Advanced Membrane Technologies
Stanford University, May 07, 2008

Membranes for Water Treatment: Properties and Characterization

Ingo Pinnau, Ph.D.

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Membrane Separation Processes and Characteristics

Process	Separation Mechanism	Pore Size (Å)	Transport Regime
Particle Filtration	Size Exclusion	> 50,000	Macropores
Microfiltration (MF)	Size Exclusion	500 - 50,000	Macropores
Ultrafiltration (UF)	Size Exclusion	20 - 500	Mesopores
Reverse Osmosis (RO)	Solution/ Diffusion	< 10	Molecular (Nonporous)

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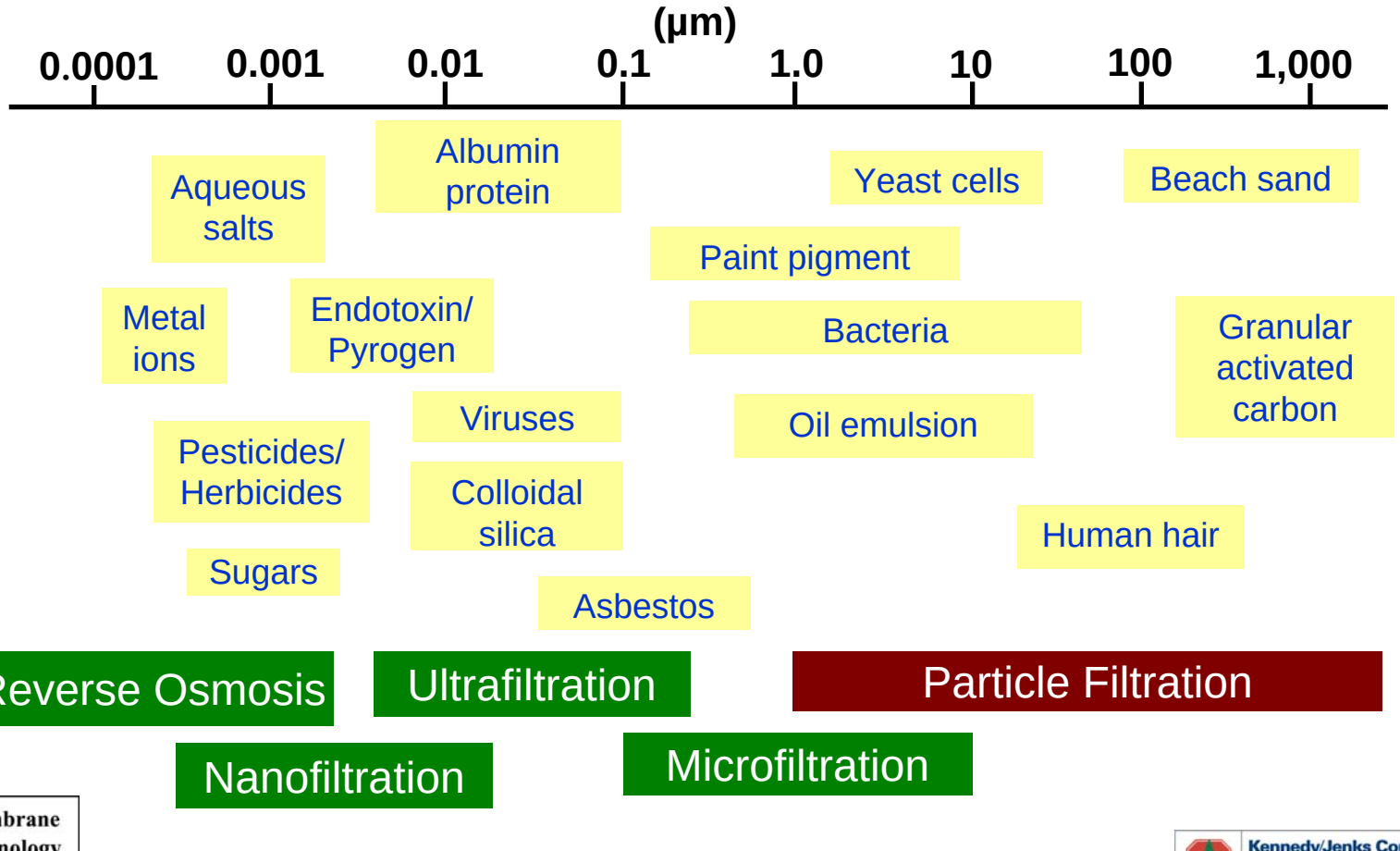
Membrane Separation Processes and Characteristics



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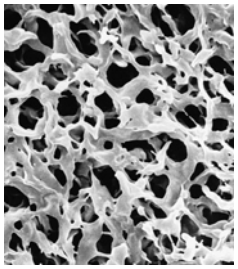
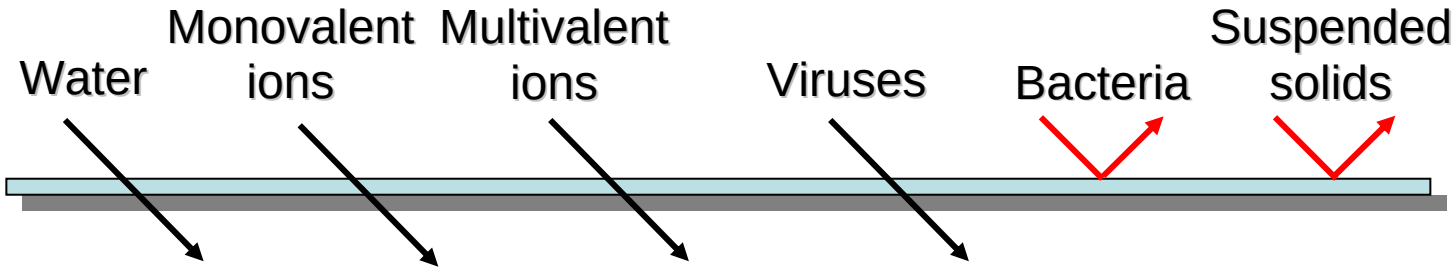
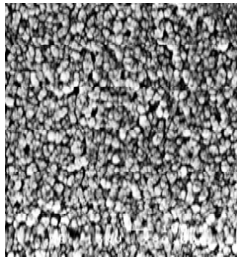
Membrane Characteristics: Porous Membranes

