LOW FOULING CONCEPT FOR MEMBRANE BIOREACTORS
OUTLINE

» Integrated Permeate Channel (IPC) membranes
  ▪ Concept
  ▪ Manufacturing
  ▪ Membrane

» Application tests
  ▪ Results lab-scale
  ▪ Results pilot-scale

» Conclusions
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Development goals for a novel flat sheet MBR

- ‘Best of both worlds’ → Combination of advantages of capillary (CAP) and flat sheet (FS) MBR technology
  - High packing density (CAP);
  - No need for extensive pre-filtration (FS);
  - Backwashable (CAP);
  - No braiding (FS);
  - No clogging (FS);
  - Low fouling (FS)

- Need for:
  - Flat sheet membrane envelopes with a reduced thickness (≤ 4 mm) and an open internal structure;
  - Robust and well-anchored membrane layers

- In addition: at low cost and a manufacturing process with limited number of steps
**IPC CONCEPT**

*Key element: use of spacer fabric as a support*

- **Spacer fabric characteristics:**
  - Flat sheet textile with typically 3 parts (2 faces and a hollow space);
  - Hollow space composed of multitude of spacer thread monofilaments;
  - High internal porosity (≥ 95%)
  - Textile can be made either by knitting, weaving, ... ;
IPC CONCEPT

Specially developed 3D spacer-fabric

- Special attention to:
  - Open-face structure;
  - No loose hairs;
  - Small face thickness;
  - Low elongation in both X and Y direction;
  - Low compressibility;
  - High internal “porosity”
MEMBRANE MANUFACTURING

Membrane casting (phase-inversion)

- Two-side simultaneous coating /impregnation, followed by membrane pore formation step by VIPS/LIPS;
- Use of high viscosity dope;
- Washing with bleach solution;
- Pores in the MF and UF range;
- Permanent hydrophilic
Membrane envelope

- single-piece membrane envelope;
- comprising 2 membrane layers;
- that are nicely “spaced-apart, adjacently to each other”;
- comprising an interposed permeate channel;
- membrane layers are connected with each other at a multiple number of points, over the entire membrane surface

⇒ first real backwashable flat sheet membrane
## Comparison with ‘state-of-the-art’ FS MBR

<table>
<thead>
<tr>
<th>Feature</th>
<th>Classical FS</th>
<th>IPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fabrication steps</td>
<td>multistep</td>
<td>single step</td>
</tr>
<tr>
<td>Connection between the membrane layers</td>
<td>only in the edge region (except for Microdyn Nadir)</td>
<td>≤ 100 monofil./ cm²</td>
</tr>
<tr>
<td>Dope type</td>
<td>low polym. content</td>
<td>high polym. content</td>
</tr>
<tr>
<td>Thickness membrane layers</td>
<td>150-200 μm</td>
<td>450-600 μm</td>
</tr>
<tr>
<td>Mechanical strength</td>
<td>limited</td>
<td>good</td>
</tr>
<tr>
<td>Membrane adhesion</td>
<td>poor</td>
<td>good</td>
</tr>
<tr>
<td>Backwashable</td>
<td>no (or limited)</td>
<td>yes</td>
</tr>
<tr>
<td>Maximum backwash pressure</td>
<td>0 to 0.3 bar</td>
<td>2 bar</td>
</tr>
</tbody>
</table>
OUTLINE

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APPLICATION TESTING

Equipment:

» Lab-scale: installation with 6 parallel test positions, MBR panels of 0.1 m² each

<table>
<thead>
<tr>
<th>Type of waste water</th>
<th>Origin</th>
<th>COD (mg O₂/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal</td>
<td>SCK/Vito residential site + restaurant</td>
<td>&gt; 500</td>
</tr>
<tr>
<td>Industrial</td>
<td>NF permeate of the waste water of a detergent producer</td>
<td>&gt; 500</td>
</tr>
</tbody>
</table>
» Make use of the back-wash step!
» Backwash flux (BF) is 2-times the filtration flux (FF)
» Best results obtained for cycle time of 5 min.
» Recovery benchmark and IPC kept constant at 80%

<table>
<thead>
<tr>
<th>Operational mode</th>
<th>Benchmark</th>
<th>IPC (+ BW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&quot;F/R 10&quot;</td>
<td>&quot;F/BW/R 10&quot;</td>
</tr>
<tr>
<td>Cycle time (min.)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Filtration time (min.)</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Backwash time (min.)</td>
<td>-</td>
<td>0,5</td>
</tr>
<tr>
<td>Relaxation time (min.)</td>
<td>2</td>
<td>0,5</td>
</tr>
<tr>
<td>Recovery (%)</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Airflow rate lab-scale (Nm³/h)</td>
<td>0,7</td>
<td>0,7</td>
</tr>
<tr>
<td>Airflow rate pilot-scale (Nm³/h)</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>Backwash flux (times FF)</td>
<td>-</td>
<td>2</td>
</tr>
</tbody>
</table>
LABSCALE RESULTS BENCHMARK

