The IETS TCP's International Conference

Energy Future in Industry

9–11 May 2023
Gothenburg, Sweden
Membranes in biorefineries

TASK XVII
10th of May, 2023

Frank Lipnizki, Claus Hélix-Nielsen, Morten Christensen, Maria Norberta de Pinho and Bettina Muster-Slawitsch
## Membrane in biorefineries

Since 2014
8 Industry & 17 Academia/Institutes
7 countries

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Why membranes in biorefineries?

Definition of biorefineries
"Full utilization of the incoming biomass for the simultaneous production of biofuels, biochemicals, heat and power in analogous to petroleum refineries”

Need for high selective, low energy separation and electrifiable technology:
MEMBRANE TECHNOLOGY

Modified after P. Axegård, 1st Int. Biorefinery Workshop 2005
Subtask A – Integration & Optimisation

Subtask leader: (ITM-CNR, Italy)

Activities:

• Mapping of the state-of-the-art (ongoing)
• Optimization of membrane processes to reduce investment and operating costs.
• Adjusting operating parameters to minimise energy consumption.
• Membrane reactors combining separation with biologic and/or chemical reactions.
• Techno-economical evaluation of hybrid processes in biorefineries.
CS1: Nanofiltration for Water Recovery in the Bleach Plant of a Kraft Pulp Mill
CS2: Ultrafiltration and Nanofiltration for the Recovery of Lignin and Hemicellulose from the E-stage Effluent of a Sulphite Pulp Mill

CAIMA – Indústria de Celulose, S.A., Portugal

Sulphite pulp mill:

Production of 125 kton/year of dissolving pulp from *Eucalyptus globulus*;

Magnesium bisulphite process;

Bleaching process: Total Chlorine Free (TCF)
Bleach plant effluent
Stora Enso Nymölla

Dilute solutions
Total dry solids content < 2 wt%

High volume reduction (VR)

\[
VR = \frac{\text{volume permeate}}{\text{volume feed}}
\]

Feed 400 m³/h → Permeate 392 m³/h

Retentate 8 m³/h

VR 98% (VRF 50)
Subtask B – Fouling & cleaning

Subtask leader: (IST, Portugal)

Activities:

• In-situ analysis of fouling and cleaning using advanced technologies, X-Ray tomography
• Use of synchrotrons for advanced fouling and cleaning studies.
• CFD-simulations to optimise fouling and cleaning.
• Techno-economical optimisation of fouling and cleaning.
Direct observation of fouling phenomena during cross-flow filtration: 
Influence of particle surface charge
Søren Lorenzen, Yun Ye, Vicki Chen, Morten Christensen

- Filter cakes have been characterized by direct optical observation.
- Filter cake behavior changes according to particle surface charge.
- The presence of charged particles increase filter cake specific resistance.
- Compressibility and relaxation is linked to particle charge.
- Removal of filter cake is only achieved by combining backwash and high cross-flow

- Micrometre-sized monodisperse
  Core: **polystyrene** core/shell particles (3.2 μm)
  Shell: 50% 100 kDa **poly(acrylic acid)**
  50% 100 kDa **hydroxypropyl cellulose** (-28.9 mV)
Hydraulic resistance and osmotic pressure effects in fouling layers during MBR operation
Morten Lykkegaard Christensen*, Mads Koustrup Jørgensen, G. Van De Staey, L. De Cock, Ilse Smets

$\text{TMP}(t) = J_p R_m' + \Delta \pi(t) + \eta_p \alpha C(t)(1 - \gamma)$

Membrane + pore blocking
Osmotic pressure induced resistance
Hydraulic resistance external fouling

- Laboratory-scale MBR experiments were performed with different salt solutions.
- High ionic strength increases fouling rate due to floc erosion or disruption.
- Soluble microbial products and small particles are the most critical foulants.
- The monovalent-over-polyvalent ratio is lower in the fouling layer than the bulk.
Membrane fouling and cleaning
Nanotomography
Subtask C – Membranes and modules