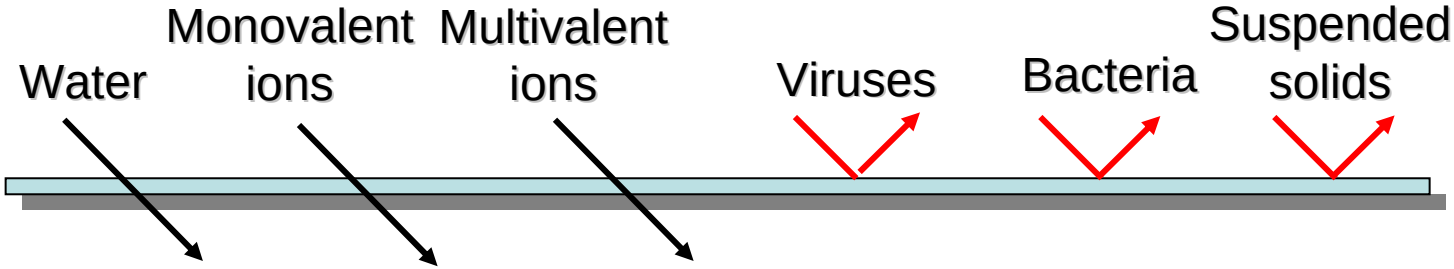
Microfiltration





Ultrafiltration





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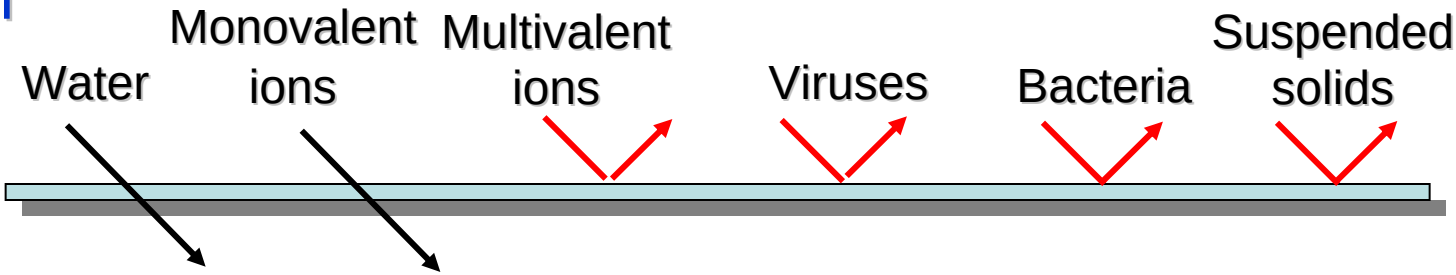
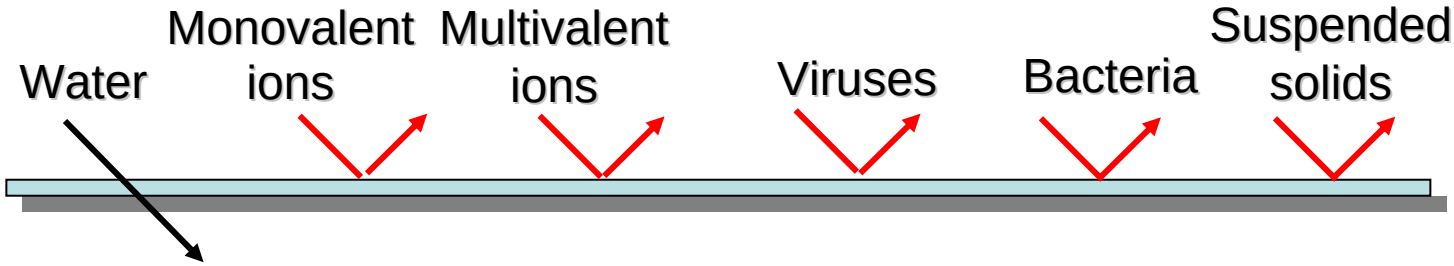
Membrane Characteristics: Non-Porous Membranes

Nanofiltration



Reverse Osmosis



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Ideal Membranes for UF, NF and RO Applications

- High water flux (low capital cost)
- High solute rejection (high water purity)
- Long-term stability of water flux and rejection (Membrane fouling)
- Mechanical, chemical and thermal stability
- Minimum pre-treatment (backflushing and chemical treatment)
- Can be processed into large-scale membranes and modules
- Inexpensive!

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Problems of Current Membranes Used in UF and RO Applications

- Poor long-term stability of water flux (Membrane Fouling)
- Backflushing and chemical treatment
- High membrane replacement cost
- Poor resistance to chlorine
- Membrane system size

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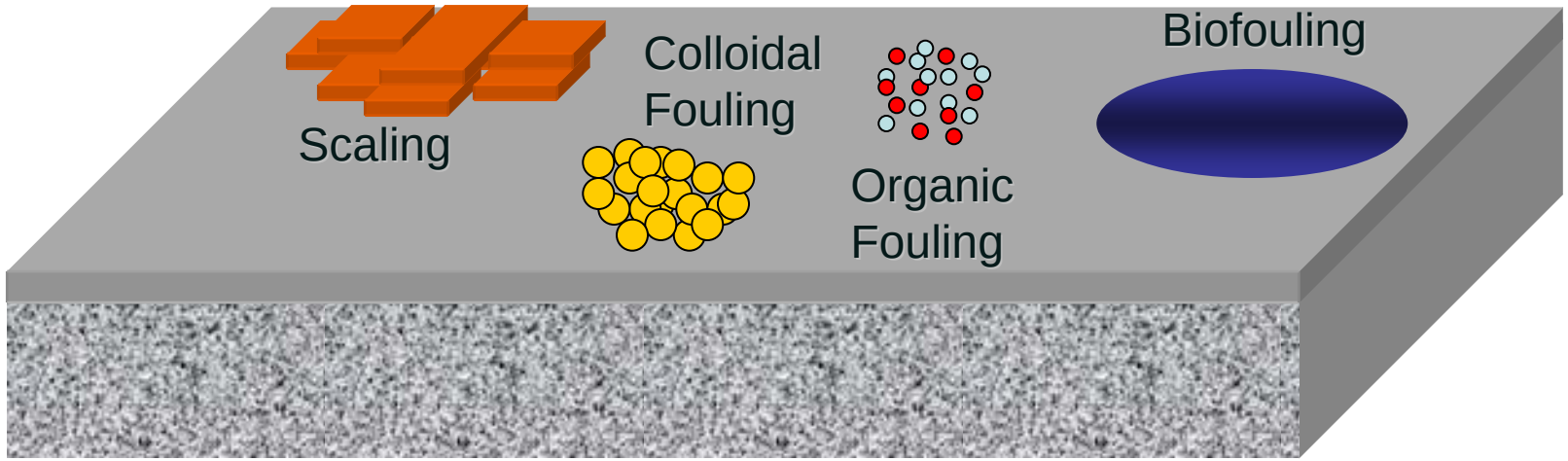
Major Foulant Types in Natural and Industrial Wastewater



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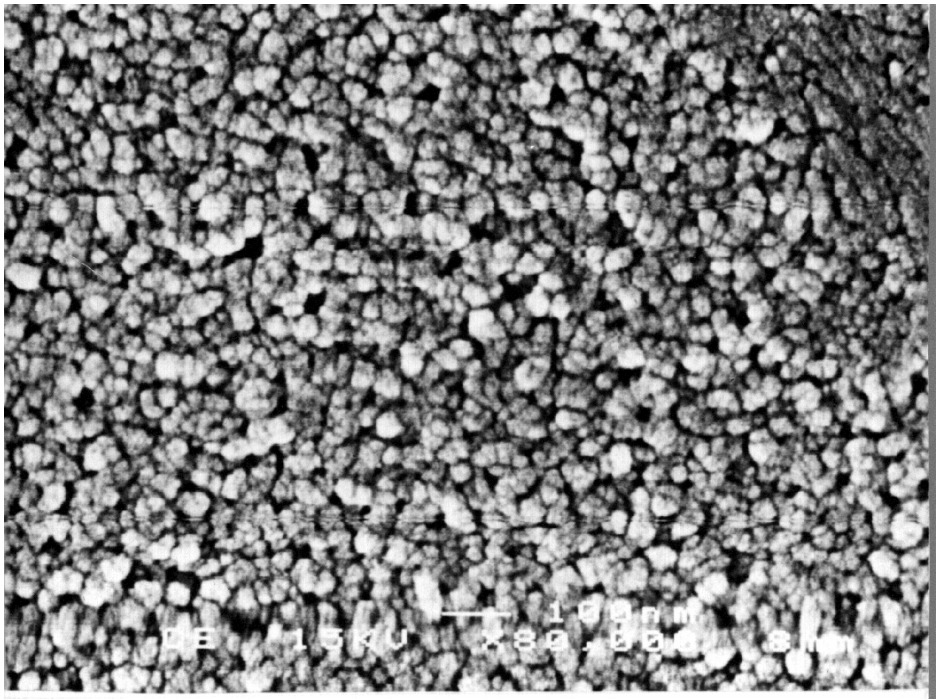
Surface Structure of a Typical UF Membrane



