# *Emerging Applications for Water Treatment and Potable Water Reuse*

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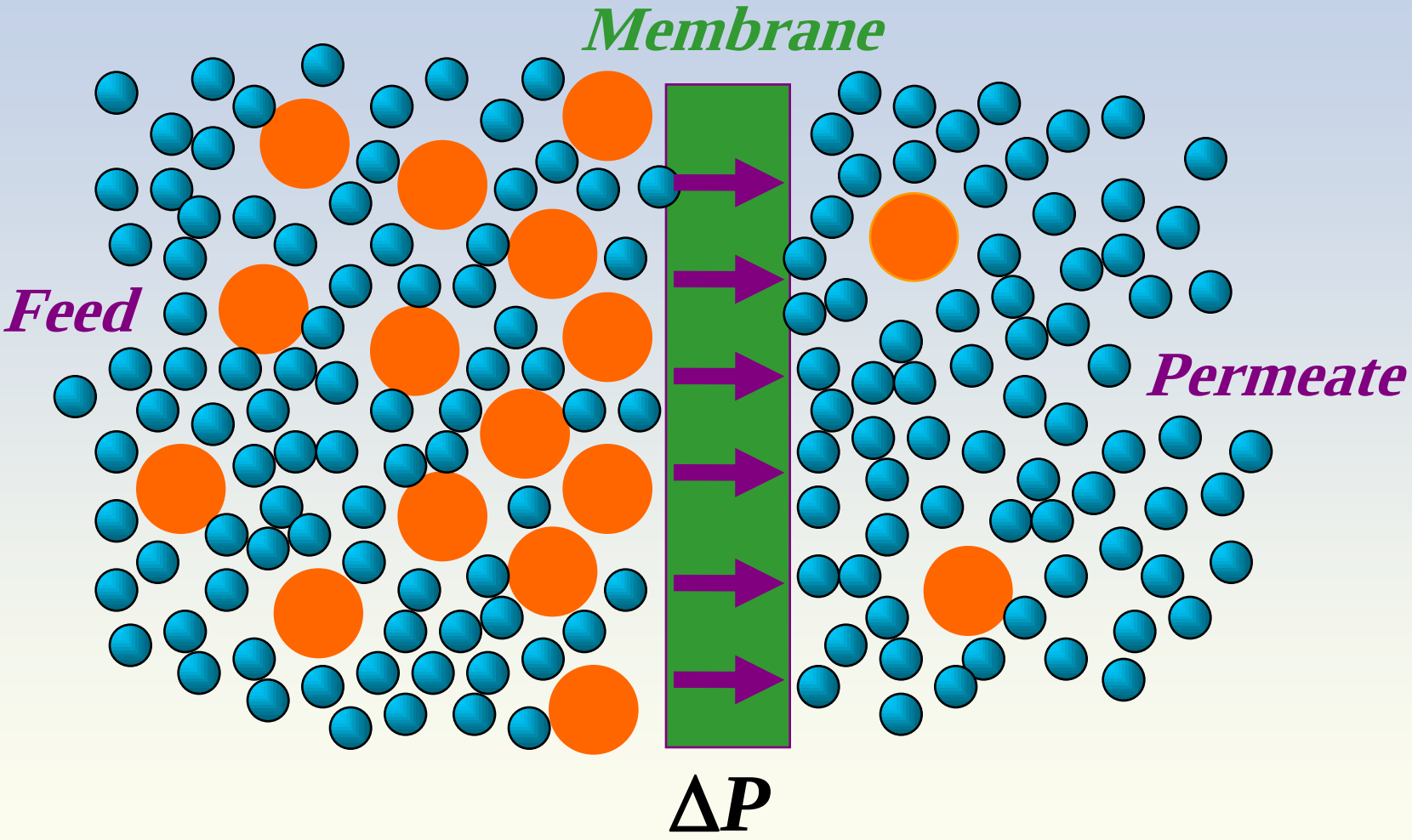
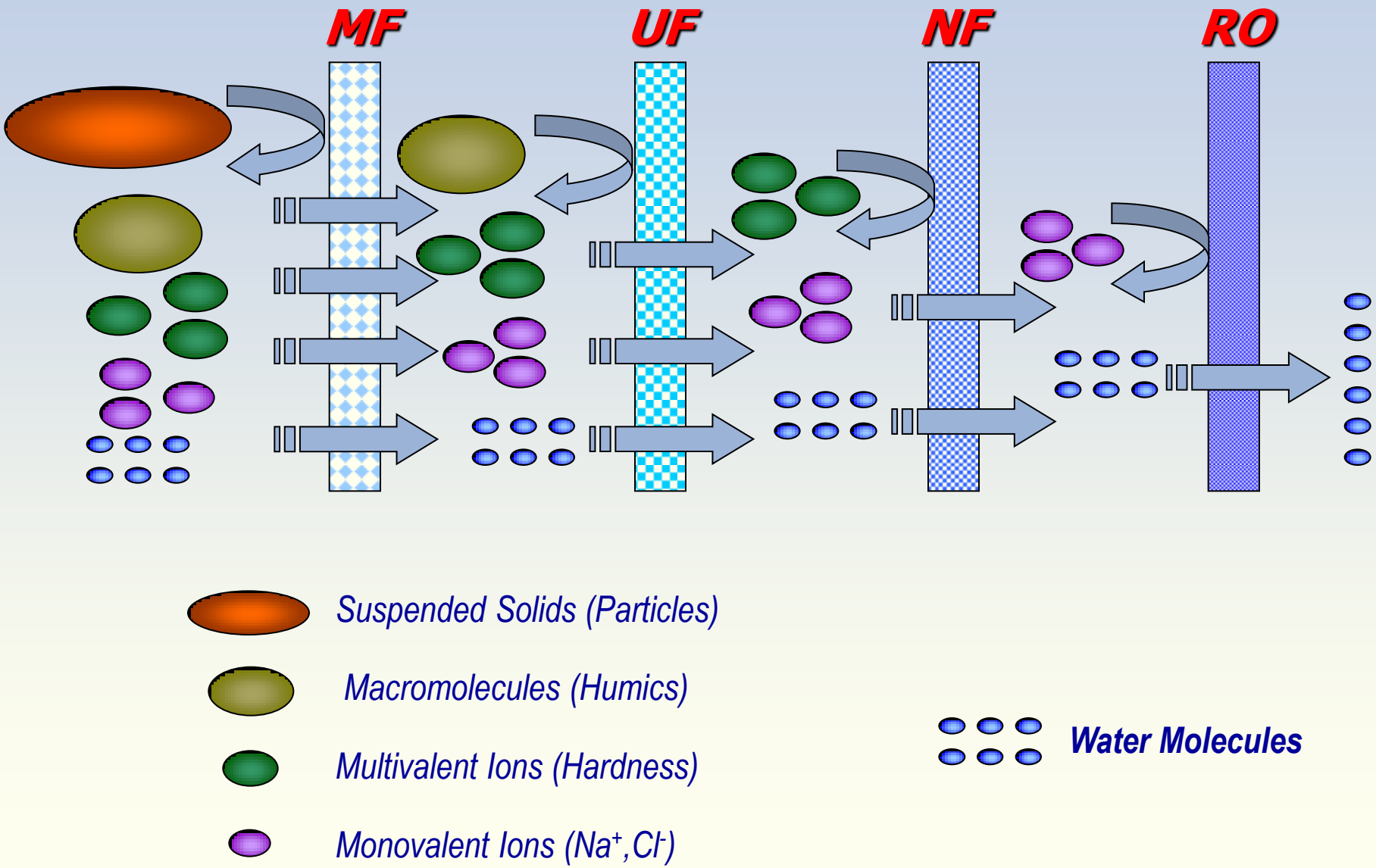
# Presentation Outline

- Overview of Membrane Processes for Water Treatment
  - Pressure-driven membrane processes
  - Membrane contactor processes
- Combination of processes for process intensification
  - Potable Reuse of Wastewater
  - Volume Minimization of Wastewater
  - Brackish Water Desalination
- Summary and Future Directions

# Pressure-Driven Membrane Processes



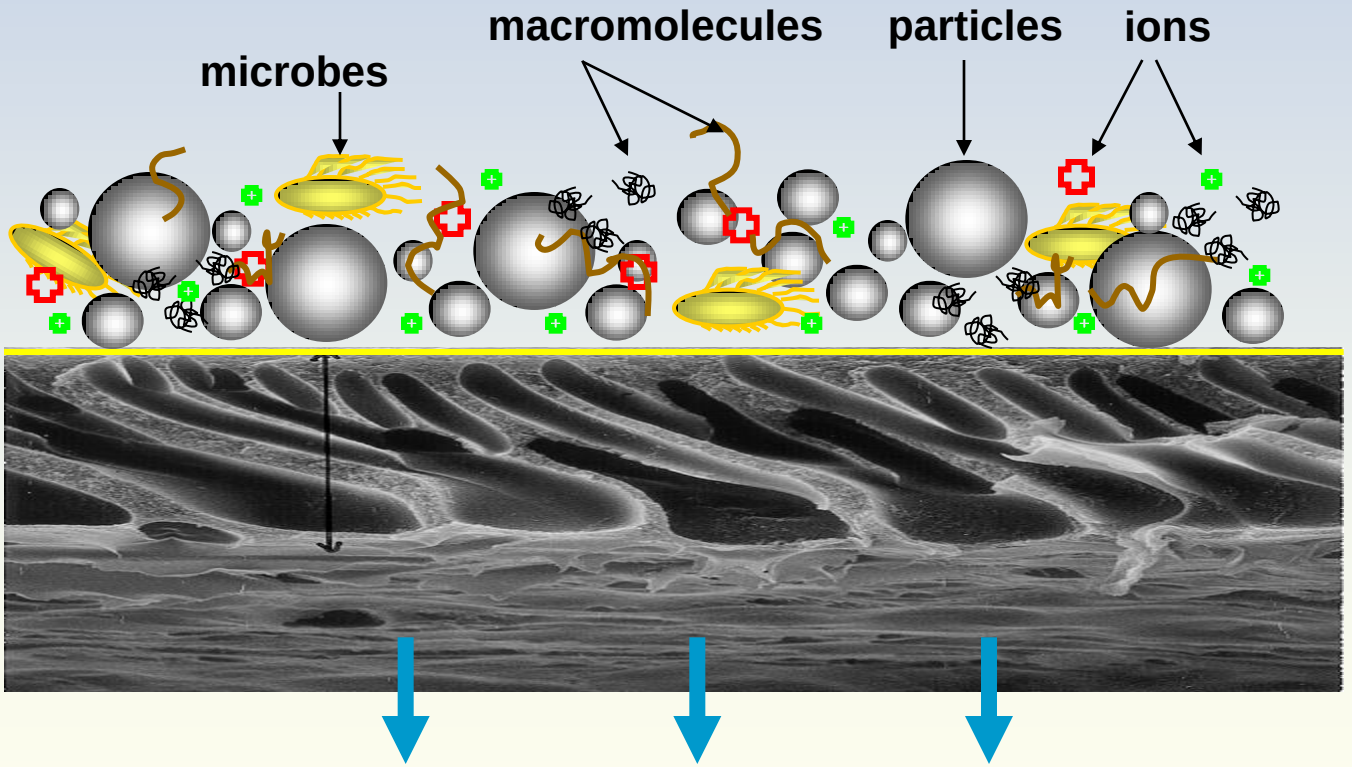
# Pressure-Driven Membrane Processes



# Limitations of Pressure-Driven Membrane Processes

- Membrane fouling
  - Limited application
- Membrane scaling
  - Limited water recovery
- Energy

