New decentralized approach to Hospital wastewater treatment
Outline

1. Brief introduction to the BioBooster technology
2. Introduction to the problematic related to hospital wastewater
3. Presentation of results after two years of operation at Herlev Hospital - DK
100% subsidiary of Grundfos established in 2006
Focused on the development of MBR technology with rotative ceramic membranes
Design, Production, Erection, Commissioning + Operation + Optimization + Maintenance

Vision to turn projects into products through *modularization*
Wastewater Treatment at the point of source/*decentralized*
Robust - easy to operate - high performance - cost competitive
Membrane Filtration Unit (MFU)

Key features

- **Ceramic rotative membrane discs** with 200nm pore size (UF)
- Scouring and shear effects by rotating the discs. **No air** is needed
  - Enables **MLSS up to 60 g/L** inside the MFU
  - Enables more biological processes in one tank (aerobic, anoxic, anaerobic)
- **No membrane exchange.** Complete thermal regeneration when burning the discs
- **Average flux** between 40 y 60 LMH depending upon the application
- **Peak flux** of 80 LMH
- **Patented** design
Membrane eccentricity: $P_1 \neq P_2$

Shear stress:
- Delivered by the rotation of the membrane
- No air scouring is needed
- High effectiveness in preventing fouling

Axis aligned: $P_1 = P_2 = P_3$
Hospital wastewater - Current situation

Common pollutants (↑ Conc.)
COD, NH$_4$, PO$_4$, SS

Hospital residues and pollutants
Emerging micropollutants [ng/L]
Antibiotic resistant bacteria
Virus
Radioactivity

Conventional WWTP
Removal ≈ 70%
Increasing concern vs absence of legislation

The UE is watching 3 substances:

- 17α-ethinylestradiol (EE2) [0,035 ng/L]
- 17β-estradiol (E2) [0,4 ng/L]
- Diclofenac [10 ng/L]

Current accepted threshold:
PNEC (Predictable non-effect concentration)
Debate: Centralization vs decentralization + (Third alternative)

Amount of micropollutants generated at the hospitals: **5-20%**

**CENTRALIZED**

Implementation of appropriate tertiary treatment

*High cost*

Possibility to remove **100%** of the micropollutants discharged to water bodies

**DECENTRALIZED**

Implementation of appropriate technology

*Lower cost + enables water reuse*

Removal of micropollutants at the source: high concentrations at discharge points

Max. removal of **20%** of all micropollutants discharged to water bodies
Increase in the intake of (some) pharmaceutics according to the OECD

4.10.2. Anticholesterol consumption, 2000 and 2011 (or nearest year)

4.10.4. Antidepressants consumption, 2000 and 2011 (or nearest year)

StatLink ➤ http://dx.doi.org/10.1787/888932917712
Social conscience, political interest, and scientific curiosity in DK

Why the Danish government is treating hospital wastewater if there is no legislation on that subject?

“The ministry of environment has initiated a plan since May 2009 with the aim to pay attention to hospital wastewater”

“Pharmaceutical by-products can be harmful for the environment. Therefore, it is important that the different administrations take this into account when authorizing discharge permits to the hospitals.”

“In the last year we have made important progresses in the field of emergent micropollutants and in the possible technologies to remove them”

“I hope that the administrations and the different regions will initiate a constructive dialogue in order to find a solution for each and everyone of the hospital to avoid that these substances reach the environment”

Hospital wastewater regulation in DK

- Watching list: 36 substances
- Ranking based on pharmaceutical and antibiotics consumption

