AD as an integral part of manure management

Michael Köttner
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1. Environmental Aspects
2. Application of Digestate
3. Digestate Processing
4. Treatment Costs - Profitability
1. Environmental Aspects
Eco-friendly liquid manure management

Very big quantities of liquid manure lead to:

- Odor impacts during treatment and production
- Spreading of pathogenic germs
- Damage of the botanical composition and building of a typical “Liquid Manure Flora” in the available grassland
- Worsening of the soil properties
- Contamination of the ground and surface waters

Biogas technology can not substantially reduce liquid manure quantities. It OFFERS HOWEVER, different solutions for this problem, thanks to its positive energy balance from the production of biogas.
Modification of composition for different substrates after passage through a biogas installation (Peretzky 2008)

Substrate Digestate

Bovine slurry

Corn silage

Wheat (all crop silage)

Rye (grain)

Fuchs and Drosg, 2010
Positive changes of liquid manure properties through fermentation

**Decomposition of organic substance**
- Decomposition rates oDM: of up to 40%
- The fermented liquid manure can be pumped and sprayed better compared to the raw liquid manure
- The agitation is reduced before the application on land

**Odor reduction**
Reduction of the odor causing substances (humid acids, Phenols, Phenol derivate)

**Sanitization**
The degree of the sanitization depends on retention time, temperature and applied procedure
Hydraulic retention time (days)

Relative concentration (%)

Odor reduction depending on retention time

- p-Kresol
- Ethyl-Phenol
- Indol
- Skatol
- Iso-Buttersäure
Positive changes of liquid manure properties through fermentation

Destroying the weed seeds
The longer the seeds in the liquid manure are exposed to the process and the higher the temperature is, the more rapidly decreases the germination capacity.

Avoidance of plant corrosion

Improvement of the fertilizer value
The fermented liquid manure has a better short term N-Fertilizer effect.
Heavy Metal load

Heavy Metals can not be reduced by the biogas process
- Cadmium (Cd)
- Chrome (Cr)
- Mercury (Hg)
- Plumb (Pb)
- Copper (Cu)
- Nickel (Ni)
- Zinc (Zn)

Because drymatter content is lowered during biogas-process, in the corelation the heavy metal concentration rises

After seperation most of the heavy metals content remains in the solid phase.
Certain Antibiotics can be reduced by the biogas process:

- Sulfadiazin
- Sulfamethazin
- Chlortetracyclin
- Oxytetracyclin
- Tetracyclin

In a field test in 15 biogas plants an elimination of antibiotics between digester entrance and exit could be proven.

In the case of Chlortetracyclin the antibiotic inactive Iso-Chlortetracycllin was confirmed as the main product of elimination.
Use of biogas digestate

**Digestate can be spread on the fields**
- no hygiene restrictions with animal slurry and plant material

**Improved Fertilizer**
- avoids nutrient losses
- reduces burning effect on plants
- improves flowing properties
- improves plant compatibility
- improves plant health
- reduces germination ability of weed seeds

**Environmentally sound**
- reduces the intensity of odor
- reduces air pollution through methane and ammonia
- reduces the wash out of nitrate
- sanitizes liquid manure
- recycles organic residues (co-fermentation)
- can avoid connection costs to a central sewer
2. Land Application of Digestate
Liquid digestate processing and fertilization

**Digestate storage**
After the anaerobic treatment of liquid manure and during the storage nitrogen losses occur in form of ammonia

**Digestate land application**
During the application nitrogen losses can be presented in gaseous form (ammonia) and in mineral form (nitrate)
Land application techniques

Drag hose tractor: precise fertilization, around 41% lower NH₃ emissions

Fertilizer distributor tractor: strong smell and ammonia emissions, wind-sensitively
Measures during liquid digestate application

- No excessive agitation before the application
- Deploy cooled substrate from the final storage
- Spread using emission-reducing techniques (drag hose tractor, etc.), and
- Processing the digestate

To prevent the nitrate leaching by liquid digestate fertilization other measures, besides the type of treatment must be taken into account:

- Sufficient storage capacity (at least 6 months)
- Periods of application
- Quantity of liquid digestate (and thus N-quantity) to be applied
- Spreading technology
### Example filling level in percent of the total end storage capacity

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflow in m³ for a daily production of 19.2 m³</td>
<td>2339</td>
<td>1131</td>
<td>595</td>
<td>575</td>
<td>595</td>
<td>1170</td>
<td>595</td>
</tr>
<tr>
<td>Taking out in m³</td>
<td>0</td>
<td>0</td>
<td>1400</td>
<td>4080</td>
<td>0</td>
<td>882</td>
<td>638</td>
</tr>
<tr>
<td>Proportional filling in m³</td>
<td>3179</td>
<td>4310</td>
<td>3505</td>
<td>0</td>
<td>595</td>
<td>883</td>
<td>840</td>
</tr>
<tr>
<td>Filling of the endstorage in % with storage capacity of 3500 m³ (=182 days or 6 months)</td>
<td>91 % *</td>
<td>123 %</td>
<td>100 %</td>
<td>0 % **</td>
<td>17 %</td>
<td>25%</td>
<td>24%</td>
</tr>
<tr>
<td>Filling of the endstorage in % with storage capacity of 4800 m³ (=250 days or 8,3 months)</td>
<td>66%</td>
<td>90%</td>
<td>73%</td>
<td>0 % **</td>
<td>12 %</td>
<td>18%</td>
<td>17%</td>
</tr>
</tbody>
</table>

* Around middle December the endstorage would be already 100% full
** Once a year the storage is emptied (+/- 20 m³)
*** 10% buffer for rain water, that accumulates in the silo, and in case of unfavorable weather conditions at the beginning of march no digestate can be spread
3. Digestate Processing
Reasons for processing digested slurry

- Saves storage volume (liquid phase)
- Surplus of nutrients or lacking area for land spreading
  - Export of nutrients required
- Digestate contains 70-90% of water
  - Removing water saves transport costs
- Reduced costs for land spreading
- Reduced environmental impacts
  - Nutrients release in the liquid phase
  - Reduction of volatile air pollutants
  - Odor reduction
Basic principles of digestate processing

- **Physical**
  - Liquid-solid separation
  - Membrane technology
  - Vacuum evaporation

- **Chemical**
  - Flocculation
  - Precipitation (MAP, Phosphate)

- **Biological**
  - Anaerobic digestion
  - Composting (aerobe)
  - Activated sludge process (aerobe)
  - Nitrification, denitrification
Processing strategies

1. Partial separation
   - Elimination of P2O5

   [Diagram showing flow of digestate from biogas plant to liquid-solid separation, followed by compost and N,P,K for land spreading.]

2. Complete separation
   - Elimination of P2O5 + N

   [Diagram showing flow of digestate from biogas plant to liquid-solid separation, primary cleaning (ultra filtration/vacuum evaporation), secondary cleaning (reverse osmosis), purified water, and concentrated fertiliser.]
Applied Technologies

- Liquid-solid separation
  - Screw press
    - Decanter centrifuge
    - Drying
- Membrane technology
- Vacuum evaporation
Liquid solid separation – partial processing

Separation of solid contents

→ always the 1st processing step!!!

Removal of:

- 20-80 % $P_{tot}$
- 10-20 % $N_{tot}$
- Production of compost

→ humus balance
## Nutrient distribution

<table>
<thead>
<tr>
<th>Liquid phase</th>
<th>Manure separation</th>
<th>Solid phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>95 %</td>
<td>Ammonium</td>
<td>5 %</td>
</tr>
<tr>
<td>5 %</td>
<td>organic Nitrogen</td>
<td>95 %</td>
</tr>
<tr>
<td>80 %</td>
<td>Potassium</td>
<td>20 %</td>
</tr>
<tr>
<td>10 %</td>
<td>Methane</td>
<td>90 %</td>
</tr>
</tbody>
</table>

### Variable content

<table>
<thead>
<tr>
<th>50-1 %</th>
<th>50-99 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorous*</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>80-90 %</th>
<th>10-20 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume**</td>
<td></td>
</tr>
</tbody>
</table>