PEI membrane surface, x 80000, ----- 0.1μm

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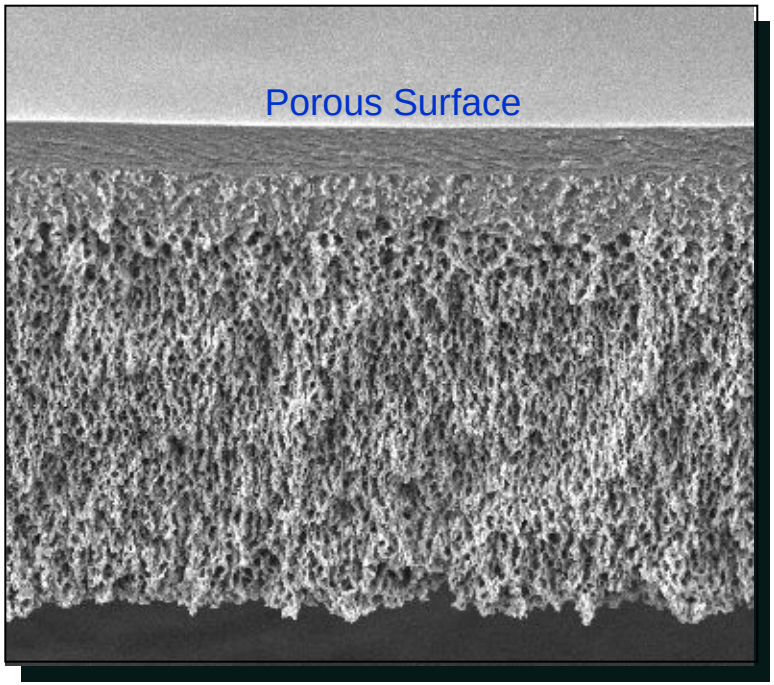
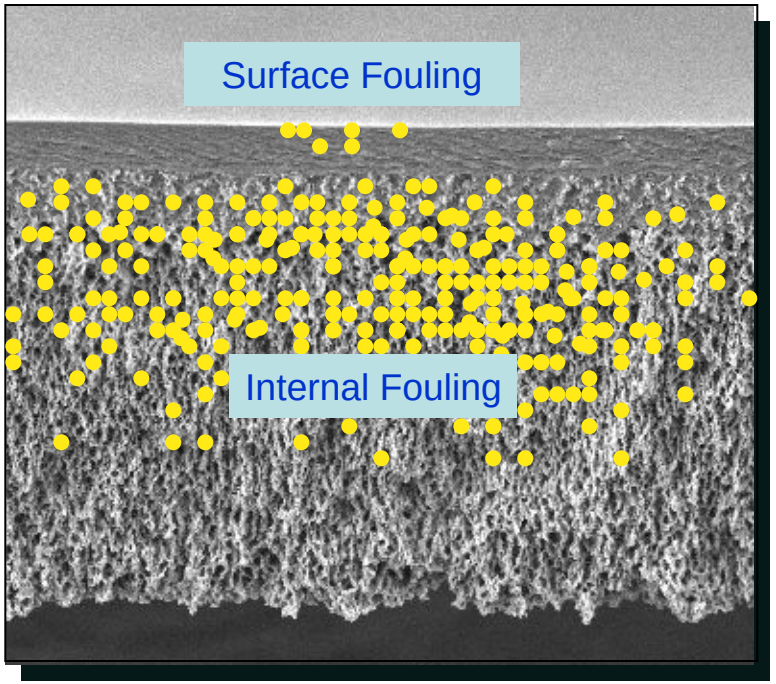
Membrane Separation Processes and Characteristics

Unfouled Membrane



Fouled Membrane



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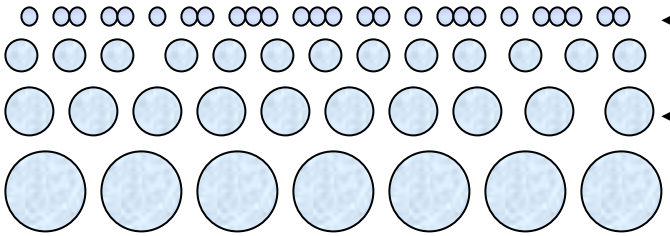
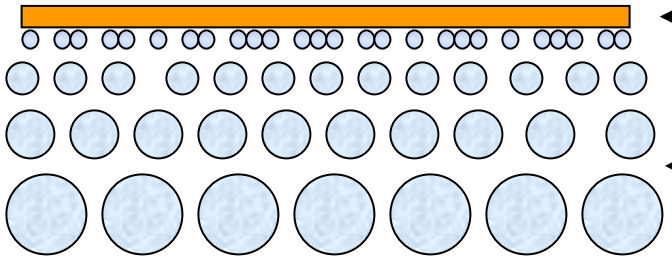
Schematic Structures of Porous and Non-Porous UF Membranes

Microporous Ultrafiltration Membrane



Non-Porous Ultrafiltration Membrane



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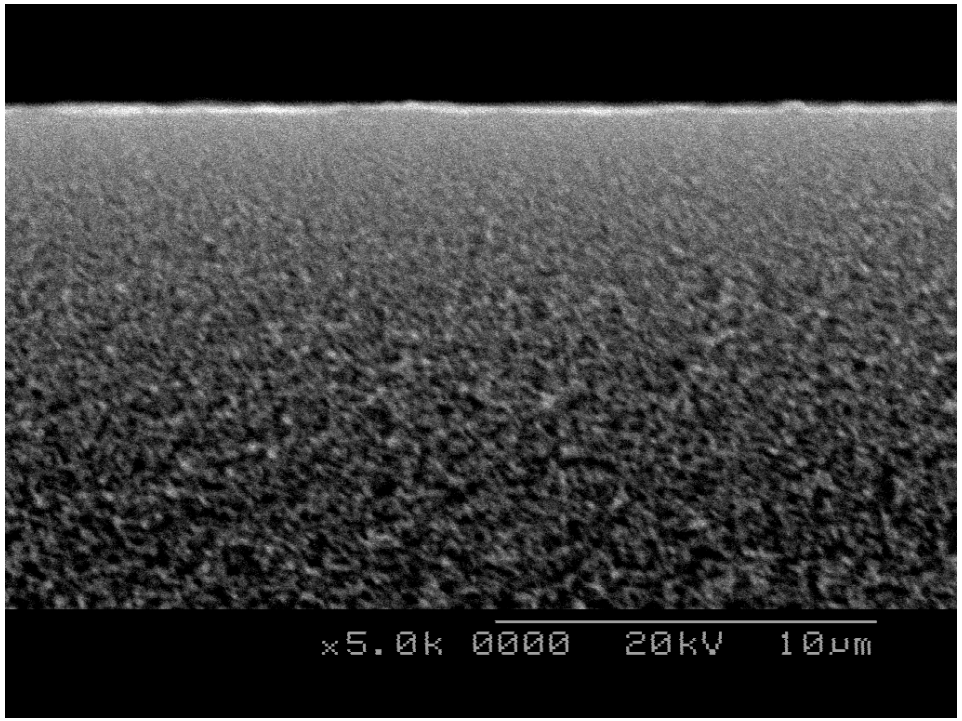
Cross-Section of a Non-Porous UF Membrane



Nonporous Polymer Coating Layer (~ 0.3 µm)