Flux: 15 l/hm² → 30 l/hm² → 40 l/hm²

Steps of 5 l/hm²
LABSCALE RESULTS IPC PVDF-UF

Flux: 25 l/hm² → 60 l/hm²

Steps of 5 l/hm²

50 l/hm²
### SUMMARY OF CRITICAL FLUXES LABSCALE TESTS

For benchmark and IPC membranes on municipal waste water

<table>
<thead>
<tr>
<th>Type of membrane panel</th>
<th>Critical flux (l/h.m²)</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark membrane</td>
<td>30</td>
<td>+ 33%</td>
</tr>
<tr>
<td>IPC PES/MF</td>
<td>40</td>
<td>+ 66 %</td>
</tr>
<tr>
<td>IPC PVDF/UF</td>
<td>&gt; 50</td>
<td></td>
</tr>
</tbody>
</table>

For benchmark and IPC membranes on industrial waste water

<table>
<thead>
<tr>
<th>Type of membrane panel</th>
<th>Critical flux (l/h.m²)</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark membrane</td>
<td>15</td>
<td>+ 83%</td>
</tr>
<tr>
<td>IPC PES/MF</td>
<td>27.5</td>
<td>+ 83%</td>
</tr>
<tr>
<td>IPC PVDF/UF</td>
<td>27.5</td>
<td></td>
</tr>
</tbody>
</table>
PILOT TESTING WITH IPC/A3 GMBH MODULE

## MODULE SPECIFICATIONS

<table>
<thead>
<tr>
<th></th>
<th>U20-002 M20-002</th>
<th>U06-001 M06-001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane surface (ca.)</td>
<td>30 m²</td>
<td>10 m²</td>
</tr>
<tr>
<td>Dimensions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width (ca.) ± 2,5</td>
<td>385 mm</td>
<td>185 mm</td>
</tr>
<tr>
<td>Height (ca.) ± 0,0</td>
<td>1058 mm</td>
<td>1090 mm</td>
</tr>
<tr>
<td>Depth without filtration pipe (ca.) ± 2,5</td>
<td>466 mm</td>
<td>316 mm</td>
</tr>
<tr>
<td>Dry weight (ca.)</td>
<td>66 kg</td>
<td>36 kg</td>
</tr>
<tr>
<td>Filtrate pipe</td>
<td>DN 25</td>
<td>DN 16</td>
</tr>
<tr>
<td>Air demand per footprint (ca.)</td>
<td>16 Nm³/h</td>
<td>4,8 Nm³/h</td>
</tr>
</tbody>
</table>

**IPC 2nd generation PVDF/UF**
RESULTS IN THE FIELD

**MBR-pilot trials @ Aquafin Mol (municipal waste water)**
## RESULTS MBR PILOT TRIALS

### Test program

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Week 1-2</td>
<td>8</td>
<td>15</td>
<td>15</td>
<td>495</td>
<td>0,06</td>
<td>12,1</td>
<td>1980</td>
<td>1485</td>
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<tr>
<td>Week 2-4</td>
<td>10</td>
<td>20</td>
<td>20</td>
<td>660</td>
<td>0,07</td>
<td>9,1</td>
<td>2640</td>
<td>1980</td>
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<tr>
<td>Week 4-6</td>
<td>10</td>
<td>25</td>
<td>20</td>
<td>725</td>
<td>0,07</td>
<td>8,3</td>
<td>2900</td>
<td>2175</td>
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<tr>
<td>Week 7-8</td>
<td>10</td>
<td>30</td>
<td>20</td>
<td>790</td>
<td>0,08</td>
<td>7,6</td>
<td>3160</td>
<td>2370</td>
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<tr>
<td>...</td>
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<td></td>
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</tbody>
</table>

### Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent</th>
<th>Filtrate</th>
<th>IPC</th>
<th>A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD&lt;sub&gt;tot&lt;/sub&gt;</td>
<td>2x/w</td>
<td>2x/w</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD&lt;sub&gt;sol&lt;/sub&gt;</td>
<td>1x/2w</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOD</td>
<td>1x/2w</td>
<td>1x/2w</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>1x/2w</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N&lt;sub&gt;tot&lt;/sub&gt;</td>
<td>1x/w</td>
<td>1x/w</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₄-N</td>
<td>1x/w</td>
<td>1x/w</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO₃-N</td>
<td></td>
<td>1x/w</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO₂-N</td>
<td></td>
<td>1x/w</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P&lt;sub&gt;tot&lt;/sub&gt;</td>
<td>1x/w</td>
<td>1x/w</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td>2x/w</td>
<td>2x/w</td>
<td></td>
<td></td>
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</tbody>
</table>
SUMMARY RESULTS MARINE MODULE - CYCLE TIME 5’

