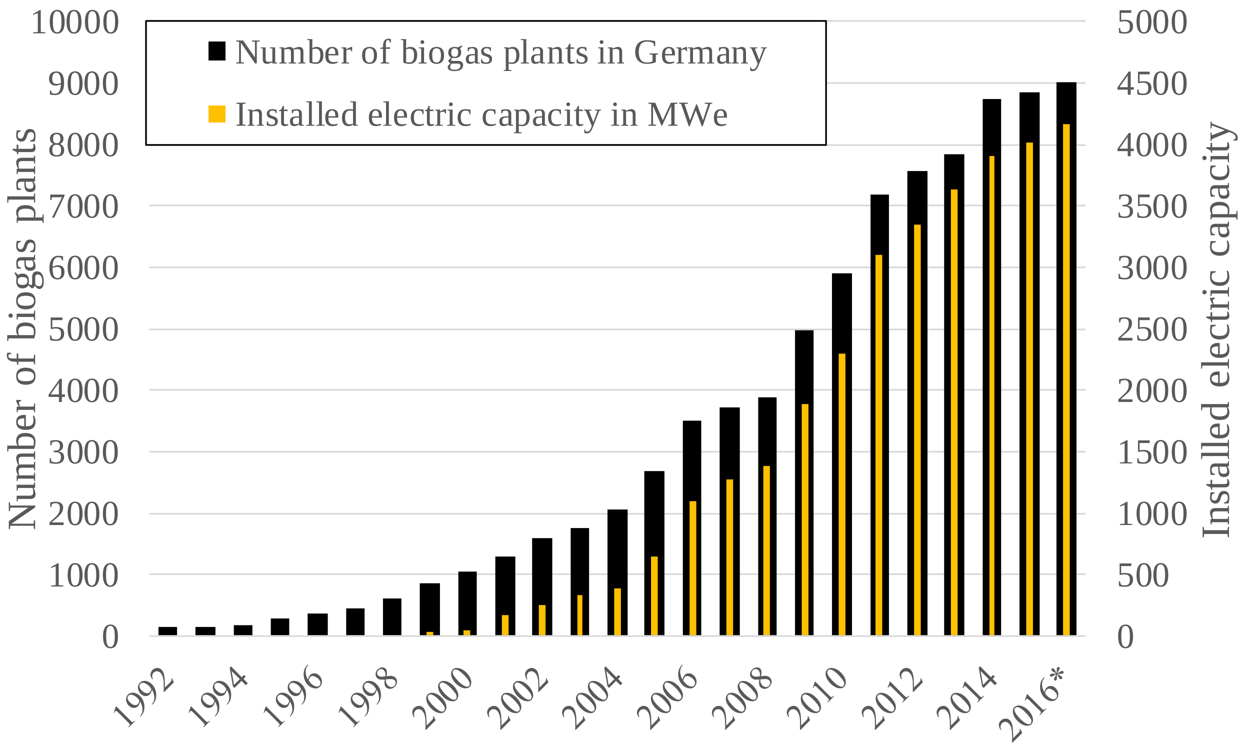

Fig. 1: Development of German biogas plants, Fachagentur Biogas e.V. (July 2016)

Motivation
Biogas plants in Germany

- In 2011, about 65,5 million m³ of anaerobic sludge from biogas plants was ejected [1]

→ **20000 – 25000** t/a sludge per MW_e

- Nutrients are highly recommended for manuring processes [1]

Nitrogen	1.2 – 9.1 kg/t
Ammonia	1.5 – 6.8 kg/t
Phosphorus	0.4 – 2.6 kg/t
Potassium	1.2 – 11.5 kg/t

<u>But:</u> Local usage is limited (excess)

Costs for transport (50-150 km):