Microporous Support Membrane

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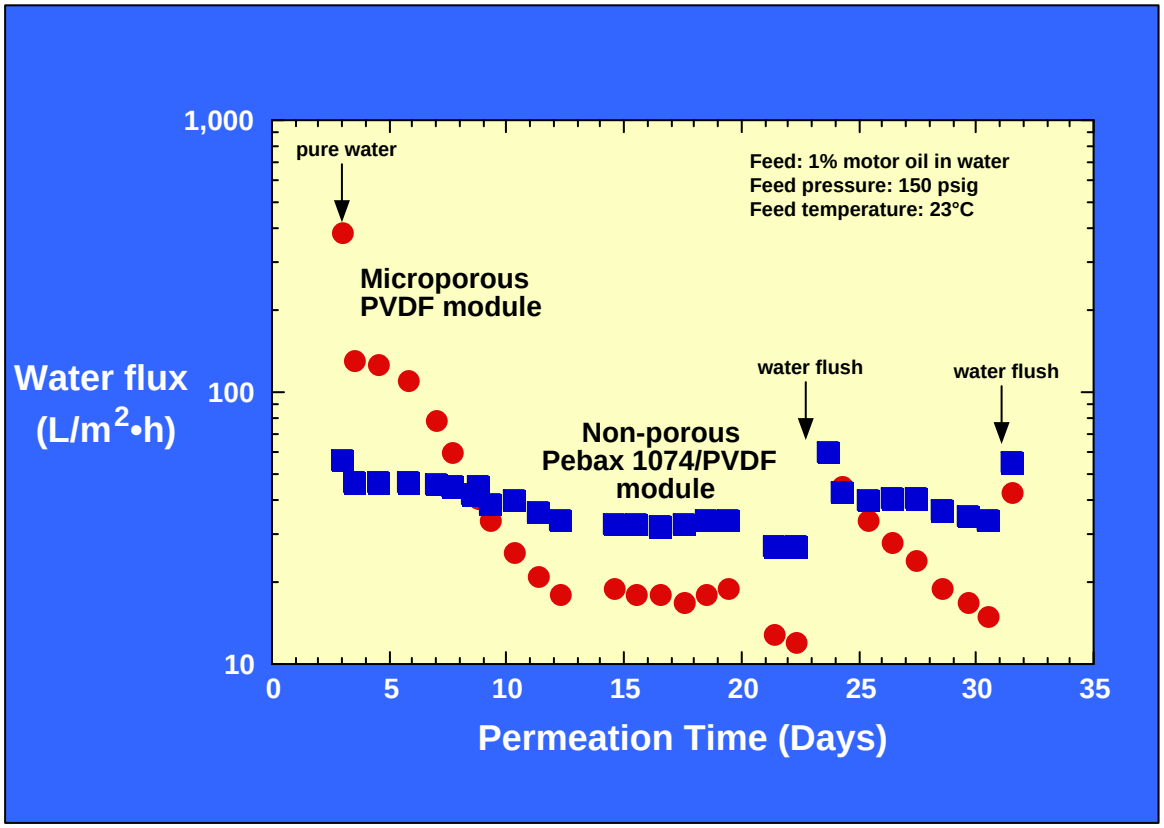
Long-Term Water Flux of Porous and Non-Porous Ultrafiltration Membranes



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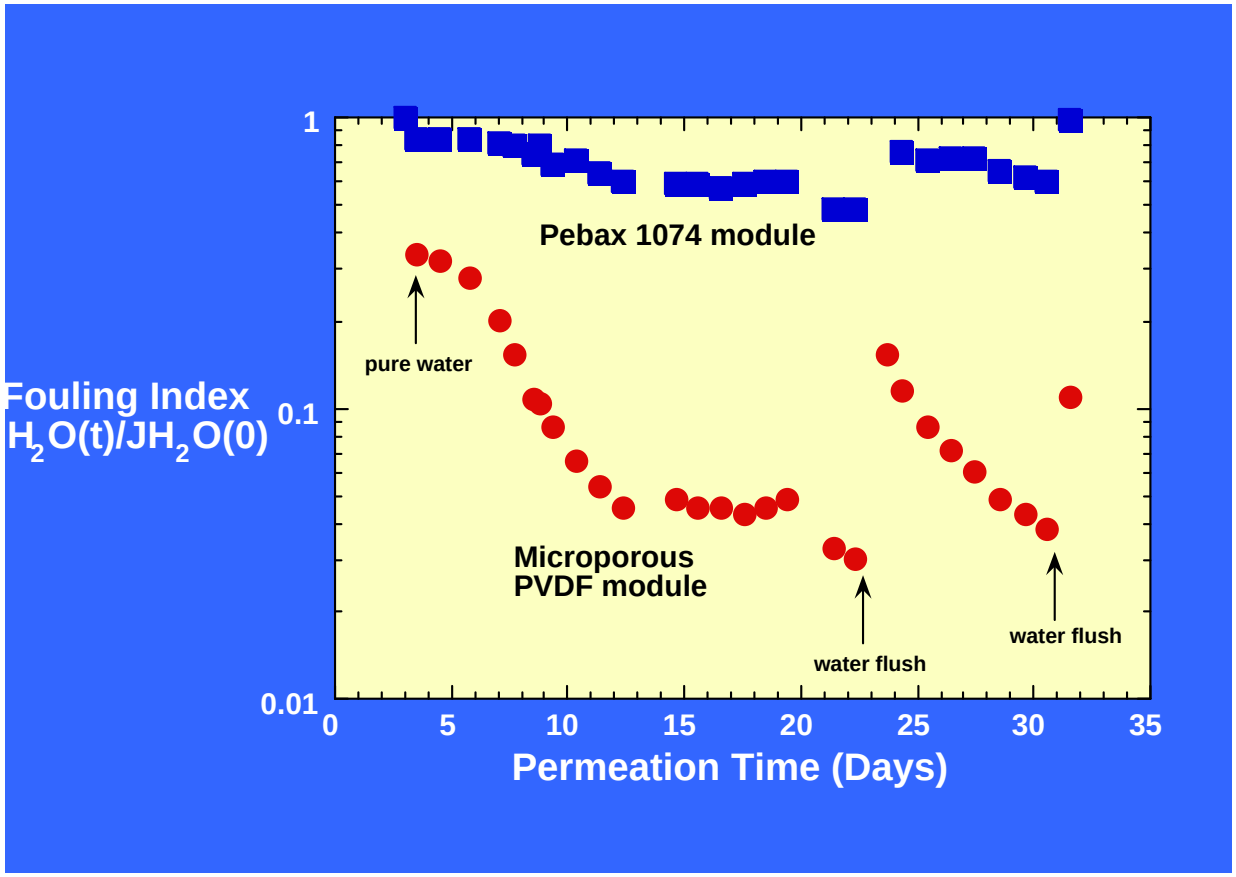
Fouling Index of Porous and Non-Porous Ultrafiltration Membranes for Separation of Oil/Water Emulsions



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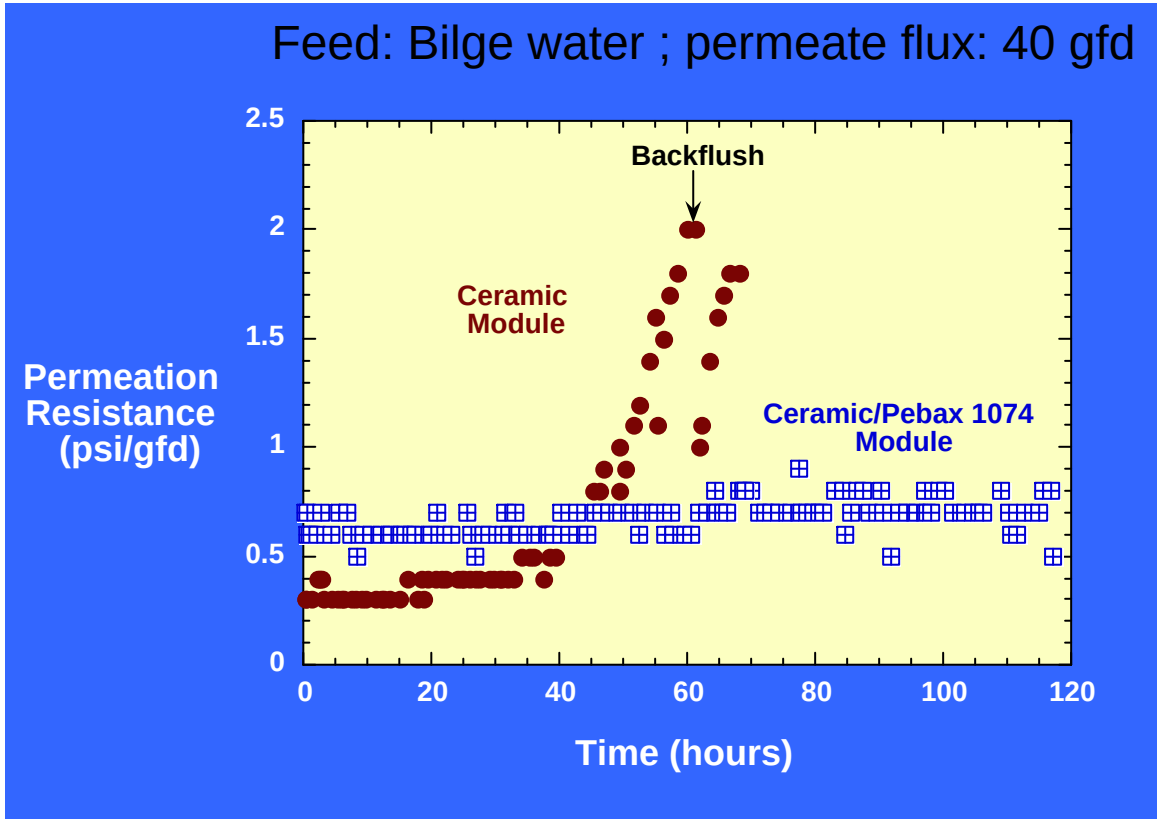
Long-Term Permeation Properties of Porous Ceramic and Ceramic/Polymer Composite Membranes