<table>
<thead>
<tr>
<th>Hospital/ Psychiatric Center</th>
<th>No. of beds</th>
<th>Catchment/ recipient</th>
<th>Highly hazardous pharmaceuticals [kg/year]</th>
<th>Hazardous pharmaceuticals [kg/year]</th>
<th>Antibiotics contribution (excl. penicillins) [%]</th>
<th>Classification as point source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bornholm</td>
<td>100</td>
<td>Small/ marine</td>
<td>15</td>
<td>134</td>
<td>58</td>
<td>Medium source</td>
</tr>
<tr>
<td>Amager</td>
<td>120</td>
<td>Large/ marine</td>
<td>25</td>
<td>205</td>
<td>2</td>
<td>Minor source</td>
</tr>
<tr>
<td>Psych. Ballerup</td>
<td>140</td>
<td>Large/ marine</td>
<td>9</td>
<td>33</td>
<td>&lt; 0,1</td>
<td>Minor source</td>
</tr>
<tr>
<td>Psych. St Hans</td>
<td>180</td>
<td>Large/ marine</td>
<td>68</td>
<td>50</td>
<td>&lt; 0,1</td>
<td>Minor source</td>
</tr>
<tr>
<td>Gentofte</td>
<td>280</td>
<td>Large/ marine</td>
<td>52</td>
<td>337</td>
<td>2</td>
<td>Medium source</td>
</tr>
<tr>
<td>Glostrup</td>
<td>310</td>
<td>Large/ marine</td>
<td>50</td>
<td>286</td>
<td>13</td>
<td>Medium source</td>
</tr>
<tr>
<td>New Northern Zealand</td>
<td>670</td>
<td>Small/ fresh</td>
<td>130</td>
<td>989</td>
<td>79</td>
<td>Major source</td>
</tr>
<tr>
<td>Hvidovre</td>
<td>800</td>
<td>Large/ marine</td>
<td>111</td>
<td>818</td>
<td>27</td>
<td>Major source</td>
</tr>
<tr>
<td>New Bispebjerg</td>
<td>860</td>
<td>Large/ marine</td>
<td>147</td>
<td>754</td>
<td>9</td>
<td>Major source</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>1100</td>
<td>Large/ marine/ fresh</td>
<td>436</td>
<td>1381</td>
<td>28</td>
<td>Major source</td>
</tr>
<tr>
<td>New Herlev</td>
<td>1100</td>
<td>Large/ marine/ fresh</td>
<td>181</td>
<td>700</td>
<td>18</td>
<td>Major source</td>
</tr>
</tbody>
</table>
Map of hospitals in DK - Herlev steppes up

90 hospitals in DK
56 more important hospitals are represented in the map
10-15 candidates to be monitored

Herlev Hospital
900 beds (2020)
480 m³/d week - 270 m³/d weekends

Motivation to develop the project
Plan launched by the ministry of environment
Discharge fee = 3,4 €/m³ wastewater discharged

Herlev Hospital
Private-public project. First full scale to treat hospital wastewater

PROJECT PARTICIPANTS

Steering Committee
Herlev Hospital
The Capital Region of Denmark
Grundfos
DHI

Project partners
Herlev Hospital (owner of the plant)
Grundfos BioBooster A/S (project holder and MBR technology)
DHI (testing and documentation)
Ultraqua (ozone, activated carbon, UV light)
Neutralox Umwelttechnik GmbH (air treatment)

Advisory group
The Danish Nature Agency
Hospitals: Rigshospitalet, New North Zealand Hospital,
Hvidovre Hospital, Glostrup Hospital, Viborg Hospital
Municipalities: Hvidovre and Viborg

Overall budget for the project
€ 5,7 million
Sevilla > 26, 27 y 28 de noviembre de 2014
**Plant configuration**

- **Modular concept**
- **All elements integrated in skids**
- **Quality control in the factory**: reduces execution time