- **10 – 17 €/m³ digestate (N-Germany)**

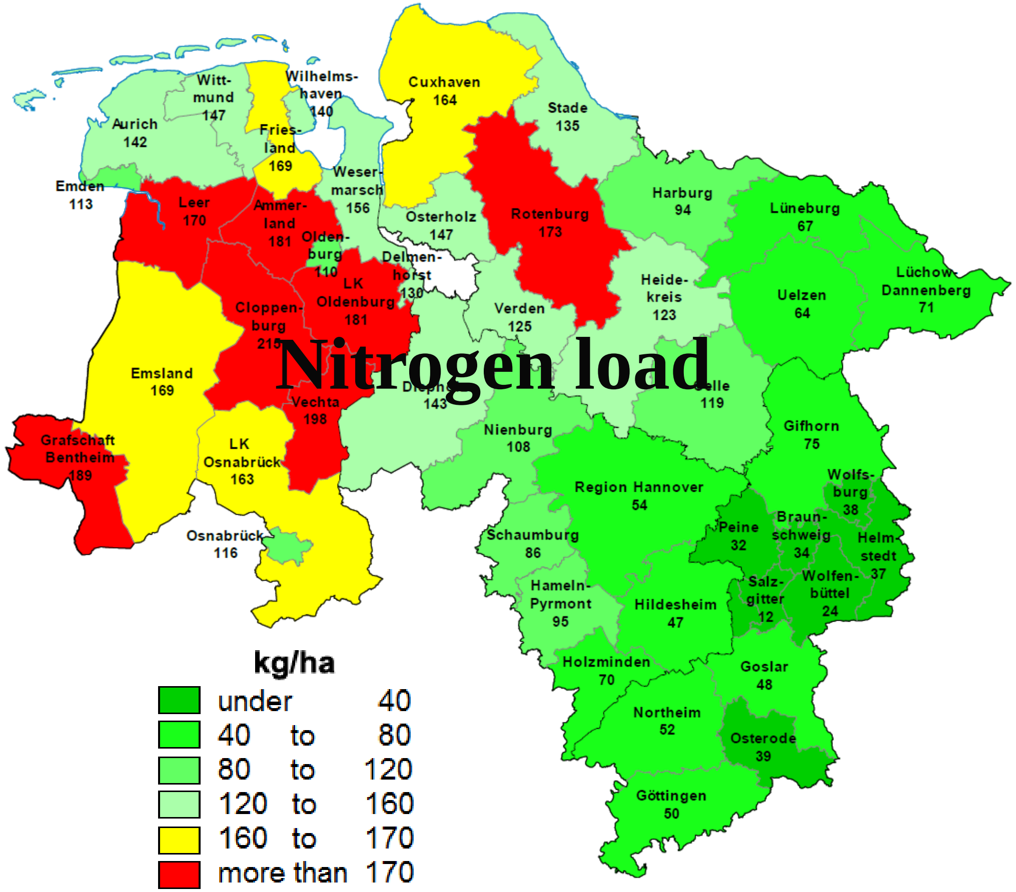

Fig. 2: Nitrogen load on agricultural fields, Lower Saxony [2]

[1] Möller, K., Müller, T., 2012. Effects of anaerobic digestion on digestate nutrient availability and crop growth: A review. Eng. Life Sci. 12, 242–257.
[2] Nutrient report, Germany, Lower Saxony 2013/2014

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Fig. 3: Ultrafiltration plant Inwil- Switzerland