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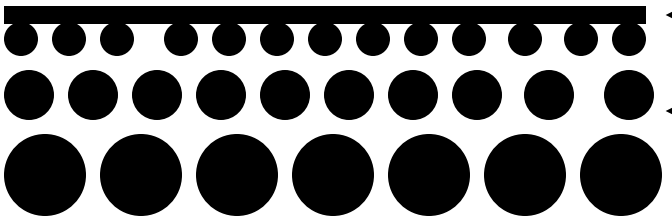
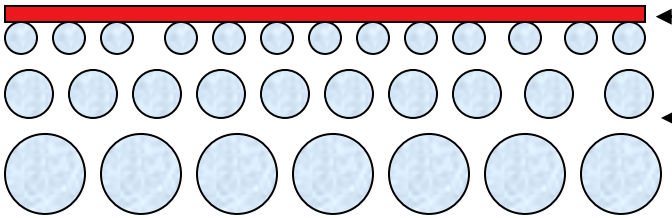
Membrane Types Used in Ultrafiltration, Nanofiltration and Reverse Osmosis

Integral asymmetric membrane (Cellulose acetate)



Thin-film composite membrane (Polyamide)



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2003 RO/NF Membrane Sales

Company	Sales ($ MM)	Share (%)
Dow/Filmtech	**115**	**34**
Nitto Denko/ Hydranautics	**99**	**30**
Toray	**36**	**11**
GE Osmonics	**27**	**8**
Koch/ Fluid Systems	**18**	**5**
Toyobo	**15**	**4**
TriSep	**12**	**4**
Others	**15**	**4**

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R. Truby, *Water Executive*, September/October 2004, p.11
(Supplement of *Ultrapure Water 21*, 2004)

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2003 RO/NF Module Sales Distribution

Module Type	Market Share (%)
Polyamide spiral-wound (8'x40')	**91**
Cellulose acetate hollow fiber module	**5**
Plate-and-frame	**4**

- Expected RO/NF membrane lifetime ~ 3-5 years.
- Actual RO/NF membrane lifetime ~ 7-12 years.
- Membrane replacement makes up for ~ 60% of annual sales.

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R. Truby, *Water Executive*, September/October 2004, p.9
(Supplement of *Ultrapure Water 21*, 2004)

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Incremental Changes in Spiral-Wound RO Module Performance

Figure of Merit = $\frac{\text{(Productivity) x (1/Salt Passage)}}{\text{Cost}}$

Year	Cost (Normalized to 1980 U.S.$)	Productivity (Normalized to 1980)	Reciprocal Salt Passage (Normalized to 1980)	Figure of Merit
1980	1.00	1.00	1.00	1.0
1985	0.65	1.10	1.56	2.6
1990	0.34	1.32	2.01	7.9
1995	0.19	1.66	3.52	30.8
1999	0.14	1.94	7.04	99.3

Dave Furukawa (1999)

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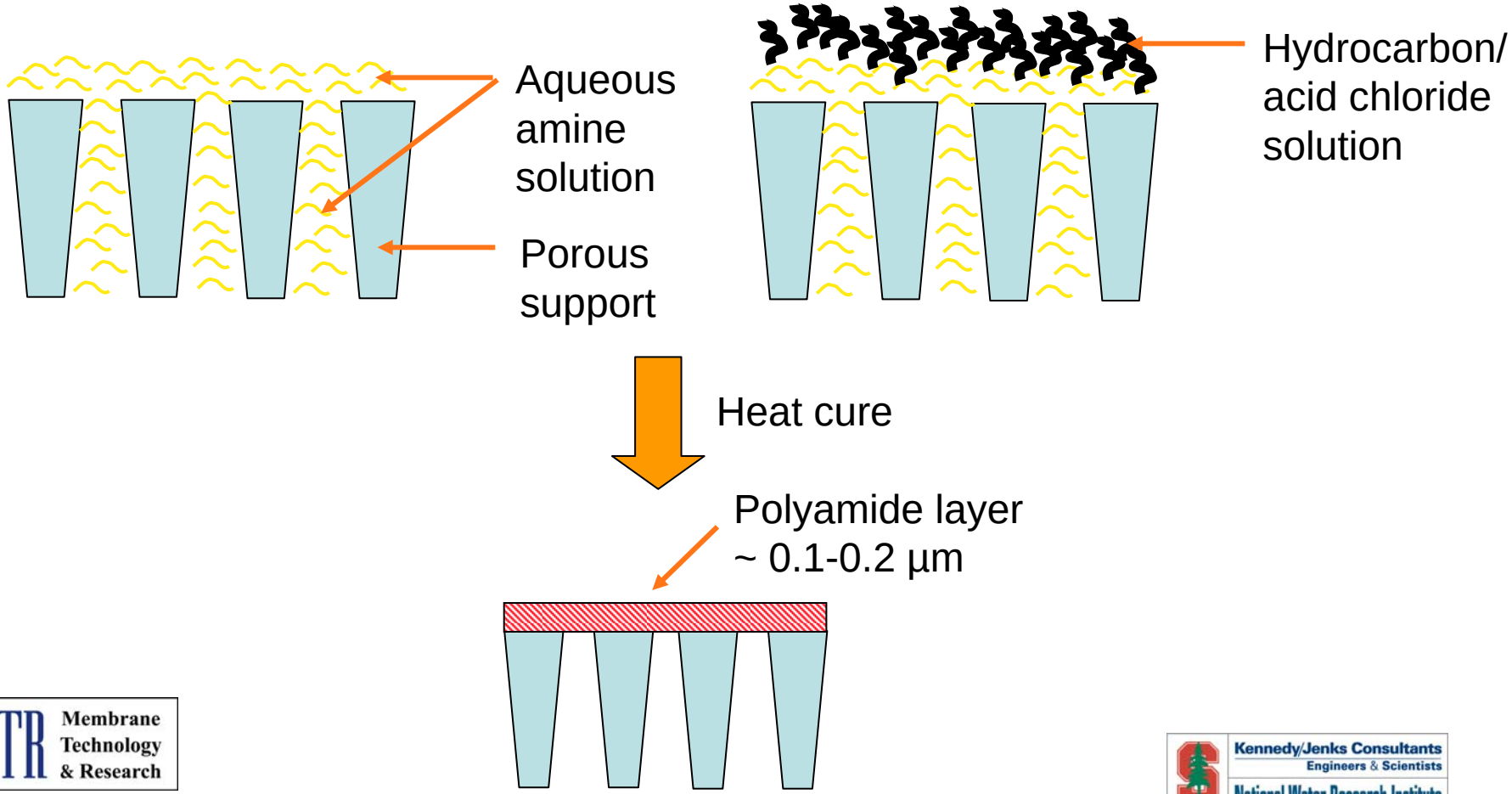
Interfacial Polymerization for Preparation of Thin-Film Composite RO Membranes