**Post-treatment**
- Line 1: GAC => O₃ => UV
- Line 2: O₃ => GAC => UV

**Membrane Filter Units (MFU)**
- Ceramic disc membranes 0.2 µm

**Pre-treatment**
- 1.5 mm punched-hole

**Bioreactor all-in-one**
- Sequential C,N,P removal

**Sludge treatment**
- Up to 90% DS

**Air treatment unit**
- To remove odours and pathogens
Operational parameters and MBR performance (Jan-Apr 2016)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net flux</td>
<td>41±4,1</td>
<td>Lm⁻²h⁻¹</td>
</tr>
<tr>
<td>MLSS</td>
<td>12±1,0</td>
<td>g/L</td>
</tr>
<tr>
<td>Turbidity permeate</td>
<td>0,086±0,25</td>
<td>NTU</td>
</tr>
<tr>
<td>Inflow</td>
<td>431±2,8</td>
<td>m³/d</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance</th>
<th>Inlet [mg/L]</th>
<th>Permeate [mg/L]</th>
<th>Removal [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>805±264</td>
<td>20±4,1</td>
<td>98</td>
</tr>
<tr>
<td>TN</td>
<td>65±12</td>
<td>3,5±1,3</td>
<td>99</td>
</tr>
<tr>
<td>TP</td>
<td>13±2,8</td>
<td>0,38±0,33</td>
<td>84</td>
</tr>
<tr>
<td>SS</td>
<td>406±58</td>
<td>4,4±4,1</td>
<td>99</td>
</tr>
<tr>
<td>E. coli</td>
<td>-</td>
<td>&lt; 2cfu/100mL</td>
<td>-</td>
</tr>
</tbody>
</table>
# Removal of pharmaceuticals (APIs) I

80 pharmaceuticals analyzed

0 with conc. > PNEC in POZ2

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>POZ1</td>
<td>POZ2</td>
<td>POZ1</td>
<td>POZ2</td>
<td>POZ1</td>
<td>POZ2</td>
<td>POZ1</td>
<td>POZ2</td>
<td>POZ1</td>
<td>POZ2</td>
<td>POZ1</td>
<td>POZ2</td>
<td>POZ1</td>
<td>POZ2</td>
<td></td>
</tr>
<tr>
<td>Rest of APIs analyzed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Values below detection limit or PNEC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ciprofloxacin</td>
<td>15</td>
<td>20</td>
<td>61</td>
<td>23</td>
<td>61</td>
<td>10</td>
<td>180</td>
<td>28</td>
<td>15</td>
<td>&lt;10</td>
<td>52</td>
<td>40</td>
<td>73</td>
<td>6</td>
<td>170</td>
</tr>
<tr>
<td>Clarithromycin</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>32</td>
<td>&lt;10</td>
<td>10</td>
<td>&lt;10</td>
<td>71</td>
<td>&lt;10</td>
<td>22</td>
<td>&lt;10</td>
<td>37</td>
<td>&lt;10</td>
<td>59</td>
<td>&lt;10</td>
<td>60</td>
</tr>
<tr>
<td>Erythromycin dehydrato</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;50</td>
<td>&lt;50</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>82</td>
<td>&lt;10</td>
<td>19</td>
<td>&lt;10</td>
<td>36</td>
<td>&lt;10</td>
<td>58</td>
<td>&lt;10</td>
<td>40</td>
</tr>
<tr>
<td>Ifosfamide</td>
<td>&lt;10</td>
<td>17</td>
<td>&lt;10</td>
<td>22</td>
<td>&lt;10</td>
<td>10</td>
<td>&lt;10</td>
<td>12</td>
<td>35</td>
<td>&lt;10</td>
<td>29</td>
<td>&lt;10</td>
<td>44</td>
<td>&lt;10</td>
<td>20</td>
</tr>
<tr>
<td>Sulfamethoxazole</td>
<td>44</td>
<td>35</td>
<td>150</td>
<td>59</td>
<td>150</td>
<td>51</td>
<td>430</td>
<td>88</td>
<td>66</td>
<td>&lt;10</td>
<td>300</td>
<td>30</td>
<td>400</td>
<td>16</td>
<td>120</td>
</tr>
</tbody>
</table>
Removal of pharmaceuticals (APIs) II

- **N Nervous system**
- **M Musculo - skeletal system**
- **L Antineoplastic agents**
- **J Antiinfectives for systemic use**
- **H Systemic hormonal preparations**
- **D Dermatologicals**
- **C Cardiovascular system**
- **B Antitrombotic agents**
- **A Antimentary tract and metabolism**

Reduction 99%

**Influent**
- **loversol**
- **iopromide**
- **lopamidol**
- **Iomeprol**
- **Iohexol**
- **Amidotrizoic Acid**

**Permeat**

**Effluent**

Reduction 99%
Removal of pharmaceuticals (APIs) III

**Findings**

- MBR itself reduces the concentration of a large number of APIs analyzed. **MBR + polishing = BAT** for treatment of hospital wastewater in DK.
- The polishing step in **first place** (GAC / O₃) removes the most.
- **GAC filters not saturated** during the first year of operation.
- **NO detection of Adsorbable organic halogens (AOX)** in the effluent.
- **O₃ recommended dosage** to ensure total API removal: 4 mg O₃ / mg COD.
- **POZ2 (O₃ --> GAC --> UV) is more effective**: Removes a larger number of compounds and prolongs the life of GAC.
## Summing up the performance of the BioBooster

