Membrane Filtration

Christopher Bellona

Assistant Professor
Department of Civil and Environmental Engineering
Clarkson University
Membrane Types

• Pressure driven membrane processes
  – Low-pressure membranes
    • Microfiltration (MF) and ultrafiltration (UF)
  – High-pressure membranes
    • Reverse osmosis (RO) and nanofiltration (NF)

• Current driven membrane processes
  – Electrodialysis (ED) and electrodialysis reversal (EDR)
Pressure Driven Membranes

Low-pressure Membranes

- Micro (MF)
- Ultra (UF)
- Nano (NF)

High-pressure Membranes

- RO

Suspended Solids (Particles)

- Macromolecules (Humics)

Multivalent Ions (Hardness)

- Monovalent Ions (Na⁺, Cl⁻)

Water Molecules

Low Molecular Weight Organics

Amy Childress, University of Nevada - Reno
Membranes Available for Waste Recycling

- Water with moderate solids (up to 5%), high COD/BOD and high TOC
  - Ceramic MF and UF membranes
  - Certain polymeric MF membrane systems
- Low solids, high TOC
  - Polymeric MF and UF
- Water with variable salinity and moderate TOC
  - Low-pressure reverse osmosis
  - Nanofiltration
Past and Current Research

• Past research focus has been on municipal wastewater reuse using membrane technology:
  - WWTP
  - MF/UF
  - NF/RO
  - AOP
  - DW

• Current research includes use of membranes for separation of components in waste streams
• Membrane bioreactors
• Optimization of membrane systems:
  – Reducing energy consumption
  – Mitigating fouling
  – Modeling membrane separations
Comparing RO to NF

![Graph comparing RO to NF](image)
Example Application

- Paper manufacturer using surface (river) water for process water:
  - Low total dissolved solids concentration and conductivity
  - Moderate TOC with relatively high color (tannins)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Average</th>
<th>Average deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>-</td>
<td>7.40</td>
<td>0.09</td>
</tr>
<tr>
<td>Conductivity</td>
<td>us/cm</td>
<td>81.49</td>
<td>1.93</td>
</tr>
<tr>
<td>TOC</td>
<td>mg/l</td>
<td>6.83</td>
<td>0.082</td>
</tr>
<tr>
<td>UV-400¹</td>
<td>1/m</td>
<td>3.4</td>
<td>0.267</td>
</tr>
</tbody>
</table>

¹UV-400 is UV absorbance at 400 nm wavelength and is a surrogate for color

- Interested in RO for color removal but evaluated NF (NF270, Dow/Filmtec) because conductivity removal not an issue
NF for Color Removal

- Evaluated TOC and color removal by NF:
  1. Effect of temperature (5 and 19°C)
  2. Membrane fouling propensity (operation for 30 hours)
NF for Color Removal

• Relatively low-pressure requirements:

<table>
<thead>
<tr>
<th></th>
<th>Average Temp (°C) $^1$</th>
<th>Average permeate flux (GFD) $^2$</th>
<th>Average Pressure (psi)</th>
<th>Specific flux (GFD/psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Water Experiment</td>
<td>5.88</td>
<td>12.15</td>
<td>84.67</td>
<td>0.14</td>
</tr>
<tr>
<td>Warm Water Experiment</td>
<td>18.87</td>
<td>12.08</td>
<td>56.30</td>
<td>0.21</td>
</tr>
</tbody>
</table>

$^1$Three separate experiments were conducted for each water temperature, $^2$The desired permeate flux set-point was 12 gfd

• Low fouling propensity:

![Graph showing specific flux over runtime]
NF for Color Removal

• Conclusions
  – NF is a viable alternative to RO for certain applications
    • Low pressure and energy requirements compared to RO
    • Good organic compound removal
    • Preferential removal of divalent ions over monovalent ions
  – Proper membrane selection important
    • Selection of low fouling membranes or measures to mitigate fouling
    • Selection of proper membrane and operating conditions to achieve desired separation performance
Clarkson Research Group

• Past and Current Research:
  – Modeling and optimizing membrane separations
  – Evaluating membrane fouling and filterability
  – Testing novel membrane systems

• Capabilities
  – Bench- and laboratory-scale membrane testing systems
  – Wide range of analytical capabilities
    • Metal analysis (ICP, AAS)
    • Organic analysis (GC-ECD, GC-FID, GC-MS/MS, etc.)
    • Surface analysis (SEM microscopy, XRD analysis)
Thank You

Feel free to contact me:
Christopher Bellona
cbellona@clarkson.edu