IPC-PVDF (30 m²) - gross flux @ recovery 90%

MBR-pilot, IPC-PVDF module, flux 55 l/hm²

- av. MTC
- av. flux
**SUMMARY RESULTS MARINE MODULE - CYCLE TIME 5’**

**IPC-PVDF (30 m²) - gross flux @ recovery 90 %**

**MBR-pilot, IPC-PVDF module, flux 55 l/hm²**

[Graph showing TMP and Flux over time]
SUMMARY RESULTS MARINE MODULE - CYCLE TIME 5’

IPC-PVDF (30 m²)

MBR-pilot, IPC-PVDF-module, flux 60 l/hm²

Diagram showing flux, average MTC, average flux, and average recovery over time from 3/09/15 to 3/10/15.
SUMMARY RESULTS MARINE MODULE- CYCLE TIME 5’

**IPC-PVDF (30 m²)**

MBR-pilot, IPC-PVDF-module, flux 60 l/hm²
SUMMARY RESULTS MARINE MODULE- CYCLE TIME 10’

Filtration cycle of 10 min, $R = 80\%$, $BW = 2 \times \text{flux}$

MBR-pilot, IPC-PVDF-T module, flux 50 l/hm², 10 min cycle
**SUMMARY RESULTS MARINE MODULE - CYCLE TIME 10’**

Filtration cycle of 10 min, $R = 80\%$, $BW = 2 \times$ flux

**MBR-pilot, IPC-PVDF-T module, flux 55 l/hm², 10 min cycle**

- **av. MTC**
- **av. flux**
- **av. recovery**

**Compressor defect**
**SUMMARY RESULTS MARINE MODULE - CYCLE TIME 20’**

Filtration cycle of 20 min, $R = 80\%$, $BW = 2 \times \text{flux}$

MBR-pilot, IPC-PVDF-T module, flux 50 l/hm², 20 min cycle
Filtration cycle of 20 min, R = 80 %, BW = 2 x flux

MBR-pilot, IPC-PVDF-T module, flux 55 l/hm², 20 min cycle
SUMMARY RESULTS MARINE MODULE - CYCLE TIME 10’

Filtration cycle of 10 min, \( R = 90 \% \), \( BW = 1,5 \times \text{flux} \)

MBR-pilot, IPC-PVDF-T module, flux 55 \( l/hm^2 \), 10 min cycle, BW

flux = 1,5 \times \text{filtr. flux}
### SUMMARY RESULTS MARINE MODULE - CRITICAL FLUX

**Critical flux summary**

<table>
<thead>
<tr>
<th>Cycle time (minutes)</th>
<th>Recovery (%)</th>
<th>Gross critical flux (l/h.m²)</th>
<th>Net critical flux (l/h.m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>90</td>
<td>55</td>
<td>49,5</td>
</tr>
<tr>
<td>10</td>
<td>80</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>20</td>
<td>80</td>
<td>50</td>
<td>40</td>
</tr>
</tbody>
</table>
SUMMARY RESULTS MARINE MODULE - CLEANING EFFECT

CIP: 3000 ppm NaOCl, pH 10.5, 30°C, 2.5 hrs

Effect CIP

MTC (l/h.m².bar)

new | before cleaning | after CIP
Permeabilities for different flatsheet membranes in A3's marine module

- MTC A3 l/m².h.bar
- MTC IPC-PES l/m².h.bar
- MTC IPC-PVDF l/m².h.bar
SUMMARY RESULTS MARINE MODULE

MLSS

- Biology
- Membrane tank

Graph showing MLSS values over time from 15/02/2015 to 31/01/2016.
**SOME KEY DATA**

*Triple deck U-100 module (based on pilot trials)*
*(U-100: 100 m², Width = 736 mm, Height = 1070 mm, Depth = 716 mm)*

- Membrane pore size: 0,08 µm
- Membrane material: PVDF or PES
- Clean water permeability: 1500 l/h.m².bar
- Net flux (municipal waste water): 40 - 50 l/m².h
- Packing density for triple deck U-100 module: 569 m²/m²
- Permeate production per m² projected area: 22,76 - 28,45 m³/m²
- Aeration demand:
  - SADm: 0,16 Nm³/m².h
  - SADp: 4 - 3,2 Nm³/m³
- Pretreatment: 3 mm
- Backwashability: up to 2 bar
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CONCLUSIONS

» IPC concept allows for fully backwashable flatsheet membranes
» efficient backwashing is key in fouling control!
» 50-100 % flux improvement demonstrated at pilot scale
» 50 % higher packing density
» IPC manufacturing at competitive price thanks to integrated concept

» IPC membranes and modules will be commercialized in Blue Foot Membranes