Separation technology
Membrane based

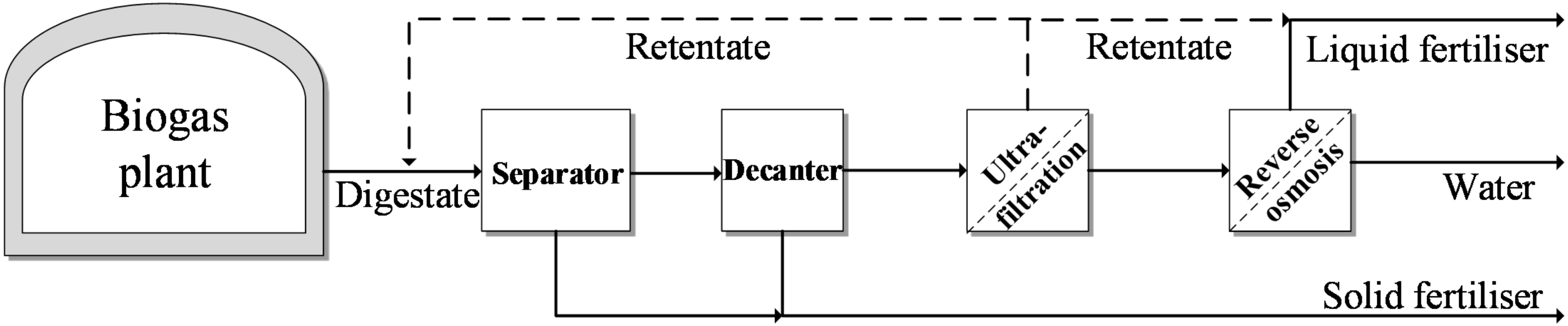

Fig. 4: Process scheme of the membrane based total conditioning process

Screw press separator

Decanter centrifuge

Ultrafiltration

Reverse osmosis

Separation technology
Membrane based

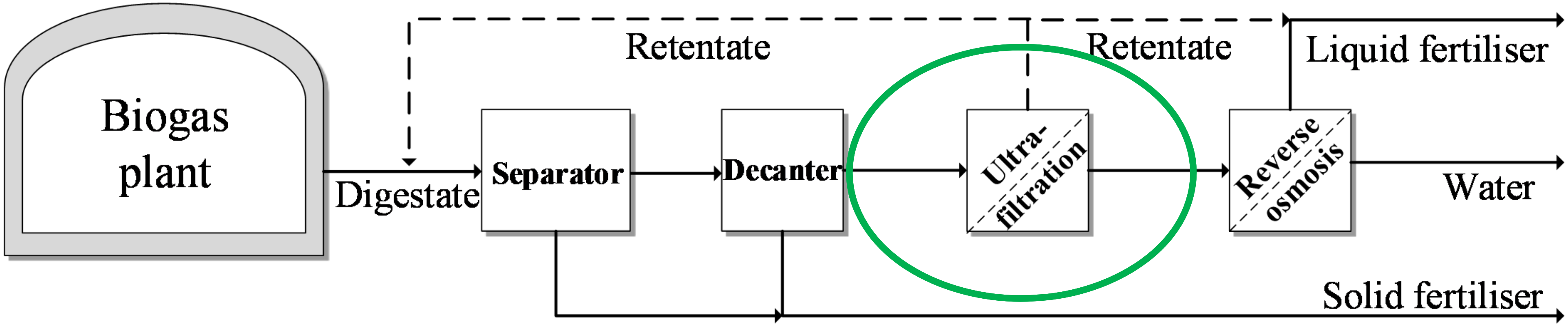

Fig. 4: Process scheme of the membrane based total conditioning process

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

Process targets:

- Energy efficient separation
- Stable process during unstable condition
- Transport worthy nutrient production
- Reduction of transport effort

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

Experimental set-up
Screening

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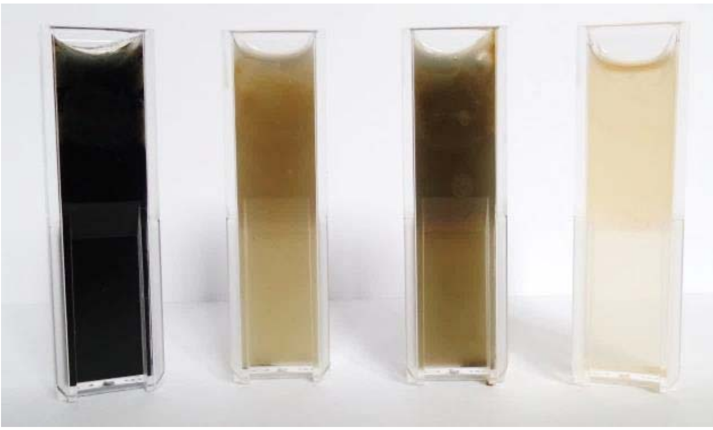
Analysed parameters:

