Stabilisation and mineralisation of sludge in reed bed system after 10 – 20 years of operation

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Investigation of stabilisation of sludges in three Danish STRBS: Helsinge, Nordborg and Nakskov.

• To evaluate the sludge quality after treatment in STRBS, comparing also the different pathways by which of stabilisation occurred.

• The efficiency in sludge stabilisation in the sludge residue within the STRBS after periods of operation between 9 – 21 years.

• Is it possible to hypothesise a connection between the sludge quality applied to the (STRBS) and different ways of stabilising (mineralisation or huminification) the sewage sludge accumulated in vertical profile.

To achieve this purpose, parameters correlated to biochemical properties of organic sludge matter have been determined.
Danish references:
Sludge Treatment System in Reed Beds

Sludge Type (Helsinge):
Mix of aerobic SAS/Conc. Anaerobic SAS

Sludge Type (Nordborg):
Mix of SAS/Digested primary sludge (Anaerobic)

Sludge Type (Nakskov):
SAS (anaerobic) from sec. sedimen. tanks

Photo: Orbicon

Photo: Orbicon

Photo: Orbicon
Helsinge (STRBS)

Basins : 10
Area load : 46-83 kg ds/m²/yr
Load/rest ratio : 40-60/4-7 days
Acc. Rate : 0.12 m/yr.
Nordborg (STRBS)

- Basins: 10
- Area load: 36-46 kg ds/m²/yr
- Load/rest ratio: 40-70/4-7 days
- Acc. Rate: 0.11 m/yr.

Photo: Orbicon
Nakskov (STRBS)

Basins : 10
Area load : 30-50 kg ds/m²/yr
Load/rest ratio : 40-50/5-7 days
Acc. Rate : 0.07 m/yr.
# Waste water treatment plants (WWTP) and STRBS operations data

<table>
<thead>
<tr>
<th>(Helsinge)</th>
<th>(Nordborg)</th>
<th>(Nakskov)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population equivalent (PE.)</td>
<td>42,000</td>
<td>18,000</td>
</tr>
<tr>
<td>Sludge type</td>
<td>Mix SAS/-Anaerobic SAS</td>
<td>Mix SAS/Digested SAS</td>
</tr>
<tr>
<td>Phosphorus removal</td>
<td>PAX/Fe</td>
<td>PAX/PIX</td>
</tr>
<tr>
<td>Capacity (tons ds y(^{-1}))</td>
<td>630</td>
<td>350</td>
</tr>
</tbody>
</table>

## Quality (Feed Sludge)

<table>
<thead>
<tr>
<th>(Helsinge)</th>
<th>(Nordborg)</th>
<th>(Nakskov)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Solid (%)</td>
<td>0.6-0.8%</td>
<td>0.6-0.8%</td>
</tr>
<tr>
<td>Loss on ignition (%)</td>
<td>45-65%</td>
<td>50-65%</td>
</tr>
<tr>
<td>Fat (mg/kg ds)</td>
<td>500-7,000</td>
<td>500-8,000</td>
</tr>
<tr>
<td>Oil (mg/kg ds)</td>
<td>100-2,000</td>
<td>100-4,000</td>
</tr>
<tr>
<td>Sludge Age (aerobic-days)</td>
<td>20-25</td>
<td>20-25</td>
</tr>
</tbody>
</table>

- **Start of the operation period**: 1996, 2003, 1990
- **Total basin area (m\(^2\))**: 10,500 (10 basins), 7,000 (10 basins), 9,920 (10 basins)
- **Basin area (m\(^2\))**: 1,050, 700, 818 – 1,308
- **Loading rate (kg ds m\(^{-2}\) y\(^{-1}\)) – Dim.**: 60, 50, 50
- **Loading rate (kg ds m\(^{-2}\) y\(^{-1}\)) – Real**: 46-83, 36-46, 30-50
- **Loading/Resting (days)**: 4-7/40-60, 4-7/40-70, 5-7/40-50
- **Resting period (months) before emptying**: 4-5, 3-4, 2-3
- **Sludge height at the emptying period (cm)**: 110 – 150, 90-100, 110-140