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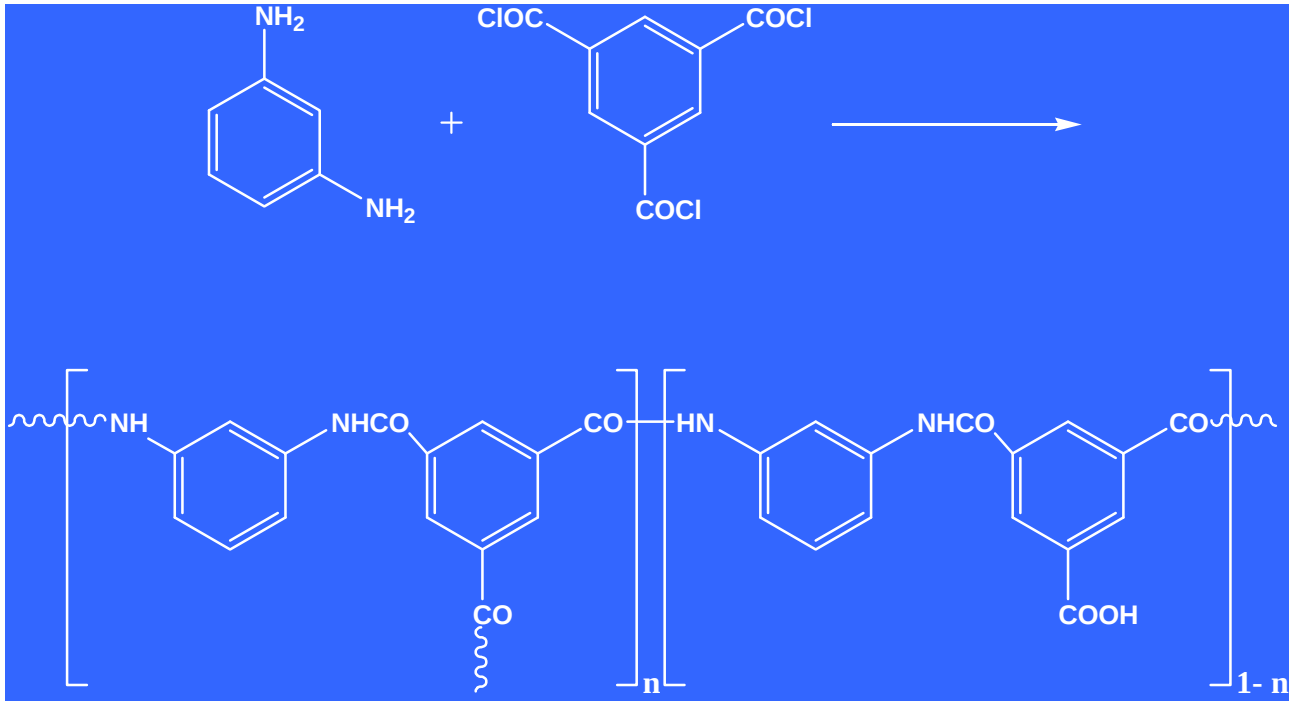
Formation of FT 30 Thin-Film Composite Membrane



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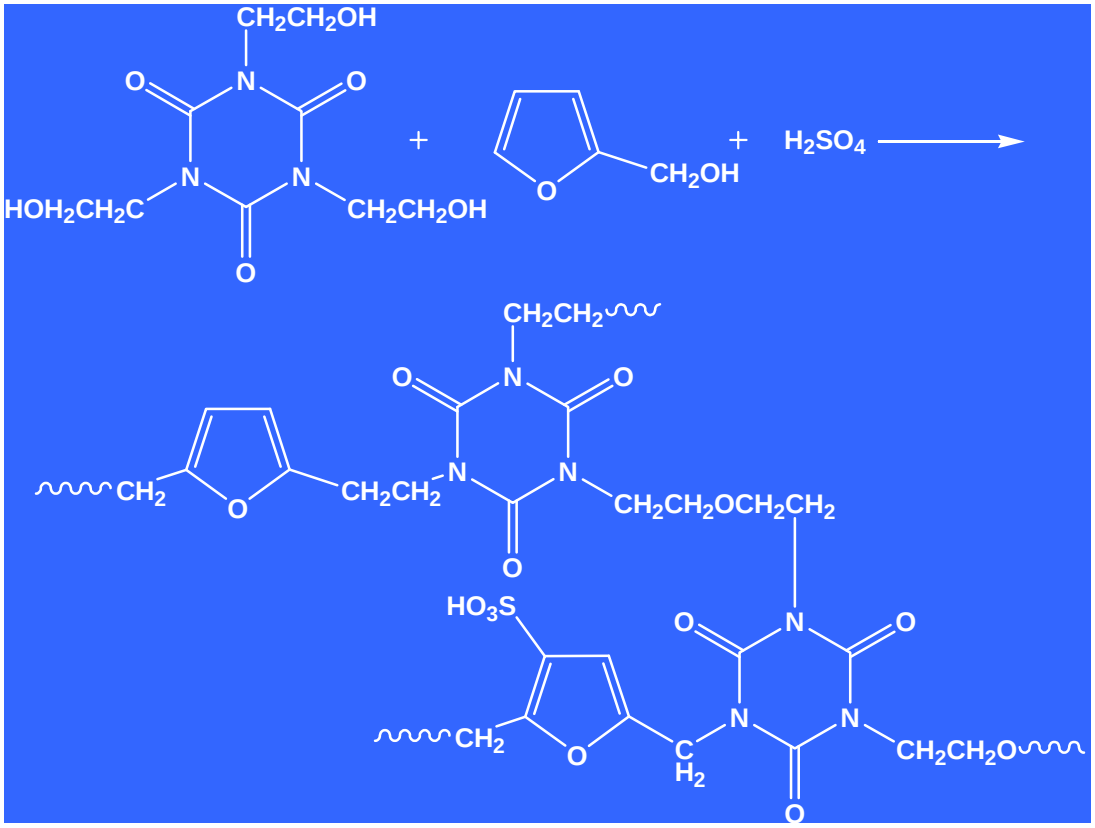
Formation of PEC 1000 Thin-Film Composite Membrane



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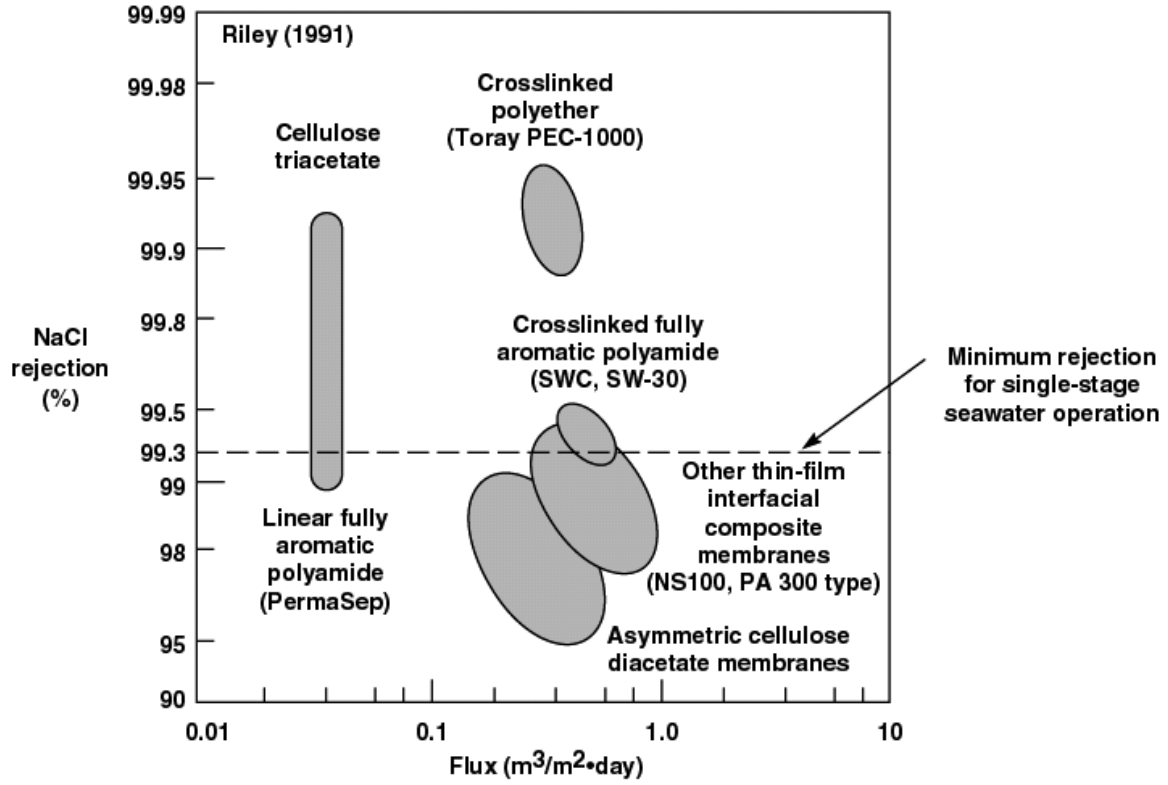
Rejection and Water Flux of RO Seawater Desalination Membranes