- Viscosity of digestate and centrate (supernatant)
- Density of digestate and centrate
- Polysaccharides and proteins
- FOS/TAC value
- N_{total}, NH_4-N, K^+, P_2O_5,
- Membrane performance with 40 nm ultrafiltration (Amicon)
- TS, VS…



digestate, centrate, retentate UF, filtrate UF

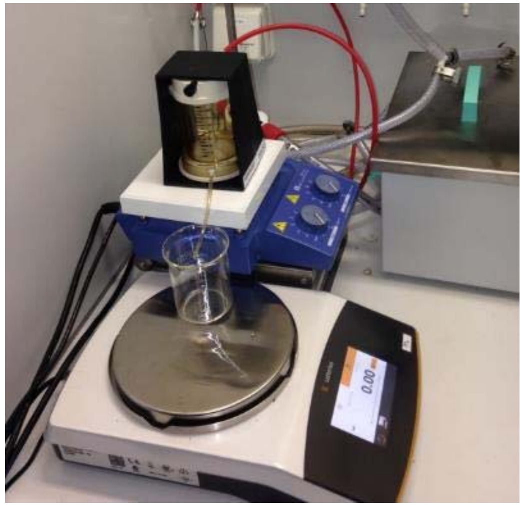


Fig. 5: Ultrafiltration test- Amicon 8200

Fig. 6: Centrifuge, 2200 g, CEPA

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 Phosporus separation required

Experimental set-up
Separation units

Container decanter centrifuge

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

Experimental set-up
Separation units

Ultrafiltration unit

- Ceramic Al_2O_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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- Separation technology
- Experimental set-up
- Results
- Conclusion and outlook

Abb. 4: Ultrafiltrationsanlage in Inwil (Schweiz)

Results Screening

Digestate:

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

Parameter	Unit	Average N = 15
TS	wt%	7.6 ± 2.4
VS	wt% of TS	71.9 ± 5.0
Density	kg·m^{-3}	997 ± 28
pH	---	7.8 ± 0.2

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

Parameter	Unit	Average N = 15
TS	wt%	3.1 ± 1.2
VS	wt% of TS	62.6 ± 7.4
Density	kg·m^{-3}	1017 ± 5.0
pH	---	7.8 ± 0.2

Results Screening

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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 diviation for the analysed samples → feeding strategy is very different