* depending on the application of precipitants
** depending on chosen machinery
Liquid-solid separation - screw press

- Simple device – often applied
- Required coarse material for efficient operation
- Wearing part: screen (depending on input matter)

Removes:

- 15-20 % DM
- approx. 5 % DM in liquid phase

Investment costs:

20,000 - 50,000 €
Liquid-solid separation - Decanter centrifuge

- Higher removal rate
- Suitable for subsequent complete nutrient elimination
- Digestate’s properties = criterium for device selection

Removes:
- 30-40 % DS
- approx. 1-3 % DM in liquid phase

Investment costs:
150,000 - 250,000 €

Source: www.huber.de
Liquid-solid separation - Solar drying

- Simple technology – mainly applied for sewage sludge
- Combined utilisation of solar heat and waste heat
- Requires complex control system

**Removes:**
- Water
- Partial N-losses

**Investment costs:**
approx. 300,000 €
(digestate from 450 kWel. Plant)
Heat coupled microgas turbine in combination with a solar supported digestate drying process at the Farm at Karle, Fuessbach, Germany
Complete nutrient separation

**Elimination of P2O5 + N**

- Digestate from biogas plant
- Liquid-solid separation
- Primary cleaning (ultra filtration/vacuum evaporation)
- Secondary cleaning (reverse osmosis)
- Purified water
- Compost: C, P\textsubscript{2}O\textsubscript{5}, N\textsubscript{org}
- Concentrated fertiliser: N, P
- Concentrated fertiliser: N, K

- Complex processes, requires sophisticated technology
- High energy demand
- Economically viable only at big biogas plants > 700 kW\textsubscript{el}
Complete separation - Membrane technology

- Anaerobic digestion = best preparation
- Requires good removal of coarse & fibrous material (DM content $\approx 1\%$)
- The better AD and solids separation were, the better performe the membranes!

Quelle: www.haase-energiotechnik.de 2007
Complete separation – (Vacuum-) Evaporation

Example:
3-MW biogas plant
Vacuum evaporation

 Digested slurry from biogas plant

Adjustment of pH-value

Separated solids (fertiliser)

Liquid-solid separation

Removal of fine fibres

3-stageous vacuum evaporation

Condensate

Concentrate (fertiliser)
Output costs depending on transport distance

Specific costs [€/m³] vs Transport distance [km]

- Tractor truck with 2 hanger (load capacity every 14t)
- Tractor truck with 2 hanger (load capacity every 14t) + 2,5 €/m³ output cost
- Motor truck (25t)
- Motor truck (25t) + 2,5 €/m³ output cost
- Self-propelled unit for output + retrieval vehicle
- Tractor truck with vacuum baril
Separated material – and now ???

- 1 substance ↔ 2-4 different material flows
- Concentrated nutrients might contain high salt loads
- Concentrated nutrients allow specific fertilizer mixing
- Utilization on own farm (partial nutrient removal)
- Marketing?
- Marketing channels?
- Quality assurance and control

Requires good planning & strategic partners
4. Treatment Costs / Profitability
Treatment costs

The total costs for a decanter separation are about 1,- € per t according to data of a Danish biogas manufacturer. This price in Denmark is profitable for many large cattle farmers.

A further separation in the evaporator is more expensive (approx. 3.40 € per t). This expenditure should be paid back by saved transport costs and by a better utilization of fertilizer as well as by the improved spreading.

Long distances transportation of manure for the fraction which cannot be used in the surroundings of the enterprise would be more profitable.

Economic value of digestate is indicated either as 10 € per LU per year or related to the nutrients also e.g. (2008):

- 55 €/ t N,
- 56 €/ t P,
- 28 €/ t K.
Partial separation - profitability

Fertilizer value improvement (Source KTBL 2010):

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>Amount C1 (kg/t)</th>
<th>Value C1 (€/t)</th>
<th>Amount C2 (kg/t)</th>
<th>Value C2 (€/t)</th>
<th>Δ Value C2 – C1 (€/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>9,69</td>
<td>5,81</td>
<td>11,5</td>
<td>6,90</td>
<td>1,09</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>4,97</td>
<td>2,24</td>
<td>13,82</td>
<td>6,22</td>
<td>3,98</td>
</tr>
<tr>
<td>K₂O</td>
<td>5,29</td>
<td>1,85</td>
<td>8,35</td>
<td>2,92</td>
<td>1,07</td>
</tr>
</tbody>
</table>

Σ = 6,14

In areas where P₂O₅ is not required, the one step treatment and external transport make sense and could be profitable.