# Membrane Fouling



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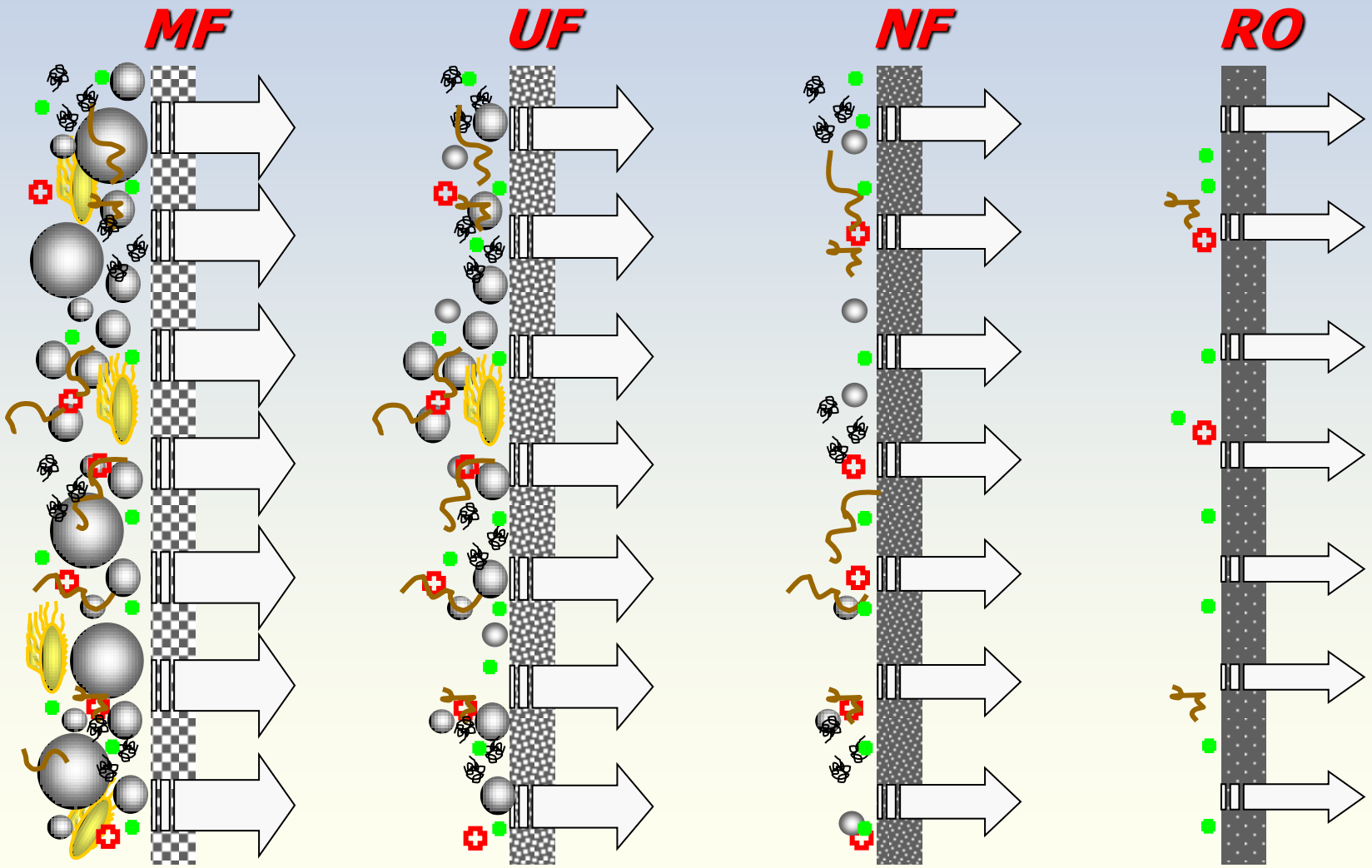
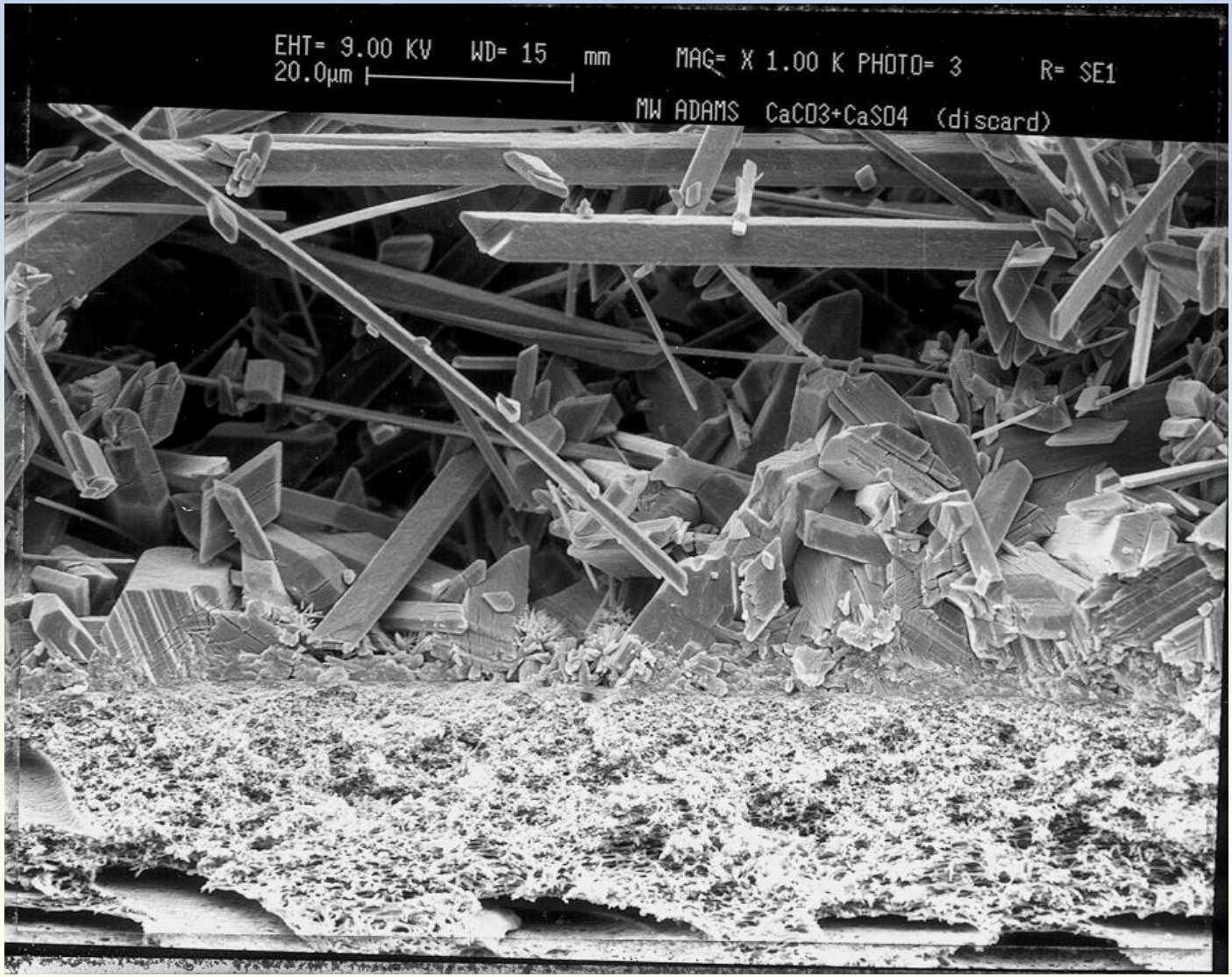


# Membrane Scaling



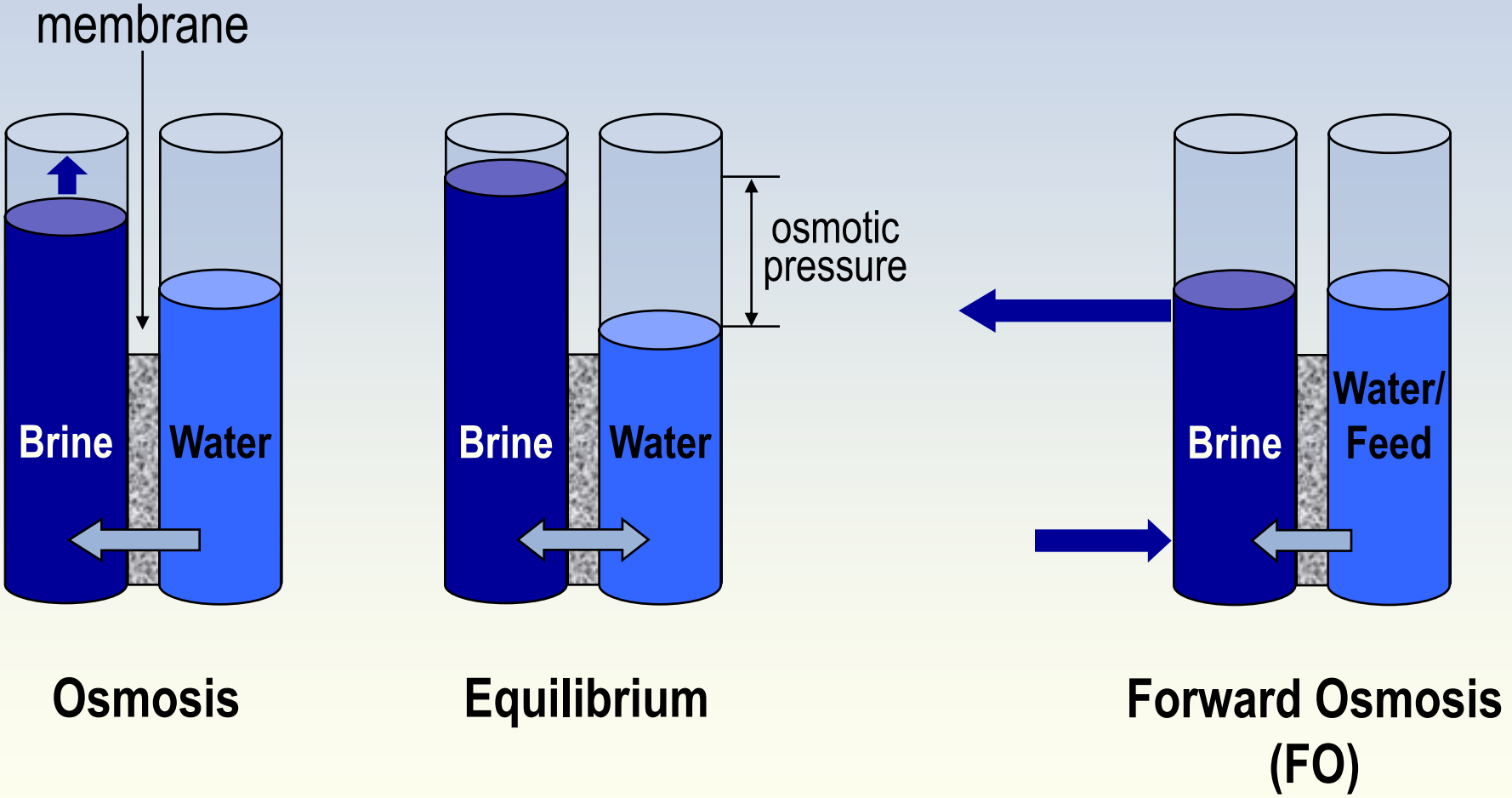
# Osmotic- and Thermally-Driven Membrane Processes