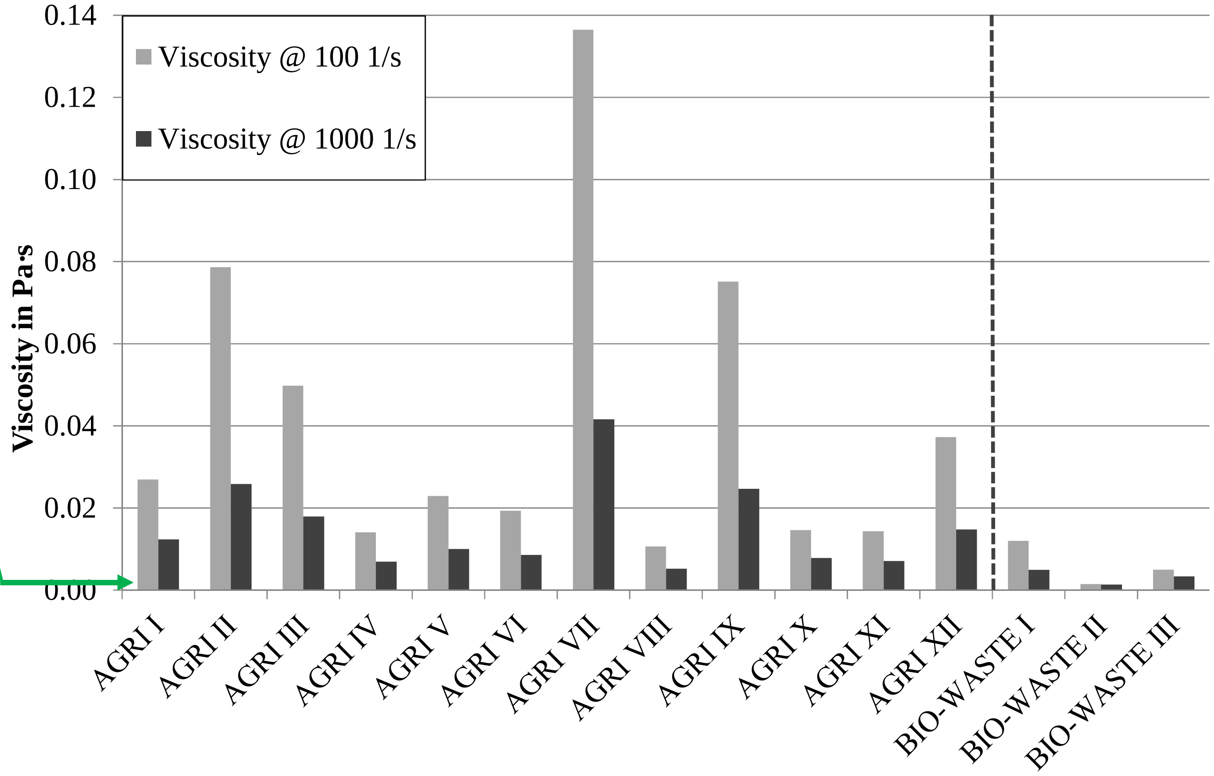
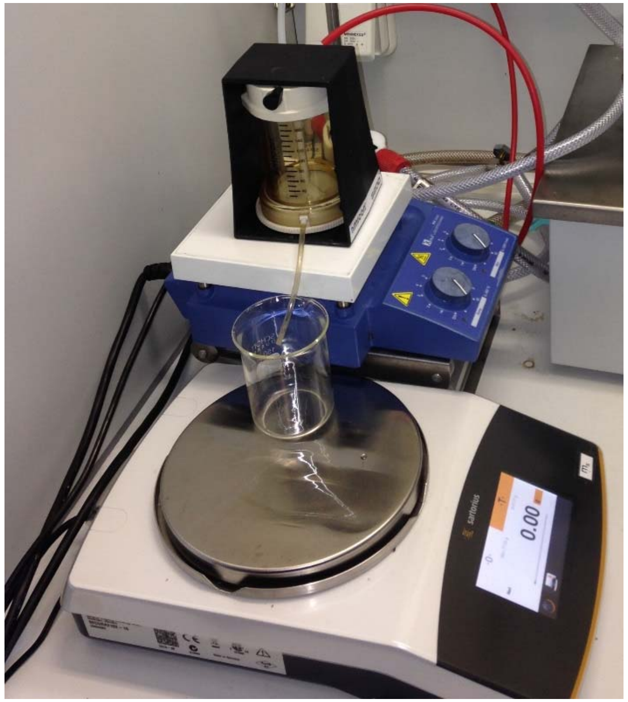


