Algae for wastewater treatment

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Project basics and aim

Title: Combined algal and bacterial waste water treatment for high environmental quality effluents (ALBAQUA)

Reduced energy demand for $O_2$ supply to aerobic treatment stages

Improved $CO_2$ balance and degradation performance

issue applicable, efficient and economical for the paper industry?
Project consortium
Project topics

- **Know how transfer**
- **WP 1**
  - Cultivation
- **WP 2, 4**
  - Operating conditions
- **WP 3, 5**
  - Degradation performance
  - Energy supply
  - Biofuel
  - Raw material
- **WP 6**
  - Utilisation of excess sludge/waste
- **WP 8, 9**
  - LCA, Economics

Microalgae
Trials – overview lab scale tests

Cultivation

• Isolation of algae from paper mill effluents
• Cultivation and pre-selection of suitable algae species

Design parameters

• Continuous operation of a lab scale waste water treatment unit
• Operated with real waste water of a paper mill wwtp
• Varying operating parameters
• Trials so far: with chlorella vulgaris
Results – algae isolation and cultivation

Example: algae observed in paper mill effluent

Isolation: dilution method by plating on agar plates

Re-suspension in medium of the isolated cells after plating

6 algae species suitable for paper industry effluent treatment found
Trials – lab scale plants
**Trials – overview lab scale tests**

**Degradation performance**

|------------------------|-------------------------------|-----------------------|----------------------------------|-----------------------------------|-----------------------------------|-------------------------------|---------------------|

**Degradation performance of various effluents from paper industry**

- Algae fixation trials
- Conventional activated sludge
- Algae-bacteria Biomass
- Algae-bacteria Biomass + Effluent 1
- Algae-bacteria Biomass + Effluent 2
- Algae-bacteria Biomass + Effluent 3
- Algae-bacteria Biomass + Effluent 4
- Single Algae-Biomass

*Nearly similar operating conditions in all bioreactors*  
*Currently all trials with *Chlorella vulgaris***
## Trials – operating conditions and parameters

<table>
<thead>
<tr>
<th>Operating parameter</th>
<th>Lab scale trials</th>
<th>Pilot trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>F/M</td>
<td>0.05–0.1 kg BOD₅/(kg dsm.d)</td>
<td>0.03 – 0.09 BOD : VS</td>
</tr>
<tr>
<td>HRT</td>
<td>2–5 d</td>
<td>2 d, 3,8 d, 1,8 d</td>
</tr>
<tr>
<td>DSM</td>
<td>0.3–2.5 g/l</td>
<td>0.5 – 2.5 g/l</td>
</tr>
<tr>
<td>nutrition load</td>
<td>C:N:P = 1100:6:0,5</td>
<td></td>
</tr>
<tr>
<td>O₂ concentration</td>
<td>2–6 mg/l</td>
<td>2–8 mg/l</td>
</tr>
<tr>
<td></td>
<td>(supplied by algae – no aeration)</td>
<td>(supplied by algae – no aeration)</td>
</tr>
<tr>
<td>temperature/pH</td>
<td>T 25 – 30° C; pH 7,5-8,5</td>
<td>T 15 – 30° C; pH 7,5-9,5</td>
</tr>
<tr>
<td>lighting</td>
<td>10:14 h and 12:12 h</td>
<td>natural daylight</td>
</tr>
<tr>
<td>measured parameter</td>
<td>Chl-a, DSM, COD, BOD₅, TOC, NH₄, NO₃, NO₂, PO₄</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(partly: microorganism composition) TOC (DOC)</td>
<td></td>
</tr>
<tr>
<td>calculated parameter</td>
<td>HRT, F/M, SRT, algae:bacteria ratio</td>
<td></td>
</tr>
</tbody>
</table>
Results – examples effluent degradation