- The driving force is temperature or concentration gradients across the membrane

| Process | Mass Transport | Driving Force |
|---|---|---|
| **Forward Osmosis (FO)** | **Diffusion** | **Osmotic Pressure** |
| **Membrane Distillation (MD)** | **Evaporation** | **Partial Vapor Pressure** |

- Combination with each other and with pressure-driven membrane processes

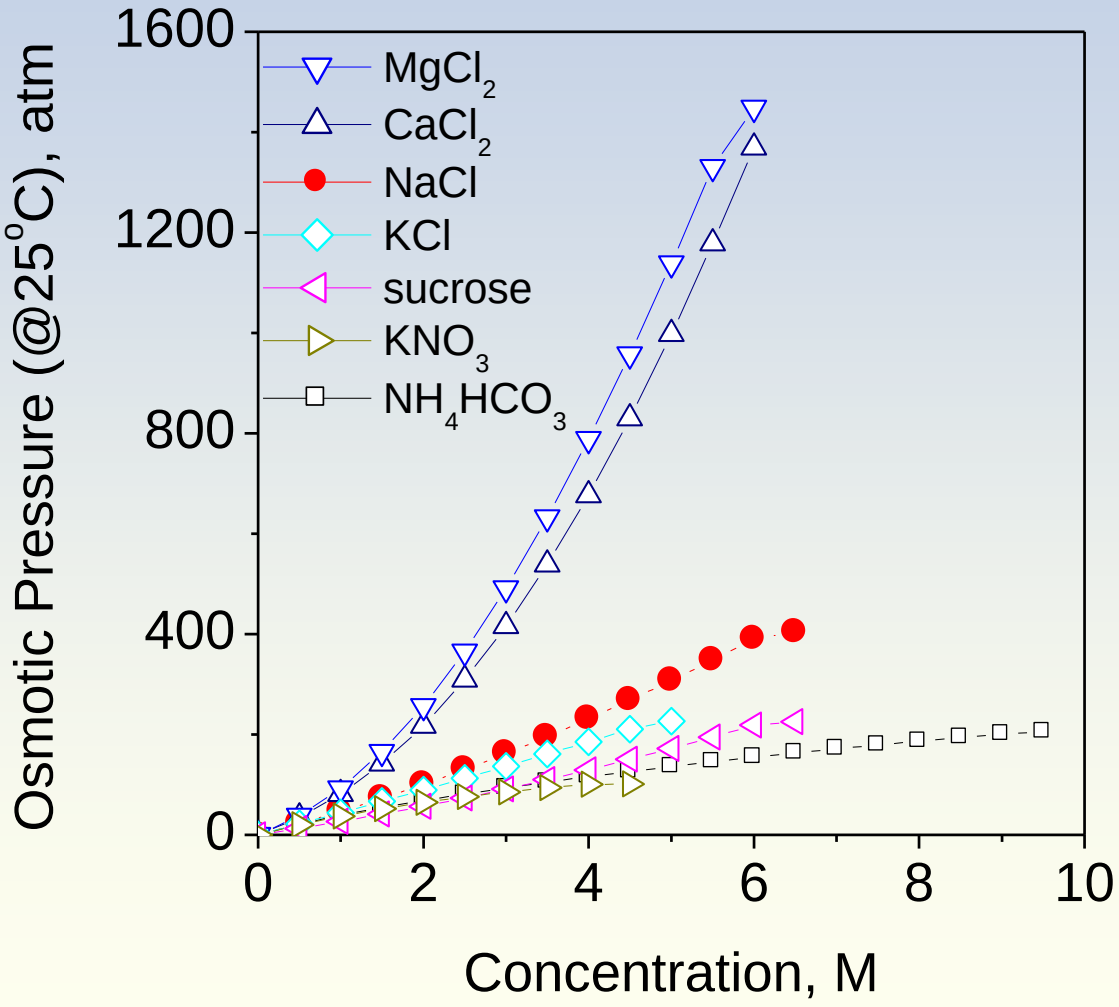
# Osmosis / Forward Osmosis



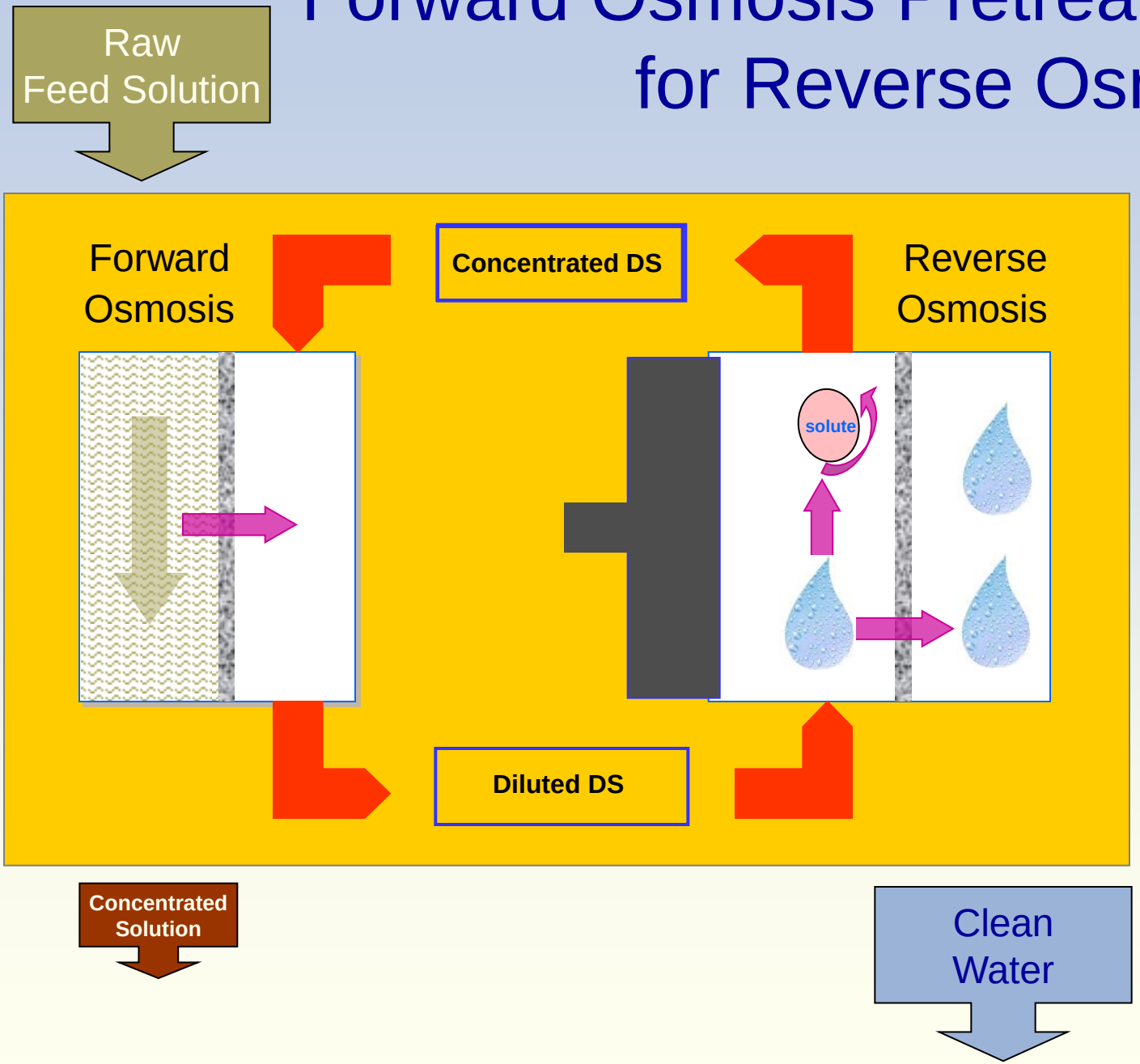

**Osmosis** | **Equilibrium** | **Forward Osmosis (FO)**

**Brine ≡ Draw Solution (DS)**

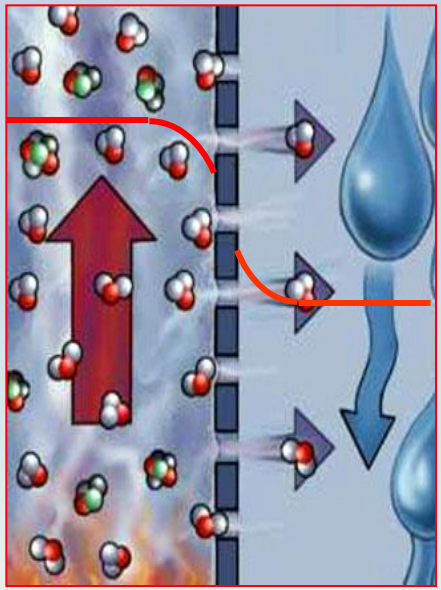
# Draw Solutions



# Forward Osmosis Pretreatment for Reverse Osmosis



# Membrane Distillation

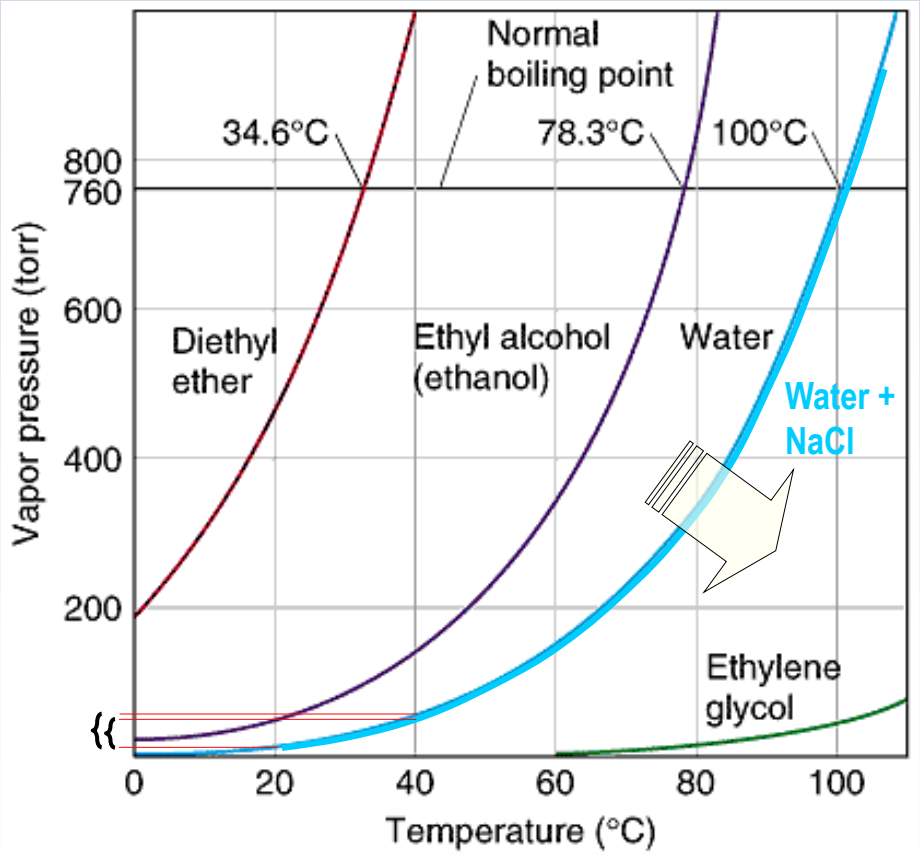


adapted from: http://www.water-technology.net/

$$J = A_m\left(P_f^* - P_p^*\right)$$

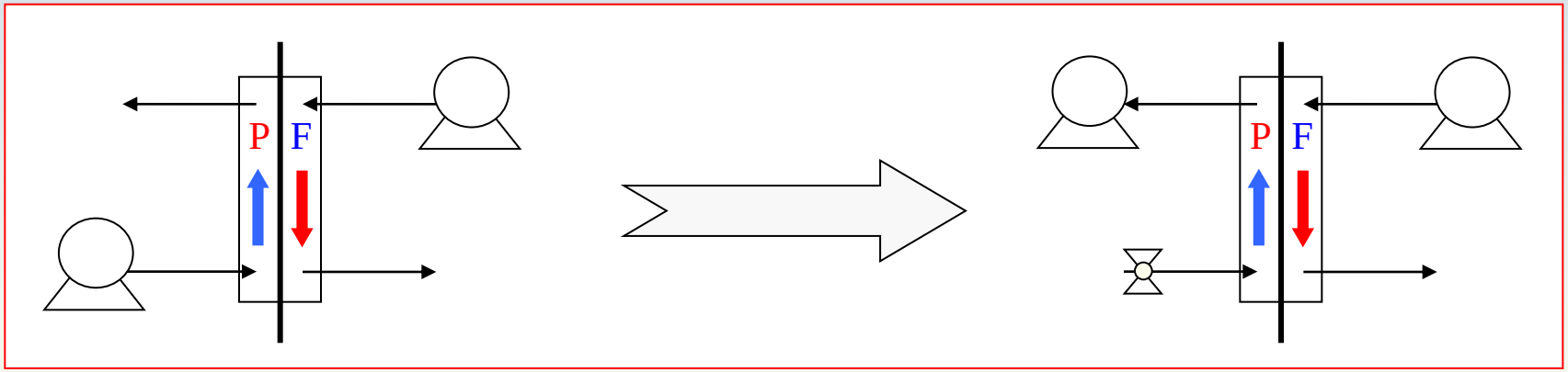
- heated aqueous feed solution is brought into contact with feed side of hydrophobic, microporous membrane
- hydrophobic nature of membrane prevents penetration of aqueous solution into pores
- cold pure water is in contact with permeate side of membrane
- vapors diffuse through pores and directly condense into cold stream

# Vapor Pressure and Partial Vapor Pressure in Microporous Membrane Evaporation Processes

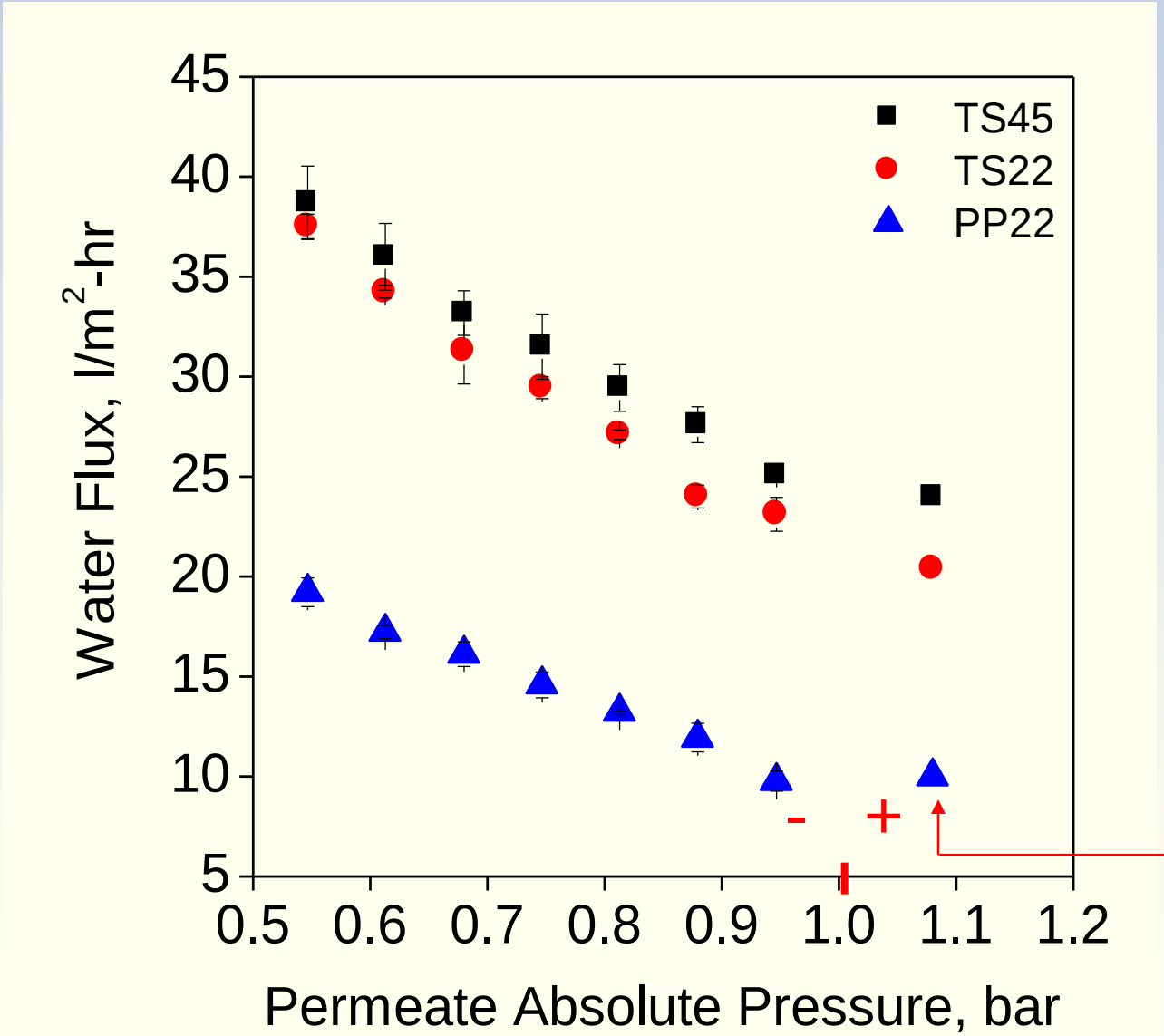