## Quality (Sludge residue)

<table>
<thead>
<tr>
<th>(Helsinge)</th>
<th>(Nordborg)</th>
<th>(Nakskov)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat (mg/kg ds)</td>
<td>App. 100</td>
<td>100-1,000</td>
</tr>
<tr>
<td>Oil (mg/kg ds)</td>
<td>100-500</td>
<td>100-1,000</td>
</tr>
<tr>
<td>Loss on ignition (%)</td>
<td>40-50%</td>
<td>40-55%</td>
</tr>
</tbody>
</table>

Steen Nielsen - smni@orbicon.dk
Sampling

1-4 in sites in 1 basin were randomly selected within each of the 3 the STRBS.

Samples were collected by a 3-cm diameter stainless steel corer.

Separated in approximately 10-cm depth fractions.

Samples from the same depth were pooled and mixed

Sampling after one entire cycle of full operation:

**Nakskov**
May 2011
Basin no. 3
3 months after the last load
Profile: 150 cm

**Nordborg**
June 2011
Basin no. 3
3 months after the last load
Profile: 90 cm

**Helsinge**
August 2008
Basin no. 10
4 months after the last load
Profile: 150 cm

The deepest sludge residue layers (layer 8 to 10) are between 9 and 21 years old.
Total organic carbon (% C) : Decreased
Water soluble carbon (mg c/kg ds h) : Decreased
β-glucosidase activity (mg PNP/kg ds h) : Decreased
Total nitrogen (% N) : Decreased
N-NH₃ (mg N/kg ds) : Decreased
Urease activity (mg NH₄+/kg ds h) : Decreased
Total organic carbon (% C) : Decreased
Water soluble carbon (mg c/kg ds h) : Decreased
β-glucosidase activity (mg PNP/kg ds h) : Decreased

Total nitrogen (% N) : Decreased
N-NH3 (mg N/kg ds) : Decreased
Urease activity (mg NH4+/kg ds h) : Stable
Total organic carbon (% C) : Unchanged
Water soluble carbon (mg c/kg ds h) : Decreased
β-glucosidase activity (mg PNP/kg ds h) : Decreased

Total nitrogen (% N) : Unchanged
N-NH3 (mg N/kg ds) : Decreased
Urease activity (mg NH4+/kg ds h) : Decreased
The level of humic carbon (FA+HA) decreased with increasing depths - suggesting that a mineralisation process was still occurring.

PEC: The increase with increasing depth indicated that the process of humification was successful in stabilizing organic matters. As the labile organic matter had been decomposed with increasing depth - the humification process had started in stabilizing the organic matter with the synergic action of plant and microorganisms.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Helsinge</th>
<th>Nordborg</th>
<th>Nakskov</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>FA (mg C/kg ds)</td>
<td>26662b</td>
<td>18720a</td>
<td>19686a</td>
</tr>
<tr>
<td>HA (mg C/kg ds)</td>
<td>13200b</td>
<td>8371a</td>
<td>7834a</td>
</tr>
<tr>
<td>PEC (mg C/kg ds)</td>
<td>9430b</td>
<td>8759ab</td>
<td>8306a</td>
</tr>
<tr>
<td>PEC/WSC</td>
<td>2.21a</td>
<td>5.07b</td>
<td>4.53b</td>
</tr>
<tr>
<td>β-Gluc ex (mg PNP/kg ds)</td>
<td>14.3ab</td>
<td>19.0b</td>
<td>10.5a</td>
</tr>
<tr>
<td>Urease ex (mg NH₄⁺/kg ds h)</td>
<td>9.37b</td>
<td>6.06a</td>
<td>7.37ab</td>
</tr>
</tbody>
</table>

Different letters (a, b, c) mean values significantly different \( (P<0.05) \) between layers within each STRBS.