Fig. 7: Viscosity at 20 °C with double-gap rheometer Anton Paar MCR 101

Results Screening

Membrane-Screening



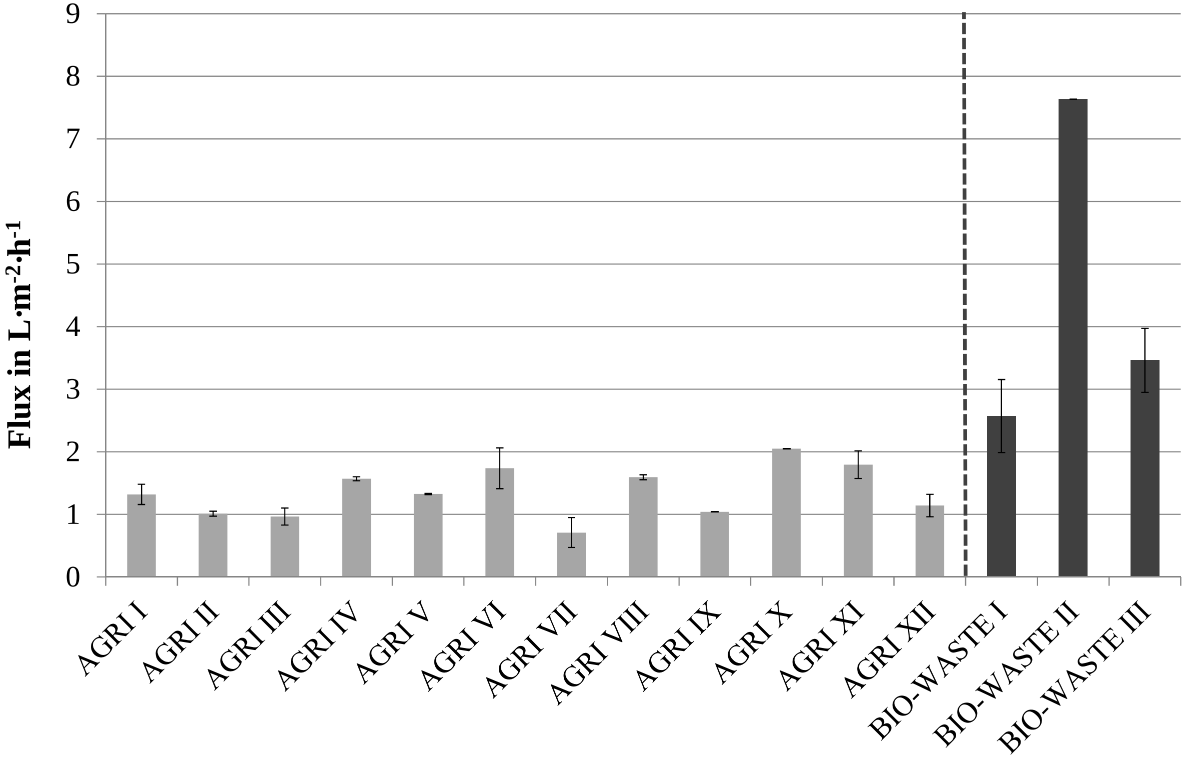


Fig. 8: Ultrafiltration flux at 20 °C, Δp = 1 bar, stirrer 120 min^{-1}, Amicon 8200 (40 nm)

- High viscosities correlate with low ultrafiltration flux (1 – 2 $L \cdot m^{-2} \cdot h^{-1}$)
- Bio-waste digestates are subjected to have higher flux (2.5 – 7.5 $L \cdot m^{-2} \cdot h^{-1}$)
  → lower TS, lower organic concentration and viscosity

Conclusion Screening

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!