# Vacuum Enhanced Direct Contact Membrane Distillation

**Traditional DCMD** **VEDCMD**



# Effect of Permeate-Side Vacuum on Flux



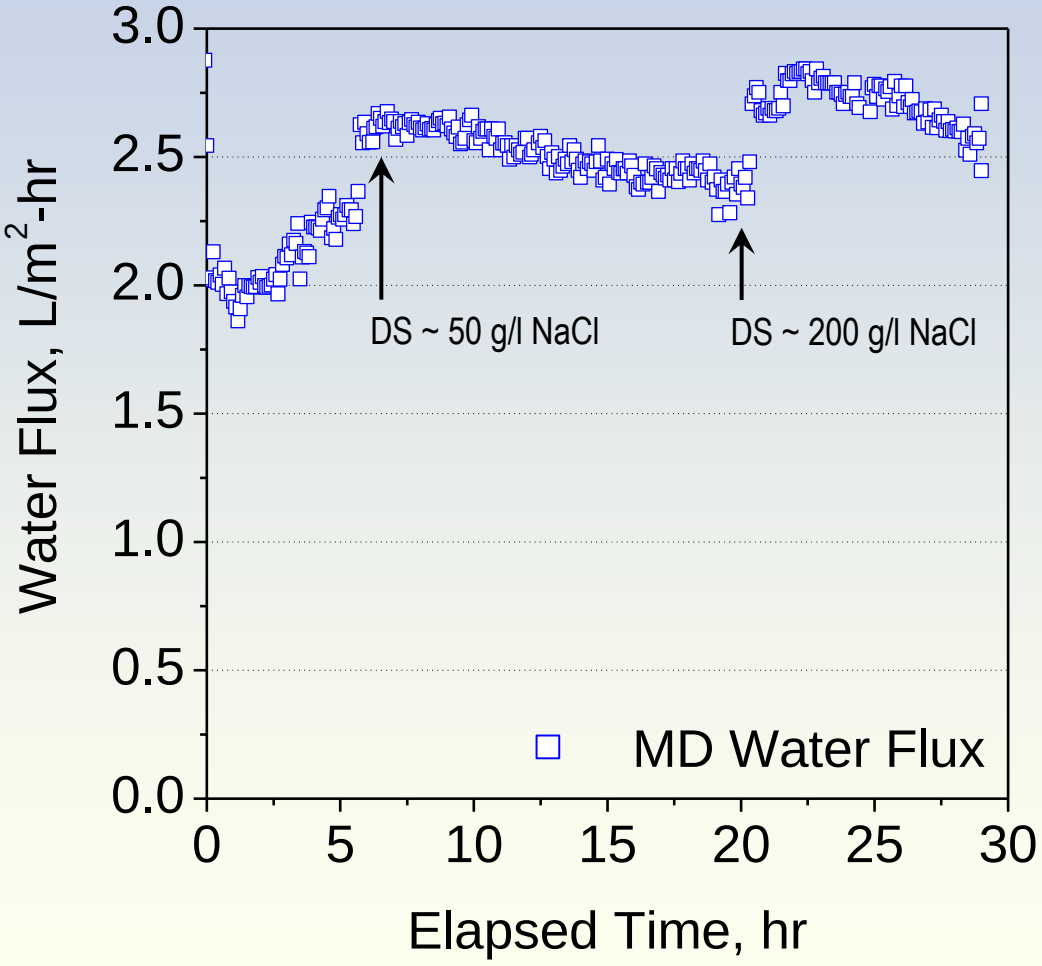

$\Delta T = 20°C$

$v_f = v_p = 1.4$ m/sec

$P_f = 1.1$ bar (abs)

Results from Traditional Configuration

# New Hybrid System for Fouling-Protected MD



# Advantages of Membrane Contactors

- High rejection of wide range of contaminants/solutes
- Low-grade energy / waste heat sources can be used
- Reduced fouling potential – less pretreatment required
- Operate at low pressure – less constraints / safety issues
- In MD, driving force not reduced by osmotic pressure
- Can provide enhanced recovery through brine desalination

# Evaluation of Forward (Direct) Osmosis Concentration (DOC) for Direct Potable Reuse of Wastewater in Long-Term Space Missions

# Project History

- Mid 1990s – Forward osmosis incorporated into a water reclamation systems
- 1999 – Osmotek Inc. completed first phase of technology demonstration
- 2002-2003 – University of Nevada, Reno completed optimization study with recommendations to modify DOC architecture
- 2004-2007 – Rapid Technology Development Team (RTDT) program to develop a more reliable system – appropriate for human testing at TRL 5-6