COD degradation all Reactors

F/M 0,05 hrt 7d
F/M↑0,25 hrt↓ 1d

degradation %

time/d

Reactor 1
Reactor 2
Reactor 3
Reactor 4
### Results – summary effluents degradation

<table>
<thead>
<tr>
<th>paper mill</th>
<th>Raw material</th>
<th>Products</th>
<th>Settle-ability</th>
<th>Degradation performance</th>
<th>No ext. Aeration</th>
<th>Chl a+b µg/ml</th>
<th>O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mech. pulp, waste paper</td>
<td>printing papers</td>
<td>☺☺</td>
<td>80 %</td>
<td>✧</td>
<td>✧</td>
<td>✧</td>
</tr>
<tr>
<td>2</td>
<td>pulp, waste paper</td>
<td>wood containing coated printing paper</td>
<td>☺☺</td>
<td>70 %</td>
<td>✧</td>
<td>✧</td>
<td>✧</td>
</tr>
<tr>
<td>3</td>
<td>waste paper</td>
<td>board</td>
<td>☺☺</td>
<td>80%</td>
<td>✧</td>
<td>✧</td>
<td>✧</td>
</tr>
<tr>
<td>4</td>
<td>waste paper</td>
<td>board</td>
<td>☺☺</td>
<td>70 %</td>
<td>✧</td>
<td>✧</td>
<td>✧</td>
</tr>
<tr>
<td>5</td>
<td>pulp</td>
<td>Woodfree graphic paper</td>
<td>☺☺</td>
<td>76 %</td>
<td>✧</td>
<td>✧</td>
<td>✧</td>
</tr>
<tr>
<td>6</td>
<td>waste paper</td>
<td>board</td>
<td>☺☺</td>
<td>72 %</td>
<td>✧</td>
<td>✧</td>
<td>✧</td>
</tr>
<tr>
<td>7</td>
<td>waste paper</td>
<td>board</td>
<td>☺☺</td>
<td>70 %</td>
<td>✧</td>
<td>✧</td>
<td>✧</td>
</tr>
<tr>
<td>8</td>
<td>waste paper, pulp</td>
<td>Woodfree graphic paper</td>
<td>☺☺</td>
<td>76 %</td>
<td>✧</td>
<td>✧</td>
<td>✧</td>
</tr>
<tr>
<td>9</td>
<td>waste paper, mech. pulp</td>
<td>Newsprint</td>
<td>☺☺</td>
<td>65 %</td>
<td>✧</td>
<td>✧</td>
<td>✧</td>
</tr>
</tbody>
</table>
Results - sedimentation of algae-bacteria-biomass

before

after 2h

SVI: 30-40 ml/g

Good settling conditions
Results - microscopic investigation
## Results – algae-bacteria biomass characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mixed sludges</th>
<th>Activated sludge</th>
<th>Algae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash (%)</td>
<td>35 - 68</td>
<td>44</td>
<td>9</td>
</tr>
<tr>
<td>C (%)</td>
<td>23 - 34</td>
<td>36</td>
<td>46</td>
</tr>
<tr>
<td>N (%)</td>
<td>2,6 – 5,7</td>
<td>4,4</td>
<td>7,8</td>
</tr>
<tr>
<td>P (%)</td>
<td>2,0 – 3,9</td>
<td>2,2</td>
<td>4,4</td>
</tr>
<tr>
<td>Algae (%)</td>
<td>2,0 – 24</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Heating value (MJ/kg)</td>
<td>8 - 12</td>
<td>7</td>
<td>25,8 (Scenedesmus) 29 (Chlorella)</td>
</tr>
</tbody>
</table>
Trials – pilot plant
ALBAQUA
Biotechnological effluent treatment

Industrial waste

River Sora

Waste water tank

Cooling/heating system

Algae-bacterial photobioreactor

Data logging (pH, oxygen, conductivity, ORP, temp. sensors)