**Subtask leader:** (Institut Europeen des Membranes, France)

**Activities:**

- Mapping of current membrane developments e.g. Aquaporin, mixed matrix membranes, artificial water channels.
- Applications of new ceramic nanofiltration membranes in biorefineries.
- Dynamic membrane systems for energy-efficient concentration of viscous and/or high solid products.
- Green/sustainable membranes.
New membrane design – beaded membranes

Fabrication of electrospun PVDF-beaded membranes for membrane distillation with:
• high hydrophobicity,
• low thickness, and
• good mechanical stability

Hu et al. J. Membr. Sci. 661, #120850, 2022
Catalytic membranes

**Advantages** | **Disadvantages**
---|---
Wide range of catalytic mechanisms possible | Potentially low turnover rates/permeate flux
Reactant concentration via interfacial polarization | Unknown pretreatment needs
High suspended particle and/or heat sensitive components treatable | Unknown catalyst stability towards operation and cleaning
Up-scaling potential | Complex technology design

Galiano et al. *Catalysts* 2019, 9, 614
Enzymatic membranes

Scope
1. Recyclable membranes
2. High catalytic efficiency
3. Stable in use

Need
1. Flexible ceramic membranes
2. High activity of immobilized enzymes
3. Improved chemical and thermal stability and stable membrane performance

Zhao et al. *Chemical Engineering Journal* 451, #138902, 2023
Subtask D – Emerging processes
Subtask leader: AEE, Austria

Activities:

• Mapping electrodialysis applications for biorefineries.
• New approaches to working with high solid processing (reactor for high solid processing, and in-situ membrane separation).
• Emerging membrane processes for separation of volatile components.
• Membrane adsorbers for water and product polishing.
1. Emerging Membrane Technologies
2. Integration Examples
3. Long-Term Studies
4. Evaluating feasibility of membrane application in biorefining
5. Recommendations, future research needs

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Integration example

- Recover Ammonia from WWTP effluent
- MD as thermal separation process
- Driving force is vapour pressure difference
- 24 h continuous operation
Subtask E – Water and resource recovery
Subtask leader: Aalborg University, Denmark

Activities:
• Mapping of membrane processes for water and resource recovery
• Concepts for water and by-product recovery and recycling in biorefineries.
• Development of new membrane-based solutions for water and resource recovery e.g. hemicellulose recovery for process water
RECOVERY OF PHOSPHORUS FROM WASTEWATER WITH MEMBRANES

Morten Lykkegaard Christensen*, Katie Kedwell, Cejna Anna Quist-Jensen

Limitation
Osmotic pressure

Table 4. Retention of the considered NF membranes [17,18].

<table>
<thead>
<tr>
<th>Component</th>
<th>NF99HF (Alfa Laval)</th>
<th>K-SR2 (Koch Membrane Systems)</th>
<th>NF90 (Dow Filmtec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl^- (%)</td>
<td>24.4</td>
<td>11.5</td>
<td>64.1</td>
</tr>
<tr>
<td>K^+ (%)</td>
<td>20</td>
<td>11</td>
<td>53</td>
</tr>
<tr>
<td>Mg^{2+} (%)</td>
<td>85.5</td>
<td>75.6</td>
<td>96.8</td>
</tr>
<tr>
<td>Na^+ (%)</td>
<td>14.2</td>
<td>7.1</td>
<td>58.7</td>
</tr>
<tr>
<td>SO_4^{2-} (%)</td>
<td>97.3</td>
<td>97</td>
<td>96.7</td>
</tr>
<tr>
<td>Ca^{2+} (%)</td>
<td>67.3</td>
<td>59</td>
<td>94.4</td>
</tr>
<tr>
<td>HCO_3^{-} (%)</td>
<td>57</td>
<td>40</td>
<td>85</td>
</tr>
<tr>
<td>Selectivity</td>
<td>5.2</td>
<td>3.6</td>
<td>11.2</td>
</tr>
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RECOVERY OF PHOSPHORUS FROM WASTEWATER WITH MEMBRANES

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Surface area high: 10-50 cm$^2$/cm$^3$
Polypropylene membranes

Figure 3. Magnesium and chloride separation at increasing concentration factor
Interested in joining the Annex ???

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