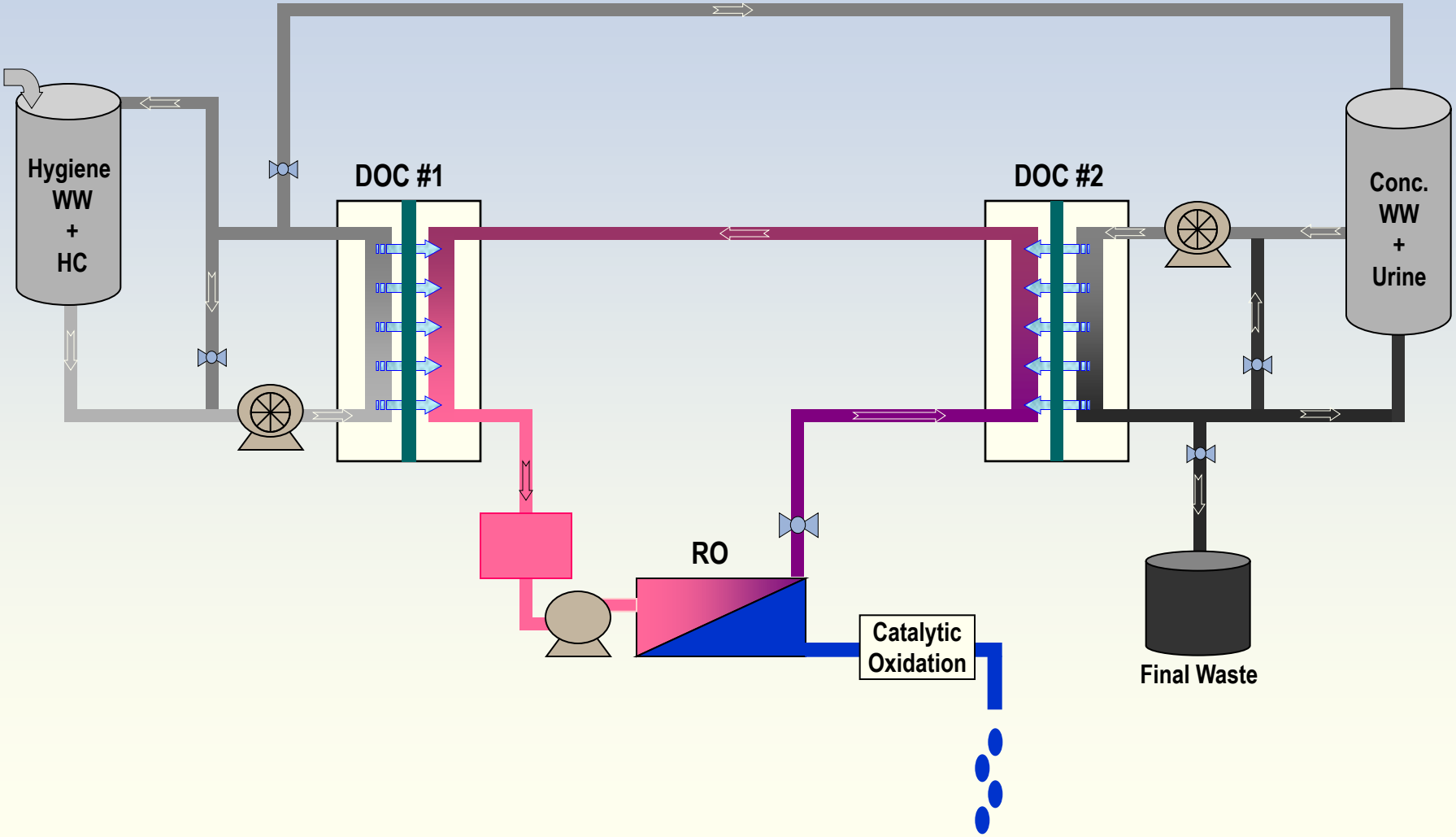
# Original DOC Concept

- Integration of three membrane processes in one system
  - Reverse osmosis – core process
  - Forward osmosis – pretreatment for RO
  - Forward osmosis/osmotic distillation – pretreatment for RO

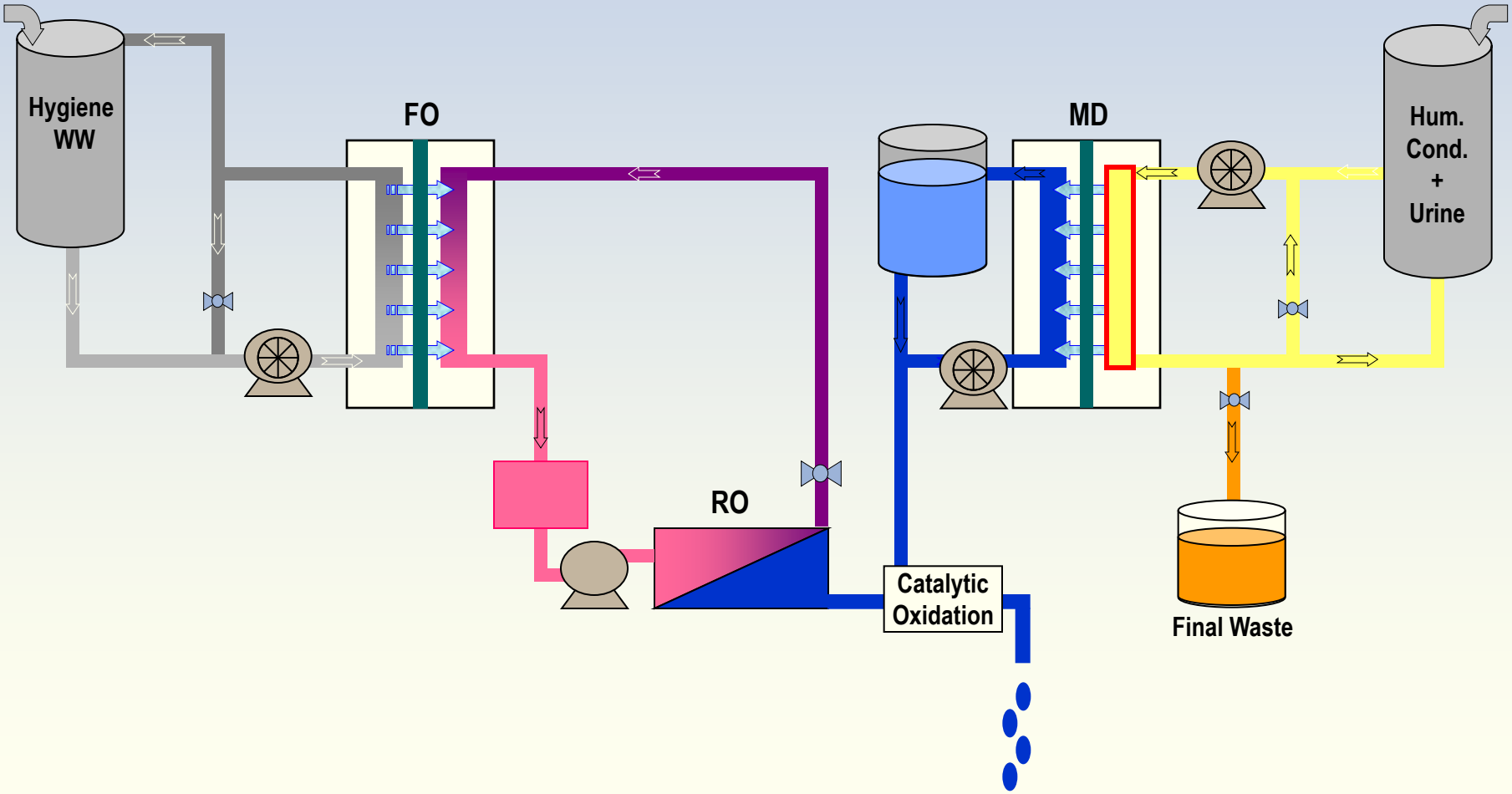
  } **Membrane Contactors**

- Treat variety of wastewater streams, including:
  - Hygiene wastewater
  - Humidity condensate (HC)
  - Urine