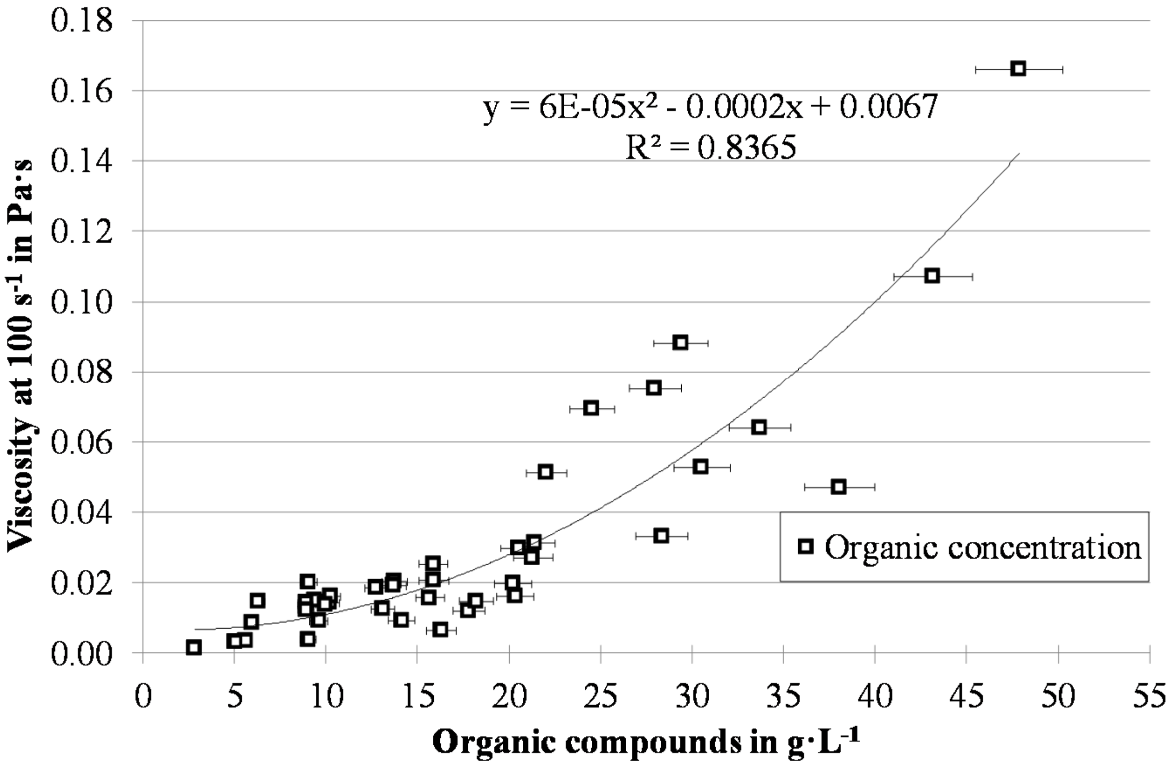


Fig. 9: Correlation of viscosity and organic concentration

Results Scale-Up

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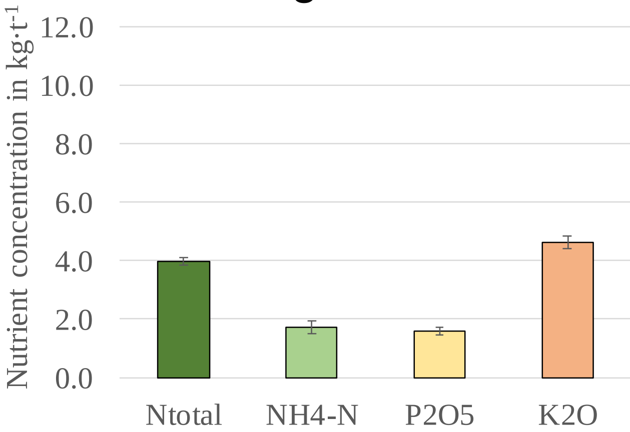
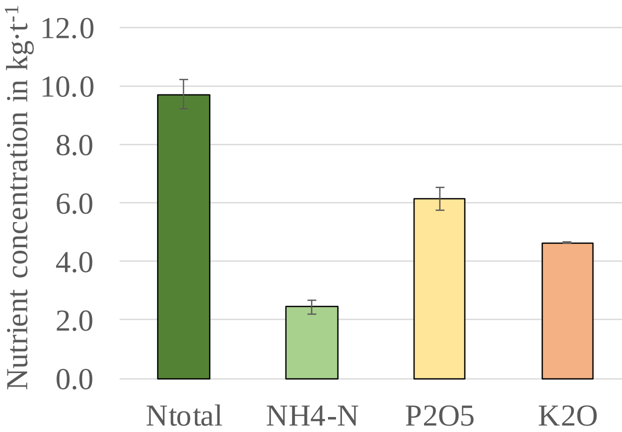
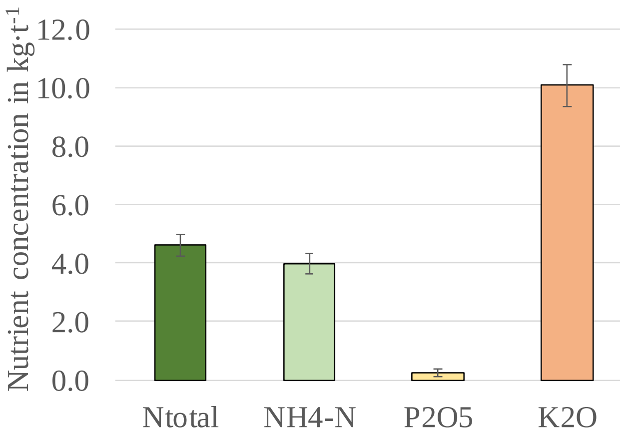
Digestate