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wastewater</th>
<th>Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toxic and hard-biodegradable antibiotics and pain killers</td>
<td>Factor 10-160 exceeding of effect limits for water living organisms</td>
<td>No exceeding of effect limits for water living organisms</td>
</tr>
<tr>
<td>X-ray contrast media (eg iomeprol)</td>
<td>High concentration (2.5-7 mg/l)</td>
<td>99% removal</td>
</tr>
<tr>
<td>Antibiotic resistant bacteria</td>
<td>High presence of multiresistant bacteria</td>
<td>No faecal or multiresistant bacteria</td>
</tr>
<tr>
<td>Ecotox effect - Fish fry (zebra fish)</td>
<td>100% mortality (death) within 96 hours</td>
<td>0% mortality (death) within 96 hours</td>
</tr>
<tr>
<td>Ecotox effect - Crustaceans (daphnies)</td>
<td>No offspring (all daphnies died)</td>
<td>Off springs survives like in clean water</td>
</tr>
<tr>
<td>Water born viruses</td>
<td>High concentration (1.7·10^5)</td>
<td>High concentration (1.7·10^5)</td>
</tr>
<tr>
<td>Estrogenic activity (A-YES)</td>
<td>Estrogen effects</td>
<td>No estrogen effects</td>
</tr>
</tbody>
</table>
OPEX - Savings for the hospital

Costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>kWh</td>
<td>0.13</td>
</tr>
<tr>
<td>PAX15</td>
<td>€/ton</td>
<td>245</td>
</tr>
<tr>
<td>Ultrasil 25</td>
<td>€/L</td>
<td>2.8</td>
</tr>
<tr>
<td>Ultrasil 78</td>
<td>€/L</td>
<td>3.2</td>
</tr>
<tr>
<td>BoFloc CG378 M</td>
<td>€/kg</td>
<td>3.6</td>
</tr>
<tr>
<td>Antifoam SG20</td>
<td>€/kg</td>
<td>5.2</td>
</tr>
<tr>
<td>O₂</td>
<td>€/kg</td>
<td>0.17</td>
</tr>
<tr>
<td>GAC POZ</td>
<td>€/2 tanks</td>
<td>5705</td>
</tr>
<tr>
<td>Grit removal</td>
<td>€/ton</td>
<td>193</td>
</tr>
<tr>
<td>Excess sludge</td>
<td>€/ton</td>
<td>58</td>
</tr>
<tr>
<td>Operator salary</td>
<td>€/h</td>
<td>60</td>
</tr>
</tbody>
</table>

64% savings (Maintenance, operation, water reuse)
Aprox cost of a plant = 3.000.000 €
Payback time = 9 years
Conclusions

• Hospital wastewater presents a challenge in the coming years

• There is not a standard solution to tackle this problem: centralized vs decentralized

• Decentralized solutions require robust, efficient, reliable and fully automatic plants

• No legislation so far regulating the discharge of pharmaceuticals

• Still, Danish authorities have taken action, leading to the first full-scale WWTP installed in a hospital with the aim to remove pharmaceuticals and antibiotic resistant bacteria

• A sample of 80 pharmaceuticals was tested at Herlev Hospital (Copenhagen-DK)

• All pharmaceuticals showed concentrations in the effluent below PNEC for the configuration $O_3 => GAC => UV$

• Non ecotoxicologic effects, viruses, antibiotic resistant bacteria, or estrogenic activity were detected in the effluent

• The effluent quality is similar to drinking water, enabling possibilities for water reuse

• The overall cost is around 1,5 €/m$^3$ representing 64% savings and a payback time around 9 years
More info about BioBooster

Application Specialist
Dr. José Antonio Gil Linares
+45 20 26 07 49
josean.gil@grundfos.com

Director, Municipal segment
Mr. Jakob Søholm
+45 23 20 75 53
jasoeholm@grundfos.com

BioBooster plant in Herlev Hospital
Copenhagen-DK

BioBooster plant in Herlev Hospital
Copenhagen-DK