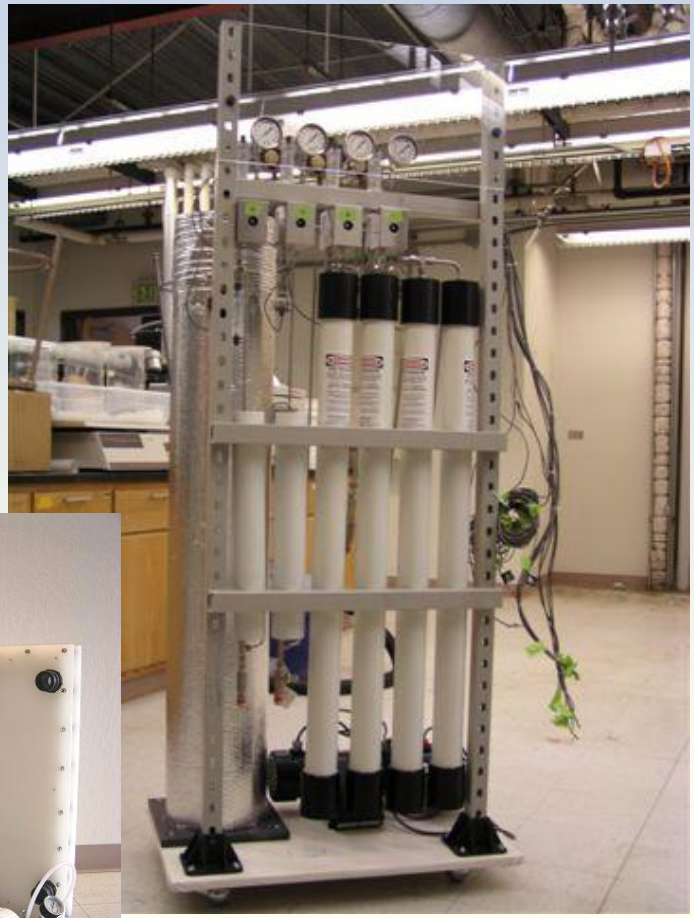
# Schematic of Original DOC Test Unit

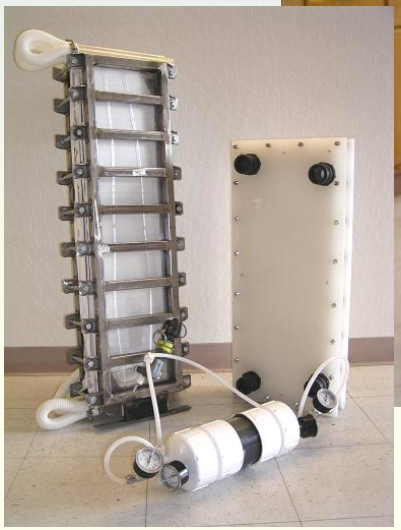


# Schematic of New DOC Test Unit



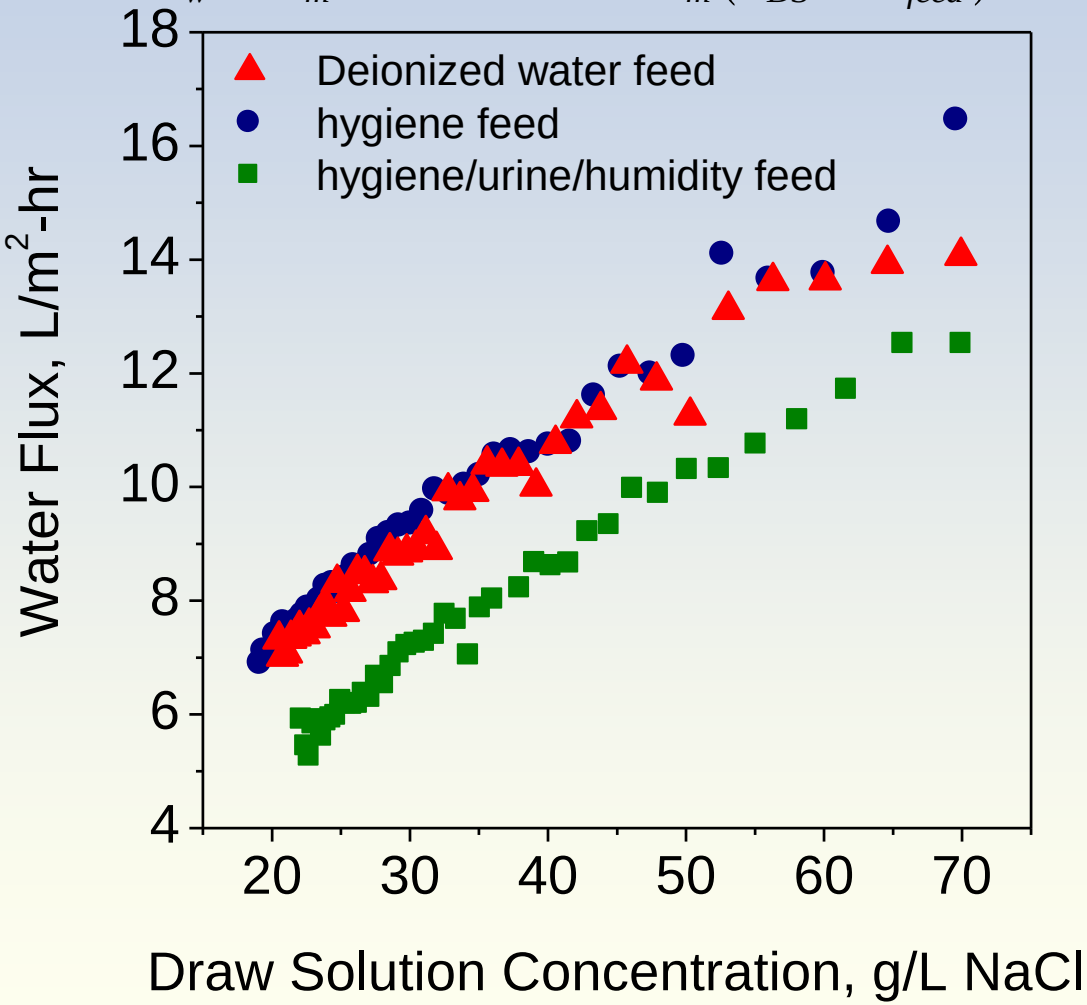
# Construction of New Prototypes





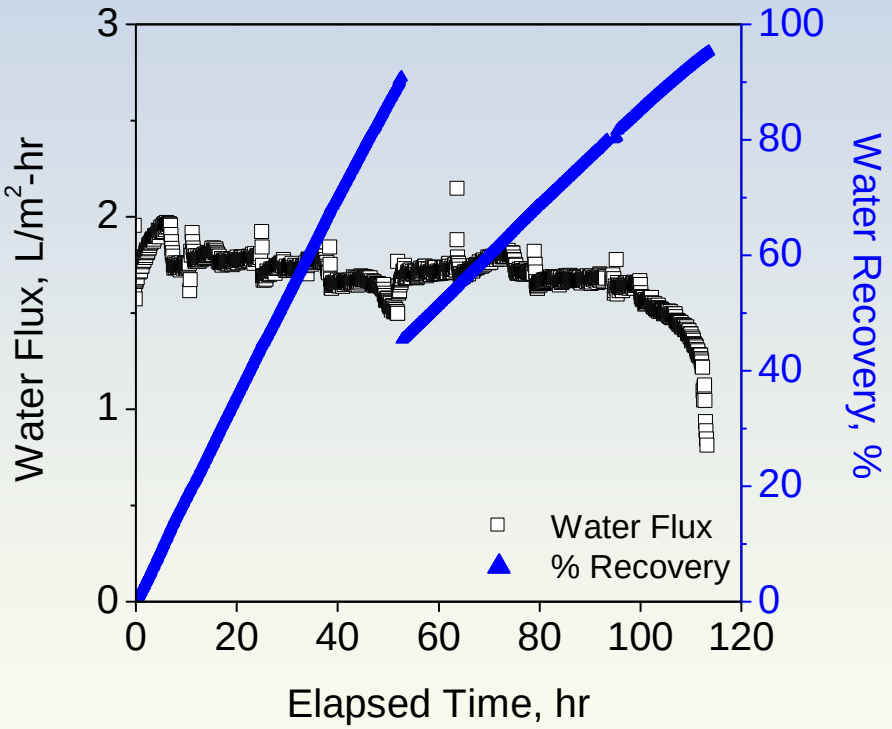
# Performance of Forward Osmosis

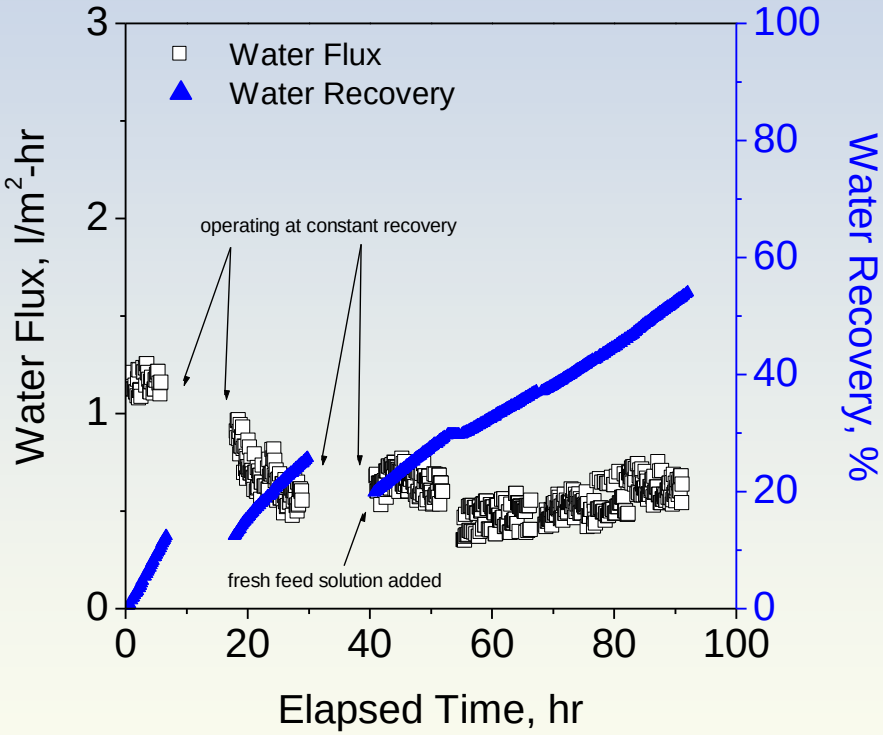
$$J_w = A_m(\Delta P - \Delta\pi) \rightarrow A_m\left(\pi_{DS} - \pi_{feed}\right)$$



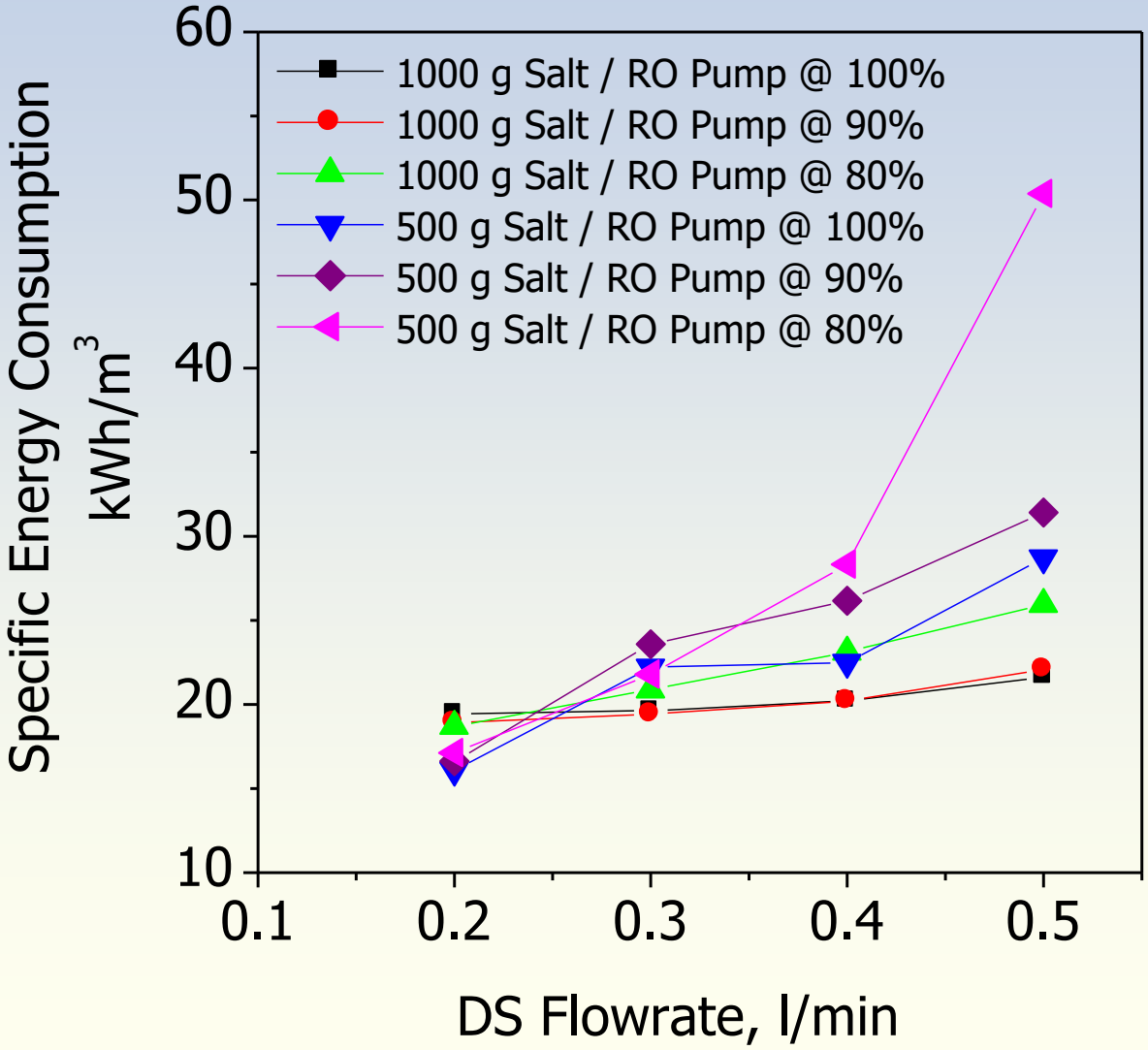
# MD for Potable Reuse of Urine and Humidity Condensate