- **Decreased**
- **Unchanged**
- **Increased**
- **Achieved height values**

Throughout the entire profile, fulvic acids (FA) and humic acids (HA) seemed to be inversely correlated: FA reduced with increasing depth, the HA raised to high concentrations.
Humic substances characterisation (2)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Helsinge</th>
<th></th>
<th></th>
<th></th>
<th>Nordborg</th>
<th></th>
<th></th>
<th></th>
<th>Nakskov</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>4</td>
<td>8</td>
<td></td>
<td>1</td>
<td>5</td>
<td>10</td>
<td></td>
<td>1</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>FA (mg C/kg ds)</td>
<td>26662b</td>
<td>18720a</td>
<td>19686a</td>
<td></td>
<td>25374b</td>
<td>19364a</td>
<td>16574a</td>
<td></td>
<td>12603a</td>
<td>18184b</td>
<td>11852a</td>
</tr>
<tr>
<td>HA (mg C/kg ds)</td>
<td>13200b</td>
<td>8371a</td>
<td>7834a</td>
<td></td>
<td>4722a</td>
<td>4185a</td>
<td>6868b</td>
<td></td>
<td>4185a</td>
<td>3756a</td>
<td>7083b</td>
</tr>
<tr>
<td>PEC (mg C/kg ds)</td>
<td>9430b</td>
<td>8759ab</td>
<td>8306a</td>
<td></td>
<td>7146a</td>
<td>7135a</td>
<td>7019a</td>
<td></td>
<td>7745a</td>
<td>7088a</td>
<td>12319b</td>
</tr>
<tr>
<td>PEC/WSC</td>
<td>2.21a</td>
<td>5.07b</td>
<td>4.53b</td>
<td></td>
<td>2.53a</td>
<td>5.08b</td>
<td>5.79b</td>
<td></td>
<td>1.36a</td>
<td>5.38b</td>
<td>6.80c</td>
</tr>
<tr>
<td>β-Gluc ex (mg PNP/kg ds)</td>
<td>14.3ab</td>
<td>19.0b</td>
<td>10.5a</td>
<td></td>
<td>12.8a</td>
<td>17.3a</td>
<td>12.2a</td>
<td></td>
<td>16.7b</td>
<td>10.4ab</td>
<td>6.8a</td>
</tr>
<tr>
<td>Urease ex (mg NH₄⁺/kg ds h)</td>
<td>9.37b</td>
<td>6.06a</td>
<td>7.37ab</td>
<td></td>
<td>6.22a</td>
<td>5.86a</td>
<td>6.08a</td>
<td></td>
<td>7.78b</td>
<td>5.42a</td>
<td>5.03a</td>
</tr>
</tbody>
</table>

Different letters (a, b, c) mean values significantly different ($P<0.05$) between layers within each STRBS.

These results are also confirmed by the trend of PEC/WSC ratio, which increased significantly in the deepest layers.

The level of humic-enzyme complexes (extracellular b-glucosidase and urease enzymes) reached high values in all STRBSs, demonstrating that a significant nucleus of humic-enzyme complexes resistant to microbial and environmental action were formed during the stabilisation process.
Principal component analysis (PCA)

Principal component loadings.

The PCA of the data set indicated that the 62.0% of the data variance as being contained in two components. *parameters used for PCA interpretation

<table>
<thead>
<tr>
<th></th>
<th>PC 1</th>
<th>PC 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Organic Carbon</td>
<td>-0.17</td>
<td>0.55</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>0.26</td>
<td>0.78*</td>
</tr>
<tr>
<td>Water Soluble Carbon</td>
<td>0.40</td>
<td>0.19</td>
</tr>
<tr>
<td>N-NH₃</td>
<td>0.01</td>
<td>0.91*</td>
</tr>
<tr>
<td>β-glucosidase</td>
<td>0.81*</td>
<td>-0.12</td>
</tr>
<tr>
<td>Urease</td>
<td>0.84*</td>
<td>0.10</td>
</tr>
<tr>
<td>Fulvic Acids</td>
<td>0.40</td>
<td>0.59</td>
</tr>
<tr>
<td>Humic Acids</td>
<td>-0.49</td>
<td>0.78*</td>
</tr>
<tr>
<td>PEC</td>
<td>-0.81*</td>
<td>0.28</td>
</tr>
<tr>
<td>β-glucosidase ex</td>
<td>0.74*</td>
<td>0.25</td>
</tr>
<tr>
<td>Urease ex</td>
<td>0.40</td>
<td>0.62*</td>
</tr>
</tbody>
</table>

On PC 2 are significant with the same sign (+) the TN, N-NH₃, HA and extracellular urease activity.