C1: unseperated digestate; C2: seperated digestate
<table>
<thead>
<tr>
<th>Case study</th>
<th>Example 1</th>
<th>Example 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Decanter-centrifuge</td>
<td>Decanter-centrifuge</td>
</tr>
<tr>
<td>Scenario</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total digestate quantity after decanter (t/a)</td>
<td>65 190</td>
<td>69 385</td>
</tr>
<tr>
<td>Liquid digestate quantity</td>
<td>24 745</td>
<td>27 995</td>
</tr>
<tr>
<td>Solid digestate quantity</td>
<td>6 860</td>
<td>7 775</td>
</tr>
<tr>
<td>UF filtrat quantity</td>
<td>-</td>
<td>23 800</td>
</tr>
<tr>
<td>RO permeat quantity</td>
<td>-</td>
<td>17 850</td>
</tr>
</tbody>
</table>

**Investments**

<table>
<thead>
<tr>
<th></th>
<th>Example 1</th>
<th>Example 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>618 625</td>
<td>-</td>
</tr>
<tr>
<td>Digestate storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Months storage, 50€/m³)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentrat storage</td>
<td>-</td>
<td>104 125</td>
</tr>
<tr>
<td>(35€/m³)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid digestate storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage capacity for 4 months, 70€/m³)</td>
<td>160 067</td>
<td>181 417</td>
</tr>
<tr>
<td>Equipments hall</td>
<td>12 000</td>
<td>30 000</td>
</tr>
<tr>
<td>Interest rate</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>Amortisation period</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

**Storage annuity**

<table>
<thead>
<tr>
<th></th>
<th>Example 1</th>
<th>Example 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>61 853</td>
<td>24 684</td>
</tr>
<tr>
<td>Decanter-centrifuge</td>
<td>110 000</td>
<td>110 000</td>
</tr>
<tr>
<td>Peripheral equipments</td>
<td>35 000</td>
<td>35 000</td>
</tr>
<tr>
<td>(Intermediate digestate storage, pipework, pump)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultrafiltration equipement</td>
<td>-</td>
<td>270 000</td>
</tr>
<tr>
<td>Reverse osmosis equipement</td>
<td>-</td>
<td>210 000</td>
</tr>
<tr>
<td>Membrane filtration peripheral equipments</td>
<td>-</td>
<td>70 000</td>
</tr>
<tr>
<td>(Intermediate storage, pumps, pipework)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipement investment</td>
<td>145 000</td>
<td>695 000</td>
</tr>
<tr>
<td>Interest rate</td>
<td>6%</td>
<td>6%</td>
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<tr>
<td>Amortisation period</td>
<td>10</td>
<td>10</td>
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</table>

**Equipment annuity**

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>19 701</td>
<td>94 428</td>
</tr>
</tbody>
</table>

