New membrane materials and processes – separation and beyond

Biochemical Processes – Membrane Separation

Claus Hélix-Nielsen
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• Bio-tech/refinery is critically dependent on access to water and aqueous feed streams which implies that water treatment technologies must be fully integrated in large-scale refining processes
• Action to neutralize water risks in production can be a lot less costly than inaction
• In 2020, companies in the Fossil Fuels segment reported to the Carbon Disclosure Project (CDP) that their maximum potential financial impact of water risks came to $80 billion
• The same companies evaluated the cost of addressing those risks at just $16 billion
• Cost of inaction is 5x higher than the cost of action on water scarcity, on average
• For food and biotech sectors this ratio is even higher (18x and 13x respectively)
Membranes and beyond

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FO in bioreactors for brewery wastewater remediation

Schneider et al. Separation and Purification Technology 257 (2021) 117786

Results

• FO-AnMBR was used to treat real brewery wastewater for water and energy recovery
• An 8-fold reduction in hydraulic retention time (HRT) resulted in an up to 9-fold methane production increase
• A maximum solid retention time (SRT) of 86 days was achieved with the FO-AnMBR
• However, process stability decreased with decreasing HRT, possibly due to shear stress and the inadequate C/N ratio of the wastewater.

Schneider et al. Separation and Purification Technology 257 (2021) 117786
FO dewatering of methanotrophic enrichments

Results

- FO membranes can extract water from methanotrophic cultures used for single cell protein production
- Biofouling did not significantly affect water fluxes
- With NaCl and brine as DS the highest water fluxes were obtained, but ammonium retention was low with high reverse salt flux
- With MgCl₂ as DS, the highest specific water flux ($J_{w}/J_{s} = 7.5 \pm 1.7$ L g⁻¹) and ammonium retention of ~85%
- With glycerol as DS, the solute back flux was the highest without affecting microbial growth. Hence it shows potential as good DS, if available as residual stream
A methaneous word of caution

Advantages
- Operable at low temperature (e.g., solar or waste heat) and pressure
- No or little pretreatment needed
- High surface to volume ratio
- Up-scaling potential

Disadvantages
- Low permeate flux compared to pressure driven processes
- Interfacial thermal polarization decreases flux
- Heat conduction resulting in gradient dissipation
- Pore wetting and fouling
- High cost

Fredenslund et al. Waste Management 157 (2023) 321-329

New membrane design – beaded membranes

Results

• High membrane hydrophobicity. WCA increasing from 134° to 148° when changing from a fully fibrous to a bead-based membrane morphology.

• Compared to commercial PVDF, this new membrane showed a 34.1% increase in membrane permeability with a higher and constant water flux in high-recovery experiments.

• This suggests a potential saving of ~33% membrane area when working with the same operating conditions in MD, leading to substantial savings in installation costs.

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

Galiano et al. Catalysts 2019, 9, 614

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

Enzymatic membranes - aim

Zhao et al. Chemical Engineering Journal 451, #138902, 2023

Scop

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
Enzymatic membranes – scaffold structure

Membrane modifications:
- Silanization treatment
- Co-deposition of polydopamine (PDA)/ polyethylene imine (PEI). The introduction of PEI increased the amine group density on the membrane surface allowing for subsequent enzyme immobilization.

Enzymatic membranes – enzyme immobilization
Enzymatic membranes – enzyme activity

- Immobilized laccase maintained more than 40% of its optimum activity within a broader pH range
- Improved thermal stability of the immobilized laccase
- Operational stability over cycles of use

Zhao et al. Chemical Engineering Journal 451, #138902, 2023

Enzymatic membranes – depletion efficiency

- Promising depletion outcomes (≥95%) for all selected emerging pollutants
- Maintained transformation efficiency > 90% after three times of reuse

Zhao et al. Chemical Engineering Journal 451, #138902, 2023
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