This means that all these parameters are positively correlated and have the same behaviour (when one of these parameters increase, also the other increase, and vice versa).
Principal component analysis (NORDBORG): Biplot of scores and loadings

(PC 1 linket to Huminification vs PC 2 linket to Mineralisation).

- The samples shifted on PC 1 and PC2.
- Humification and mineralization processes are present in the same level.
- With increasing depth, the layers were shifted from the top right to the bottom left of the plot.
- Suggesting equilibrium in mineralisation and humification processes.
Principal component analysis (HELSINGE):
Biplot of scores and loadings

(PC 1 linket to Huminification vs
PC 2 linket to Mineralisation).

The samples shifted only across PC 2, from the top to the bottom of the plot, highlighting the decrease with increasing depth of all parameters linked to N cycle.

Clearly linked to mineralisation process,

which has involved not only the easily degradable compounds, but also the more stabilised.

This fact means that in the surface layers, the content of TN, N-NH3, HA and extracellular urease activity is higher with respect to the deepest layers.

The process of mineralization seemed to have interested not only:

• the easily degradable organic matter (decrease of TN and N-NH3 from the surface to the depth)
• but also the humic acids (HA), which represent the more stable forms of organic matter.

Decrease of HA means an high level of mineralization

High content of TN and N-NH3 mean a high degree of mineralization
**Principal component analysis (NAKSKOV): Biplot of scores and loadings**

(PC 1 linket to Huminification

**vs**

PC 2 linket to Mineralisation).

Clearly associated to the humification process, the layers were shifted along the PC1.

With increasing depth, the layers were shifted along the PC1, from the right to the left, thus highlighting the decrease of total enzymatic activities and the increase in PEC.

PEC increase means high level of humification

Low level of total enzymatic activities means low level of mineralization process.

Comment: On PC 1 are significant the B-Gluc activity, the urease activity, the extracellular B Gluc (all with + sign), and the PEC (with – sign).

This fact means that where the b-glucosidase activities and the urease activities are higher, the PEC is lower, and vice versa (total and extra b-gluc activities and total urease activity, are negatively correlated).

For what concern the Nakskov samples, they shifted from right to left across PC 1 and they don’t change on PC 2, so this RBS is more influenced by the parameters that are significant on PC 1.

The layers of Nakskov samples shifted from right to left as their depth, so the surface layers are in the right of the plot, while the deepest are in the left.

This fact means that the surface layers are characterized by higher level of enzymatic activities and low level of PEC, while the deepest layers are characterized by low level of enzymatic activities and a higher level of PEC.
Conclusions (1 – 2)

Stabilisation of sludges was investigated in three different Danish STRBSs (Helsinge, Nordborg, Nakskov).

• The study demonstrated the successful stabilisation of organic matter in the three systems.

• The quality of sludge applied did not affect the process of stabilisation, even though different pathways were followed.

• On the basis of the biochemical characterisation of sludge residue

• It is, in fact, possible to firmly establish a connection between the sludge quality applied (deriving from different treatment aerobic and/or anaerobic processes) to the STRBSs and the different pathways of organic matter stabilisation (humification and/or mineralisation processes).
Conclusions (2 – 2)

The presence/absence of anaerobic sludge seemed to have a considerable influence on the stabilisation occurring in the STRBSs:

In the case of:
Aerobic sludges, the humification process will be prevalent

Anaerobic sludges, the mineralisation process is likely to override the other processes of stabilisation.

The STRB is, if the system has the right dimensioning, design and operation in relation to the sludge quality, a feasible technology for sludge treatment and stabilisation before its final land disposal.
THANK YOU FOR YOUR ATTENTION

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Eleonora Peruzzi

Photo: Orbicon