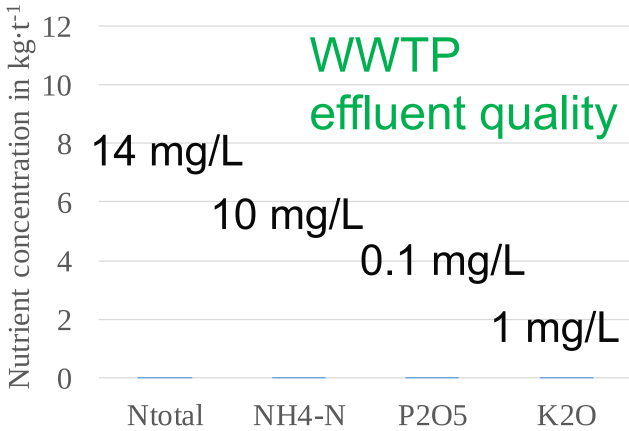
Solid organic N/P fertiliser



Liquid inorganic N/K fertiliser



Process water



Results Scale-Up

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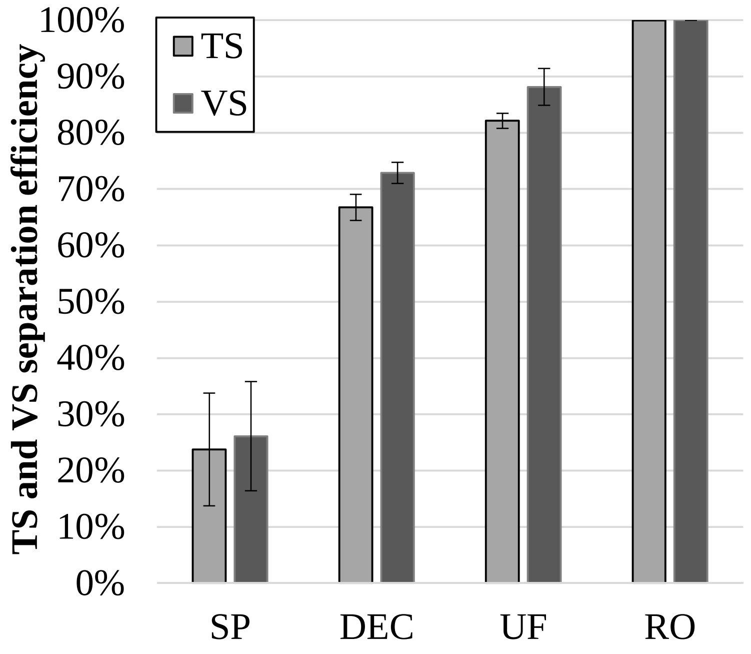

Fig. 10: Concentration based retention of total solids

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)

[3] Döhler et al. (2011), Effizente Gärrestaufbereitung und - Verwertung

Conclusion and outlook

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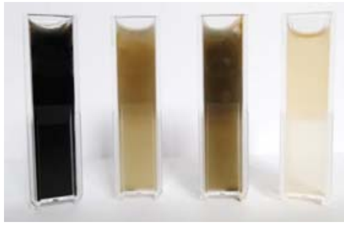
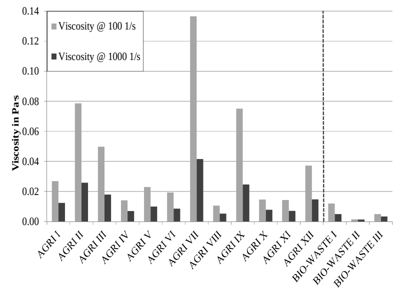
4 Years of project work…

- 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 NH_4^+-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…

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Thank you very much for your kind attention!

Please feel free to ask any questions…

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