**Total annuity**

<table>
<thead>
<tr>
<th></th>
<th>Example 1</th>
<th>Example 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>81 554</td>
<td>119 112</td>
</tr>
<tr>
<td>Case study</td>
<td>Example 1</td>
<td>Example 2</td>
</tr>
<tr>
<td>------------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>Scenario</td>
<td>Decanter-centrifuge</td>
<td>Decanter-centrifuge Ultrafiltration Reverse osmosis</td>
</tr>
<tr>
<td><strong>Current costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total repairs (3%)</td>
<td>4 350</td>
<td>20 850</td>
</tr>
<tr>
<td>Energy costs (power cost 10 €Cent/kWh, Heat cost 0 €Cent/kWh)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decanter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power requirement 3.5 kWh/m³</td>
<td>22 817</td>
<td>24 825</td>
</tr>
<tr>
<td>UF-Ultrafiltration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power requirement 12 kWh/m³</td>
<td>-</td>
<td>33 594</td>
</tr>
<tr>
<td>RO-Reverse osmosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power requirement 6 kWh/m³</td>
<td>-</td>
<td>14 280</td>
</tr>
<tr>
<td><strong>Operating resources</strong></td>
<td></td>
<td></td>
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<tr>
<td>Decanter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flocculation agent (120 g/m³, 1.2 €/kg)</td>
<td>-</td>
<td>9 991</td>
</tr>
<tr>
<td>UF-Ultrafiltration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acaline cleaning agent (1000 l/a, 2 €/l)</td>
<td>-</td>
<td>2 000</td>
</tr>
<tr>
<td>Acid cleaning agent (1000 l/a, 2 €/l)</td>
<td>-</td>
<td>2 000</td>
</tr>
<tr>
<td>Membrane replacement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Flux=50 l/m²·h, 180 €/m², durability: 3 a)</td>
<td>-</td>
<td>3 574</td>
</tr>
<tr>
<td>RO-reverse osmosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RO-sulfuric acid (1.5 kg/m³, 0.12 €/kg)</td>
<td>-</td>
<td>4 284</td>
</tr>
<tr>
<td>Antiscalant (20 ml/m³, 3.5 €/l)</td>
<td>-</td>
<td>1 666</td>
</tr>
<tr>
<td>Acaline cleaning agent (400 l/a, 2 €/l)</td>
<td>-</td>
<td>800</td>
</tr>
<tr>
<td>Acid cleaning agent (400 l/a, 2 €/l)</td>
<td>-</td>
<td>800</td>
</tr>
<tr>
<td>Membrane replacement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Flux=12 l/m²·h, 25 €/m², durability: 2 a)</td>
<td>-</td>
<td>2 327</td>
</tr>
<tr>
<td><strong>Other operating resources</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>3 000</td>
</tr>
<tr>
<td><strong>Personnel costs (20 €/h)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decanter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1 h/d, 333 working day)</td>
<td>6 667</td>
<td>6 667</td>
</tr>
<tr>
<td>UF-Ultrafiltration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2.5 h/d, 333 working day)</td>
<td>-</td>
<td>16 667</td>
</tr>
<tr>
<td>RO-Reverse osmosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1.5 h/d, 333 working day)</td>
<td>-</td>
<td>9 990</td>
</tr>
<tr>
<td><strong>Total current costs</strong></td>
<td>33 833</td>
<td>156 773</td>
</tr>
<tr>
<td>Case study</td>
<td>Example 1</td>
<td>Example 2</td>
</tr>
<tr>
<td>------------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>Scenario</td>
<td>Decanter-centrifuge</td>
<td>Decanter-centrifuge Ultrafiltration Reverse osmosis</td>
</tr>
<tr>
<td>Total cost (investment+current)</td>
<td>115 387</td>
<td>275 885</td>
</tr>
<tr>
<td>Output costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External digestate disposal (10 €/t)</td>
<td>247 450</td>
<td>-</td>
</tr>
<tr>
<td>Solid digestate utilisation (6.5 €/t)</td>
<td>44 590</td>
<td>50 538</td>
</tr>
<tr>
<td>Output costs amount</td>
<td>292 040</td>
<td>50 538</td>
</tr>
<tr>
<td>Total costs amount</td>
<td>407 427</td>
<td>326 423</td>
</tr>
<tr>
<td>Total amount</td>
<td>12,89</td>
<td>10,33</td>
</tr>
</tbody>
</table>

(per m3 digestate exported)

Fuchs and Drosg, 2010
Conclusion

- Nutrients = problem (surplus) $\iff$ nutrient separation & export might be the only solution
- But: calculate carefully (expensive technology) and be aware that you might need to market nutrients
- Also: which nutrients do you need to get rid off – where are they? (nutrient distribution between liquid and solid phase)
- Complete nutrient removal is only viable at big biogas plants - not for plants < 1–1,5 MW
- Rising demand and increasing sizes of biogas plants might lead to decreasing technology prices
Thank you for your attention!

Michael Köttner
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