Mixing

Sludge recuperation

Treated water outflow

Sedimenter

Solar energy, CO2, nutrients
# Trials – overview pilot system and operation

<table>
<thead>
<tr>
<th>Capacity bioreactor</th>
<th>340 l</th>
</tr>
</thead>
</table>
| **Start-up**        | Initial batch tests  
|                     | Continuous operation Aug-Nov |
| **Sampling**        | **1x per batch cycle:**  
|                     | input and output water  
|                     | active biomass  
|                     | waste sludge  
|                     | **2x per week:**  
|                     | input and output water  
|                     | active biomass  
|                     | waste sludge |
| **Operation conditions** | mixing, pH, temp., conduct. redox, O₂, settling time, degradation performance  
|                     | Optimization of operation conditions: |
Characteristics Slovenian paper mill

**Production**  
printing paper (primary fibers, different programs)

**wwtp**  
chemo-mechanical waste water treatment  
volume of treated water: 3,000 m³/day, 1,065,000 m³/year  
volume of sludge produced: 1,800 t/year

<table>
<thead>
<tr>
<th>Effluent quality</th>
<th>Limit output values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended solids</td>
<td>80 mg/l</td>
</tr>
<tr>
<td>COD</td>
<td>110 mg/l</td>
</tr>
<tr>
<td>BOD</td>
<td>20 mg/l</td>
</tr>
<tr>
<td>N, P total</td>
<td>N (15 mg/l); P (3 mg/l)</td>
</tr>
<tr>
<td>pH</td>
<td>7</td>
</tr>
<tr>
<td>Temperature</td>
<td>30 – 39 °C</td>
</tr>
</tbody>
</table>
Results – pilot operation

**COD (mg/L) IN, OUT**

**BOD (mg/L) IN, OUT**
Lessons learned

• Algal bacterial community develops into a **natural** mix

• Sufficient oxigenation is easily achieved with large margin

• Major threat: Chironomidae larvae consume the sludge (algae first)
  ➔ physical barriers (cover, insect net), occasional violent mixing
  and/or biological agents (Bti, Bs) integrated into the bacterial sludge

• Some additional (clean) algae inoculation will be necessary

• Insolation is **not** a major constraint, temperature and mixing are
  more important

• Flocculation is easy; thinking of more violent mixing to prevent
  insects, flocculation and sedimentation in the reactor and have
  more time for the flocculation in the sedimenter

• On-line control of nutrients and Chl a will be required

• Sludge is being tested for biogas (with good preliminary results)
Recommendations for operation

- HRT between 1-3 day(s) depending of the wastewater COD
- For highly polluted wastewaters (COD over 800 mg/l) this system can not be suggested.
- A biomass conc. 1.5 – 2.5 g/l and a SRT of 16-20 days favour the algae growth.
- A sedimentation time of 2 – 3 hours can be selected.
- Since there are no blowers in the system, stirrers are needed to keep the flocs suspended → dead zones have to be avoided.
- \( \text{O}_2 \) and pH of the system should be monitored.
- The colour of the system is a good indicator of system health.
- Intermittent aeration with blowers will favour the heterotrophic bacteria in the system and therefore it has to be avoided.
Summary

- good settling of algal-bacterial biomass most of the time and for most treated effluents from paper industry
- good degradation results
- no external aeration necessary in algae-bacteria-bioreactors; sufficient O$_2$ concentration for bacterial heterotrophic degradation activity supplied by algae photosynthesis activity
- extrusion/devour of algae by excess bacterial biomass growth under operating conditions of
  \[ \text{HRT}<24 \text{ h}, \quad \text{DSM}_{\text{total}} > 3 \text{ g/l}, \quad B_{\text{TS}} > 0,25 \text{ kg BSB}_5/(\text{kg TS d}) \]
- unsatisfactory settling of algae on carriers/extrusion of algae by bacterial biomass
- Necessity of operation of covered/closed bioreactor system under natural conditions due to serious contamination problems (larvae)
Thank you for your kind attention!

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