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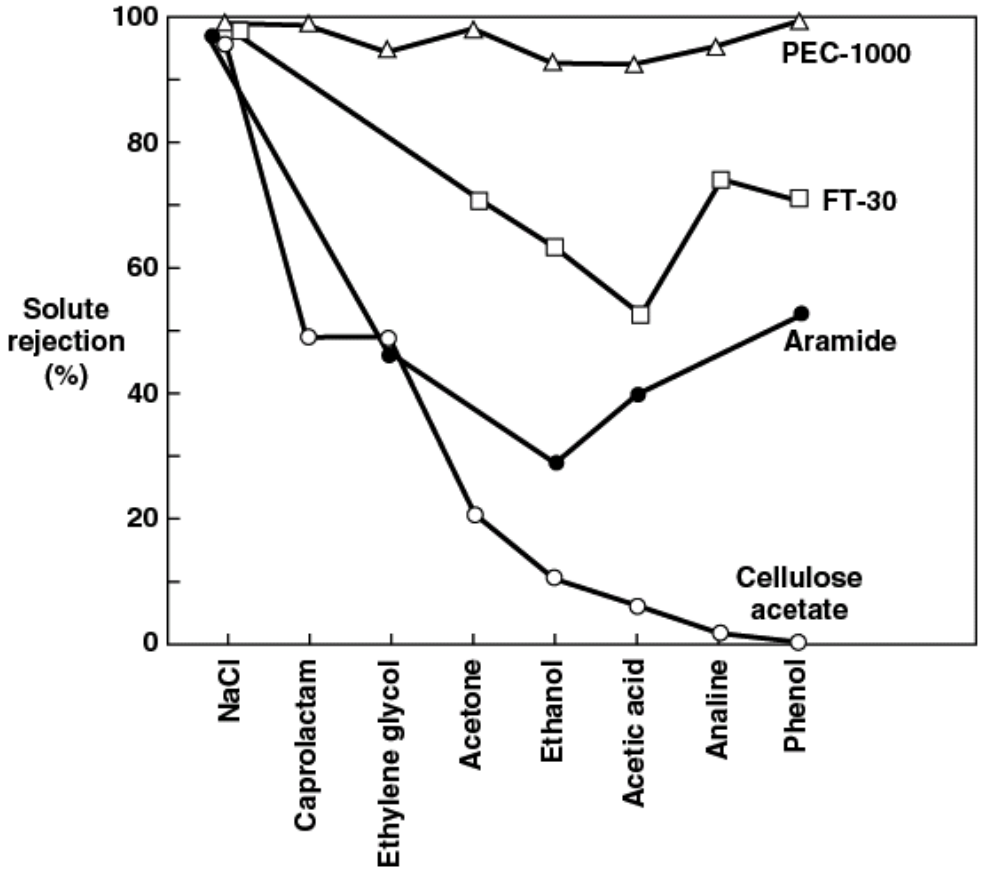
Organic Solute Rejection of Commercial RO Membranes



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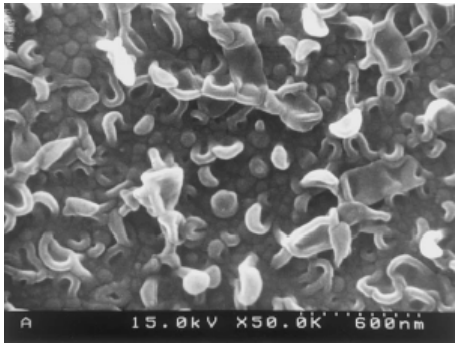
Surface Structures of Interfacial Aromatic Polyamide Composite Membranes



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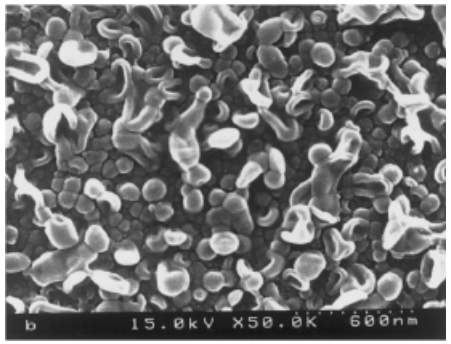

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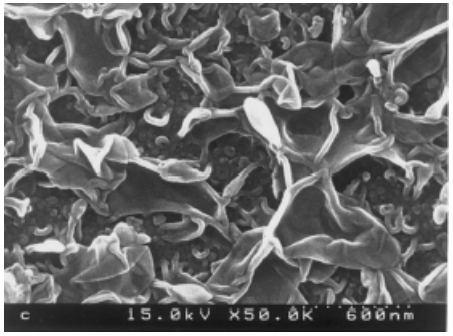

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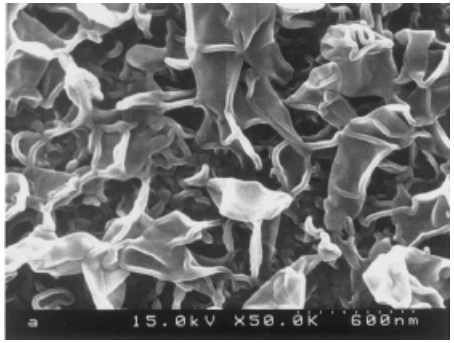

45 gfd

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S.-Y. Kwak, D.W. Ihm, *J. Membrane Sci.* 158 (1999) 143-153

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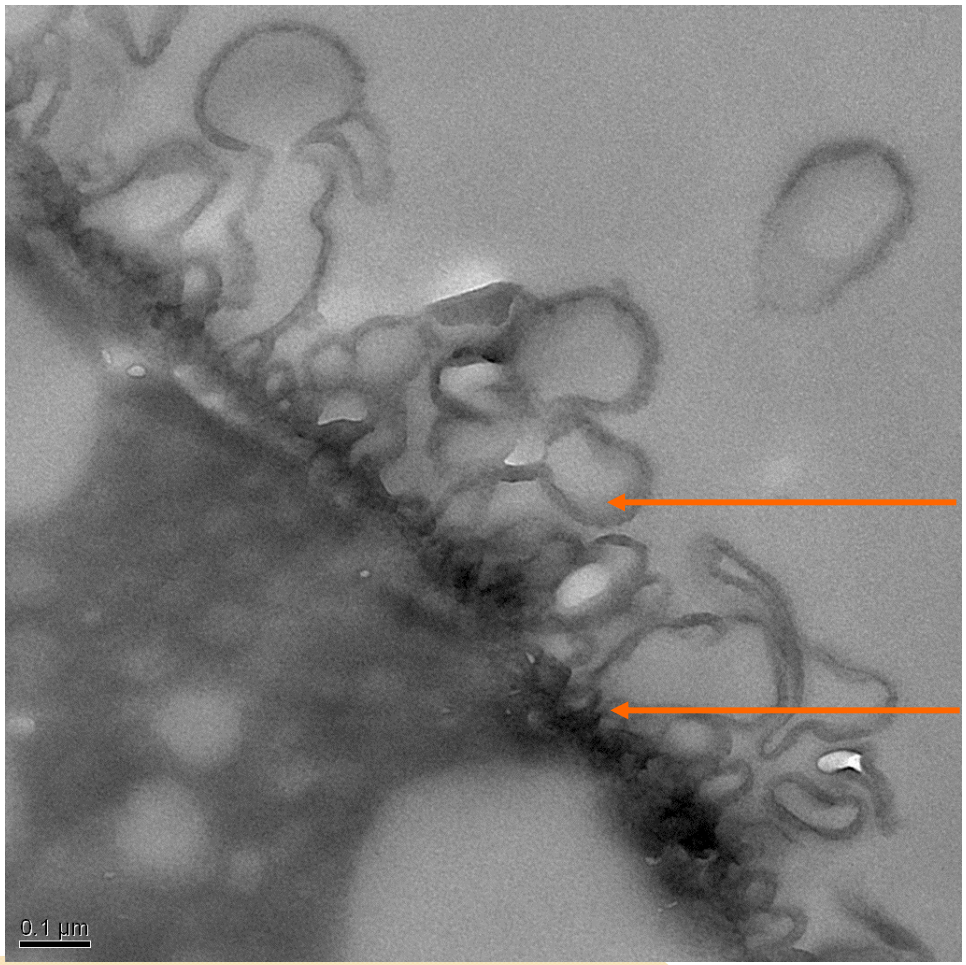
Cross-Section of Interfacial Polyamide Composite Membranes (BW 30)