($T_f$ = 40ºC, $T_p$ = 20ºC)



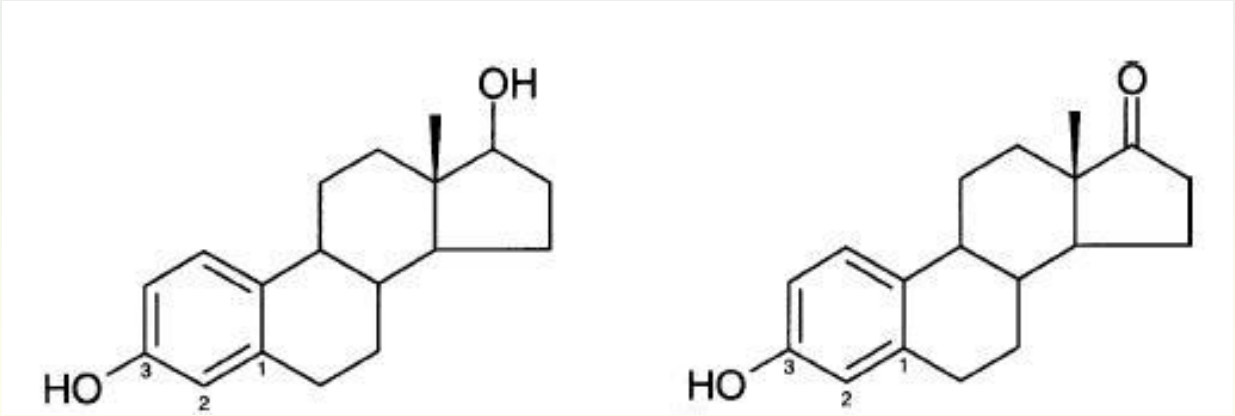



# Specific Power Consumption



# Removal of Endocrine Disrupting Chemicals (EDCs)

- Continually released to environment by humans and most often not destroyed by conventional wastewater treatment
- May be a significant problem in closed water reclamation systems

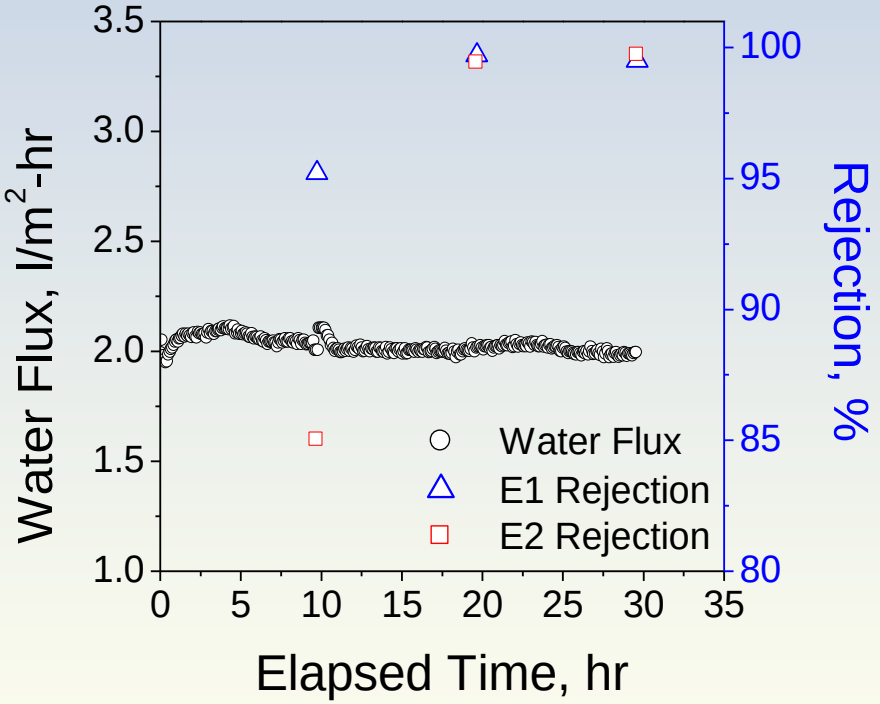



17-β Estradiol (E2)

Estrone (E1)

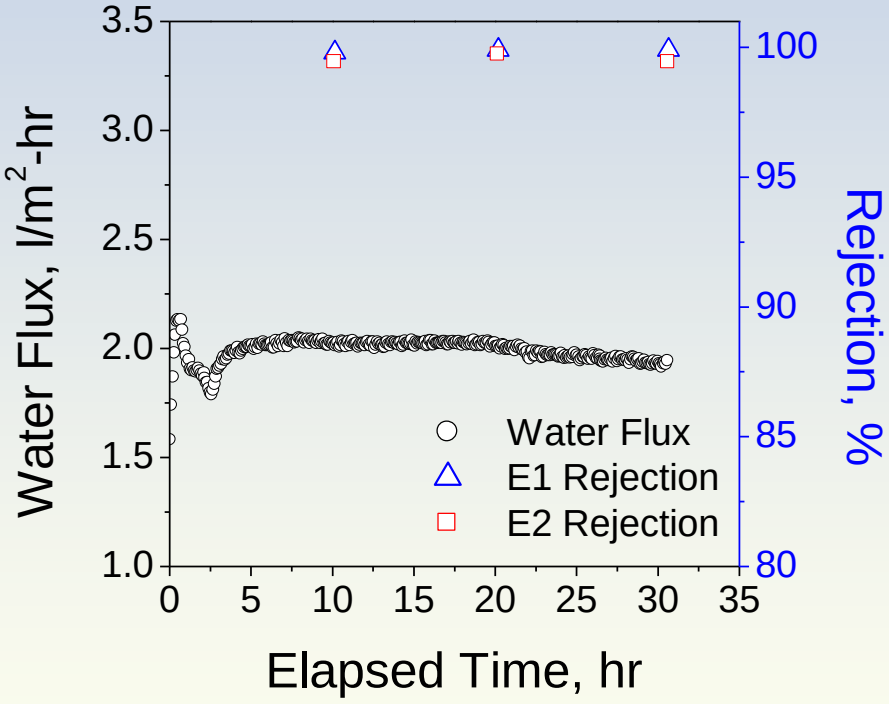
# Hormone Rejection by Membrane Distillation

## DI Water Feed

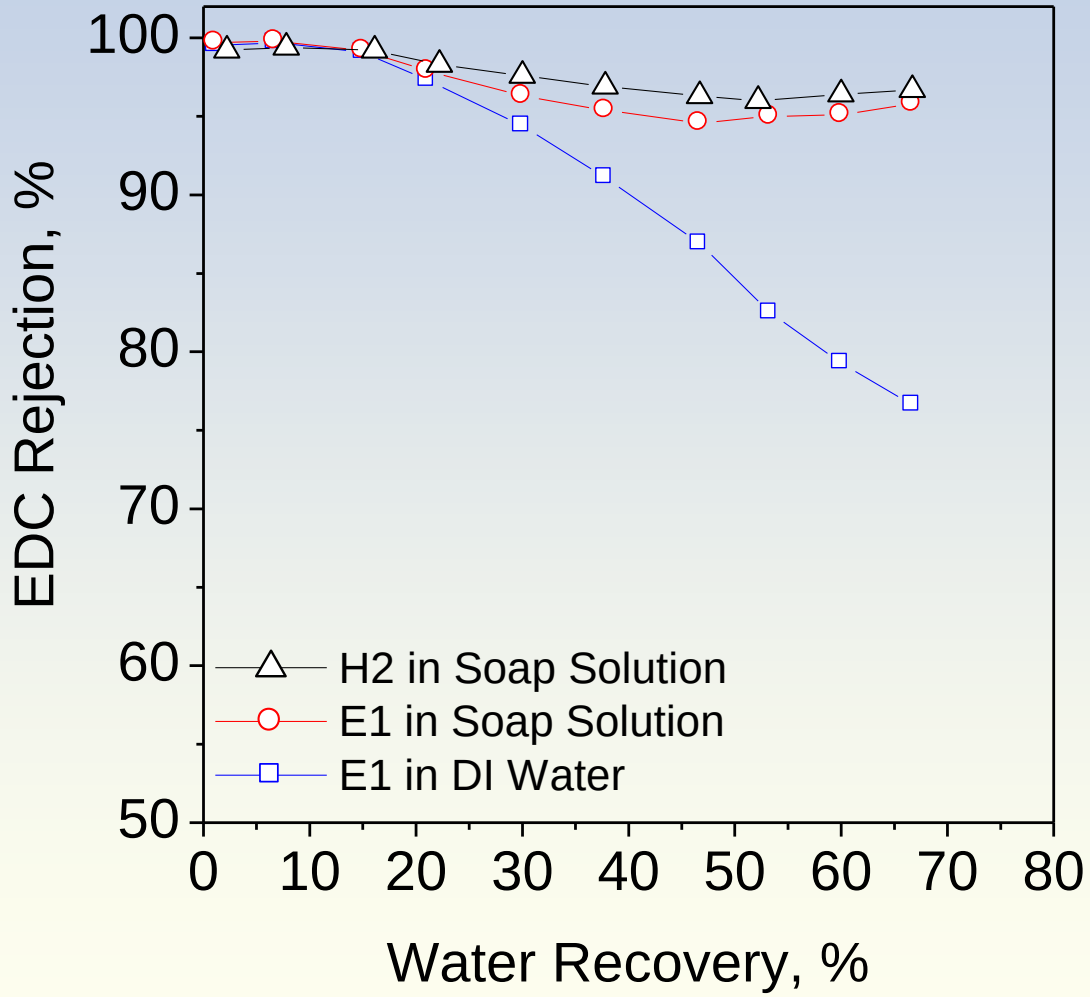



## Wastewater Feed

(urine + humidity condensate)



# Hormone Rejection by Forward Osmosis



# Forward Osmosis for Concentration of Liquids from Anaerobic Digester

# Anaerobic Digesters

- Liquid fraction (“centrate”) recycled back to beginning of treatment process
- Problems:
  - **High loading of organic matter, nutrients, and suspended solid to the main treatment train**
  - **Increased operating cost**
  - **Difficult to employ pressure-driven membrane processes**
  - **Environmental concerns**
- Potential benefits:
  - **commercial products ?**