Ridge and valley structure
~ 0.2 - 0.5 µm

Selective layer
~ 500 - 1,000 Å

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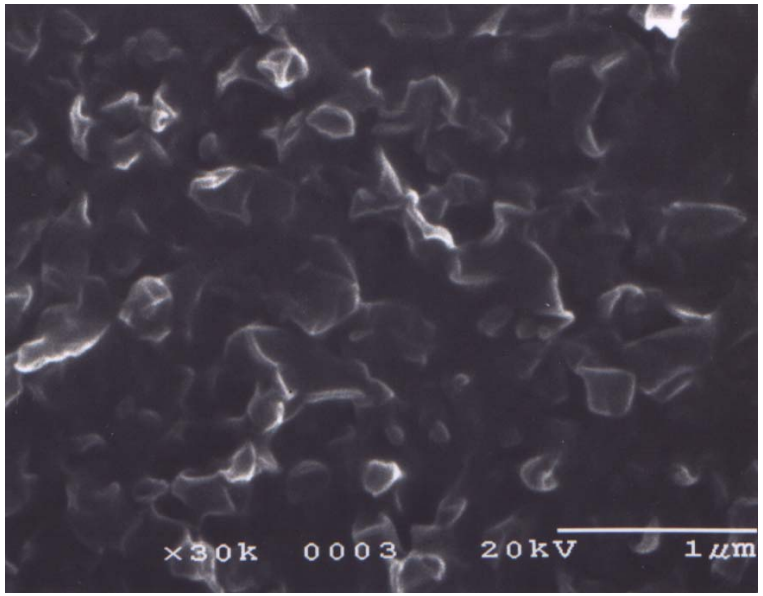
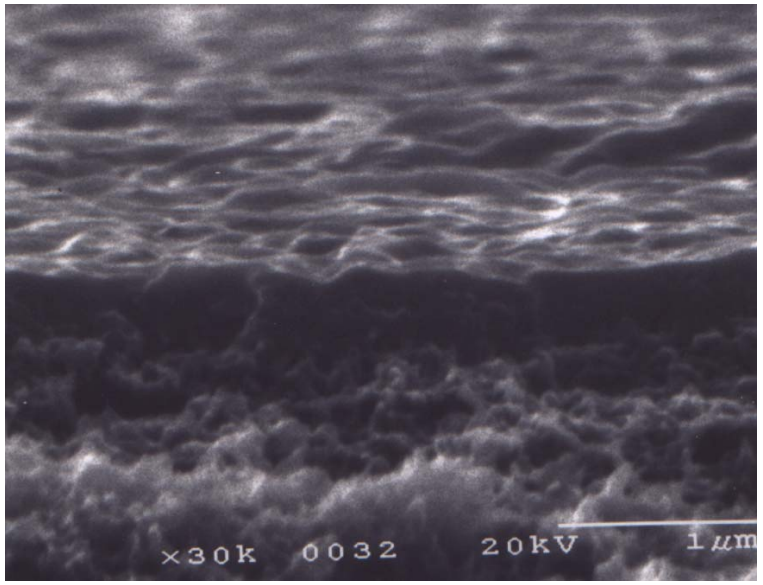
Surface Structure of Uncoated and Coated RO Membranes



Uncoated



Coated

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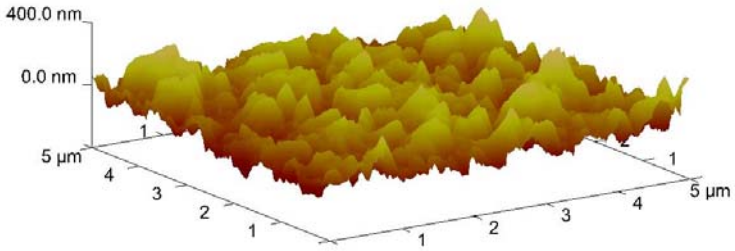
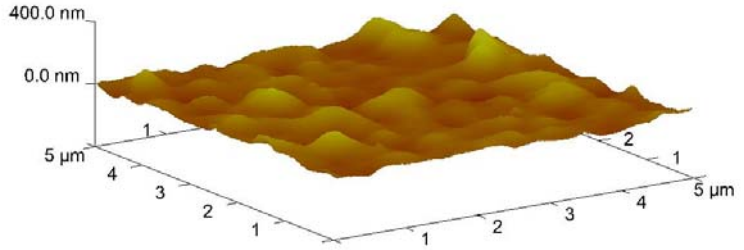
Surface Structure of Uncoated and Coated RO Membranes (AFM)



ESPA-3



ESPA-3 - coated

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AFM pictures courtesy of Jennifer Louie, Stanford University

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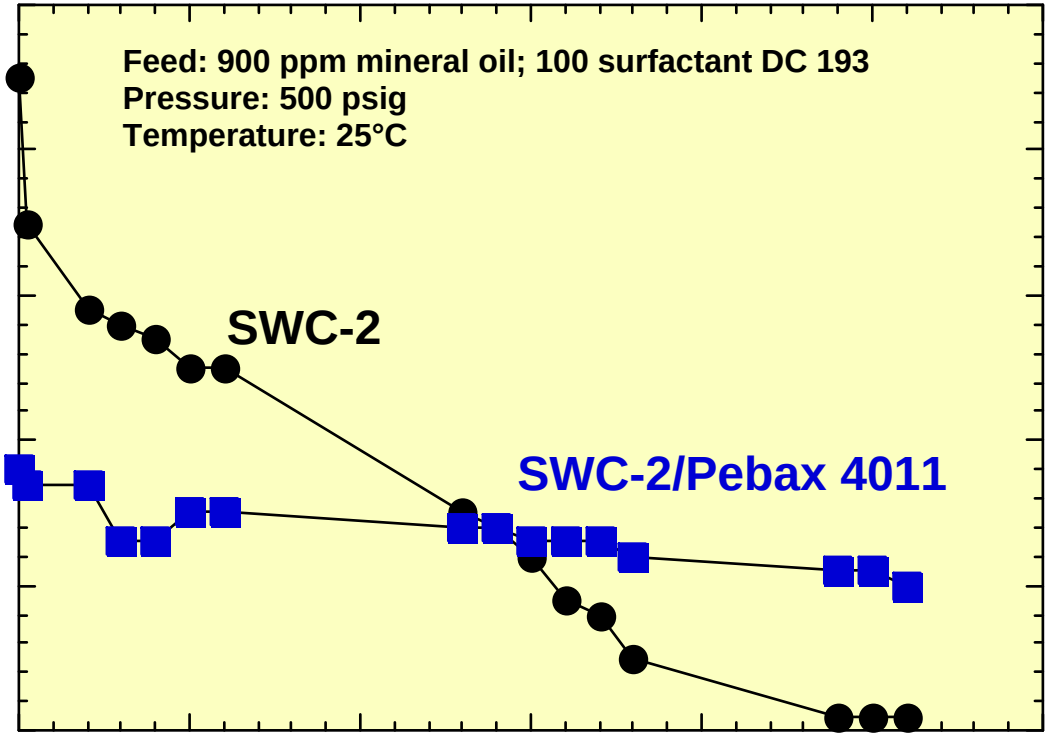
Performance of Commercial and Modified RO Membranes for Wastewater Treatment



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Acknowledgements

Financial support was provided by Office of Naval Research and SERDP

Special thanks to my colleagues Isabelle Ciobanu, Sylvie Thomas and Alvin Ng.

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