# FO Performance Tests

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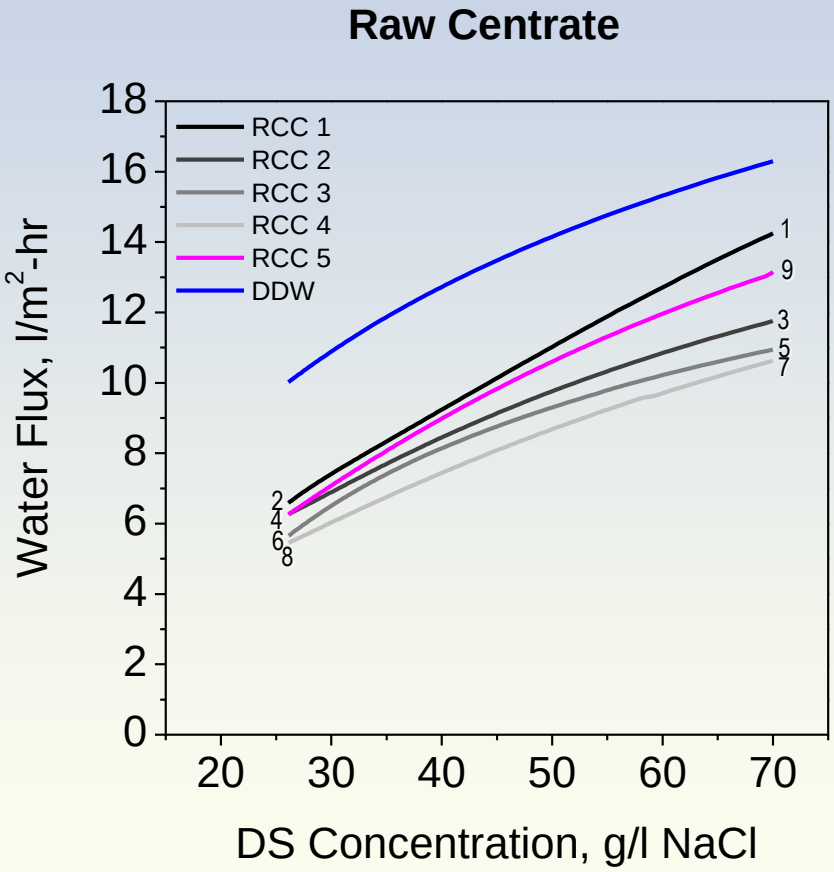
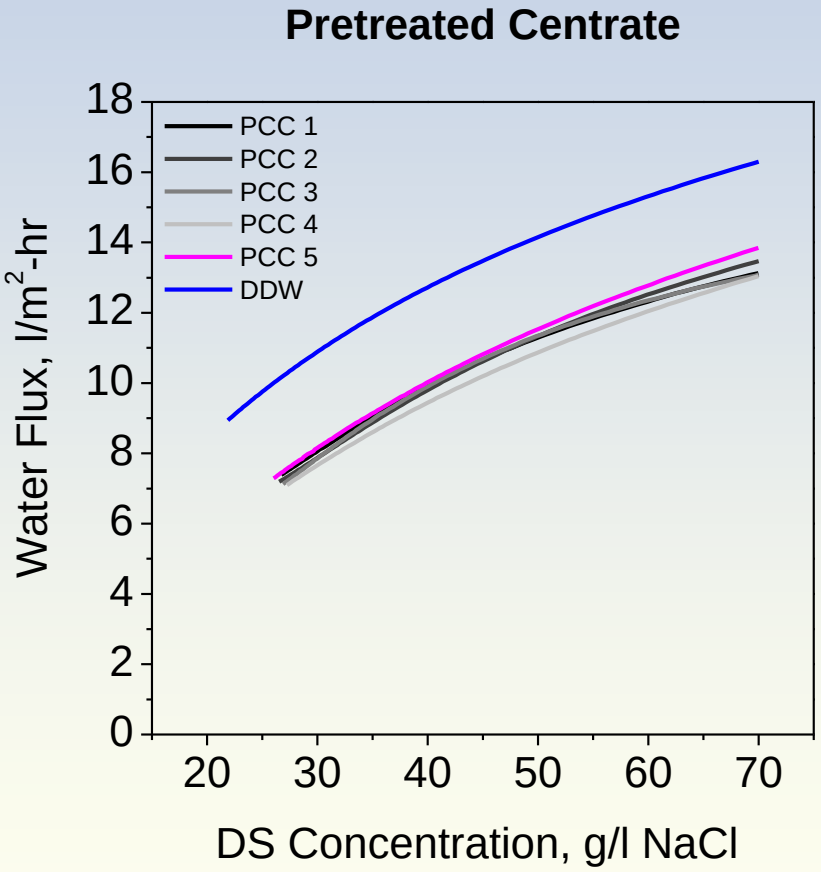
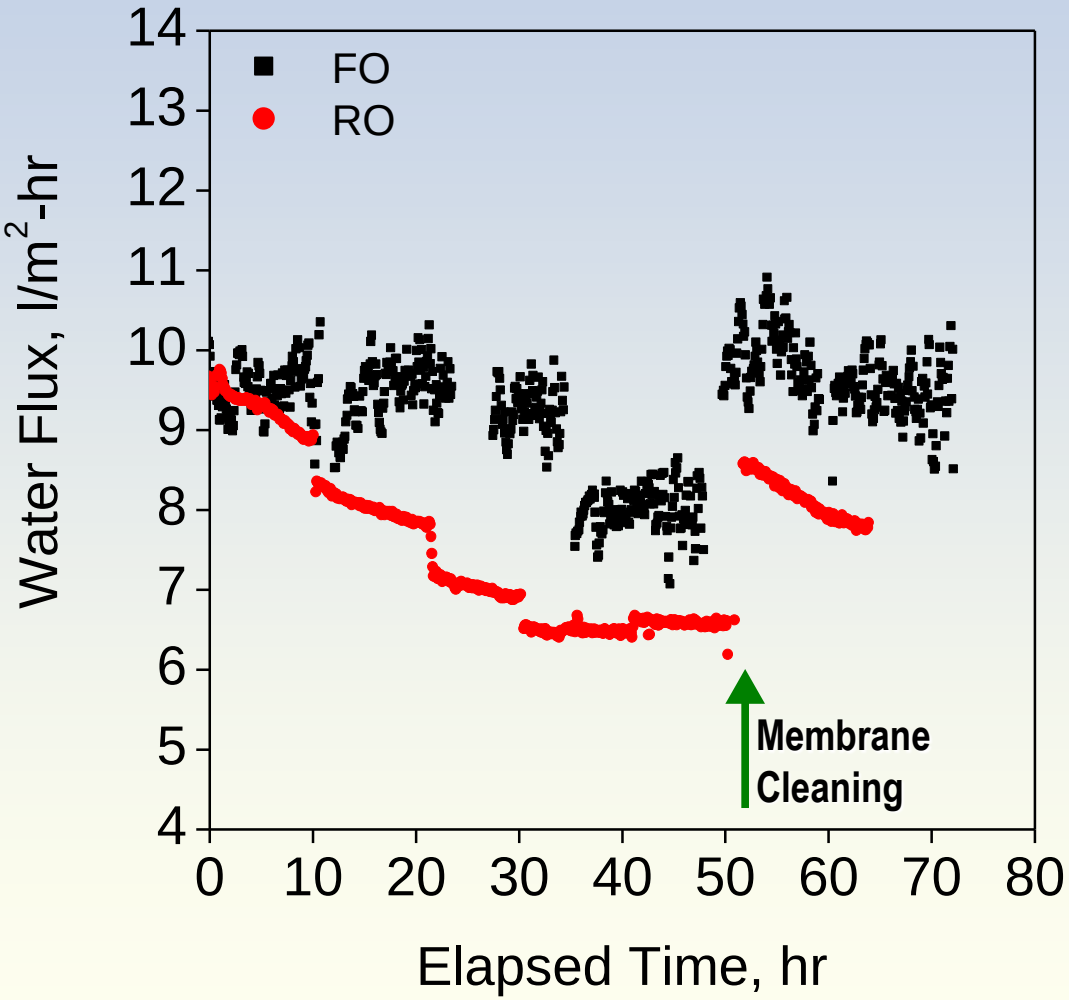


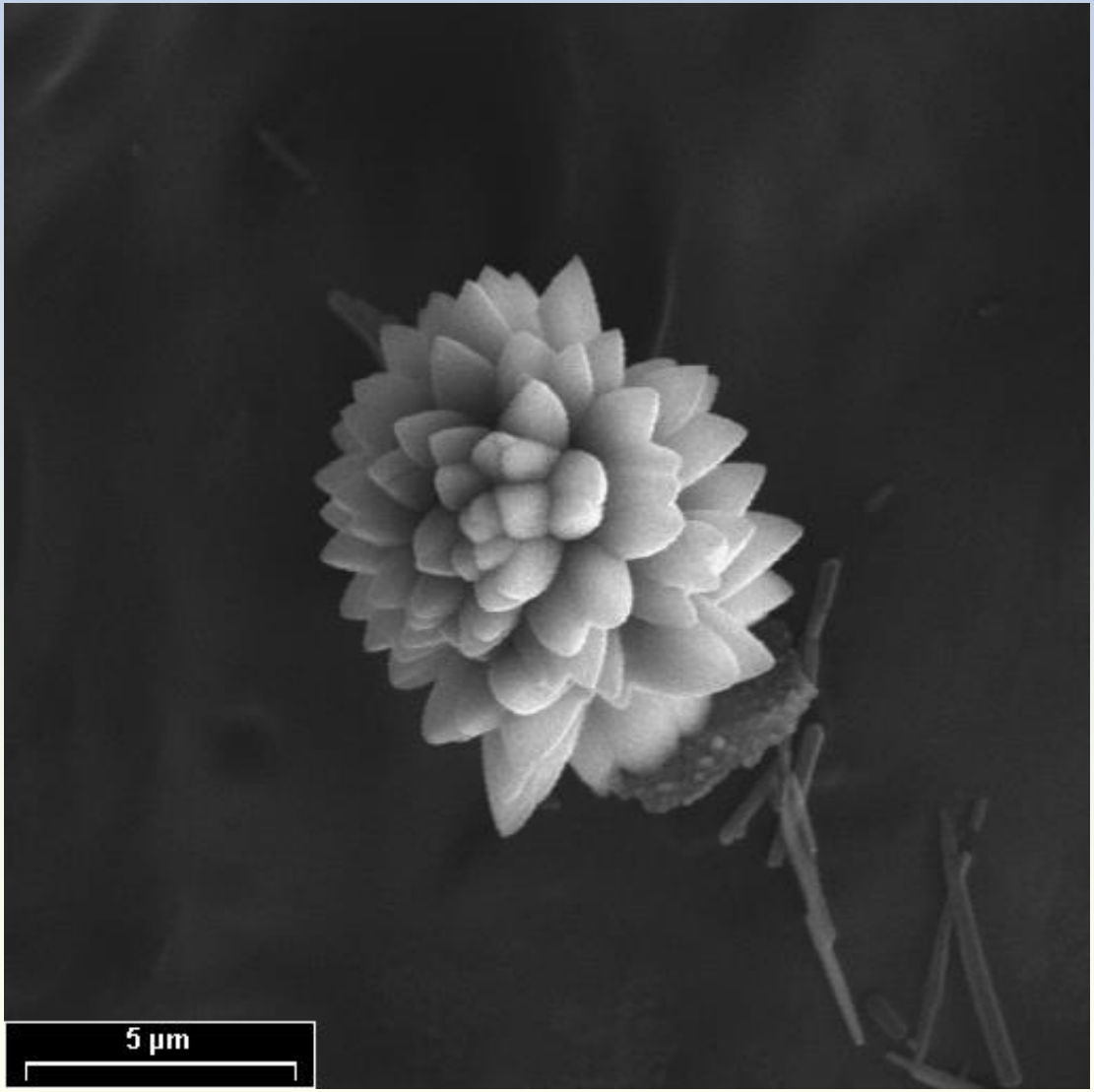
# FO Performance Tests

| Average Rejection (%) | | |
|---|---|---|
| **Ammonia** | **TKN** | **Ortho-phosphate** |
| **>87** | **>89** | **>99.5** |

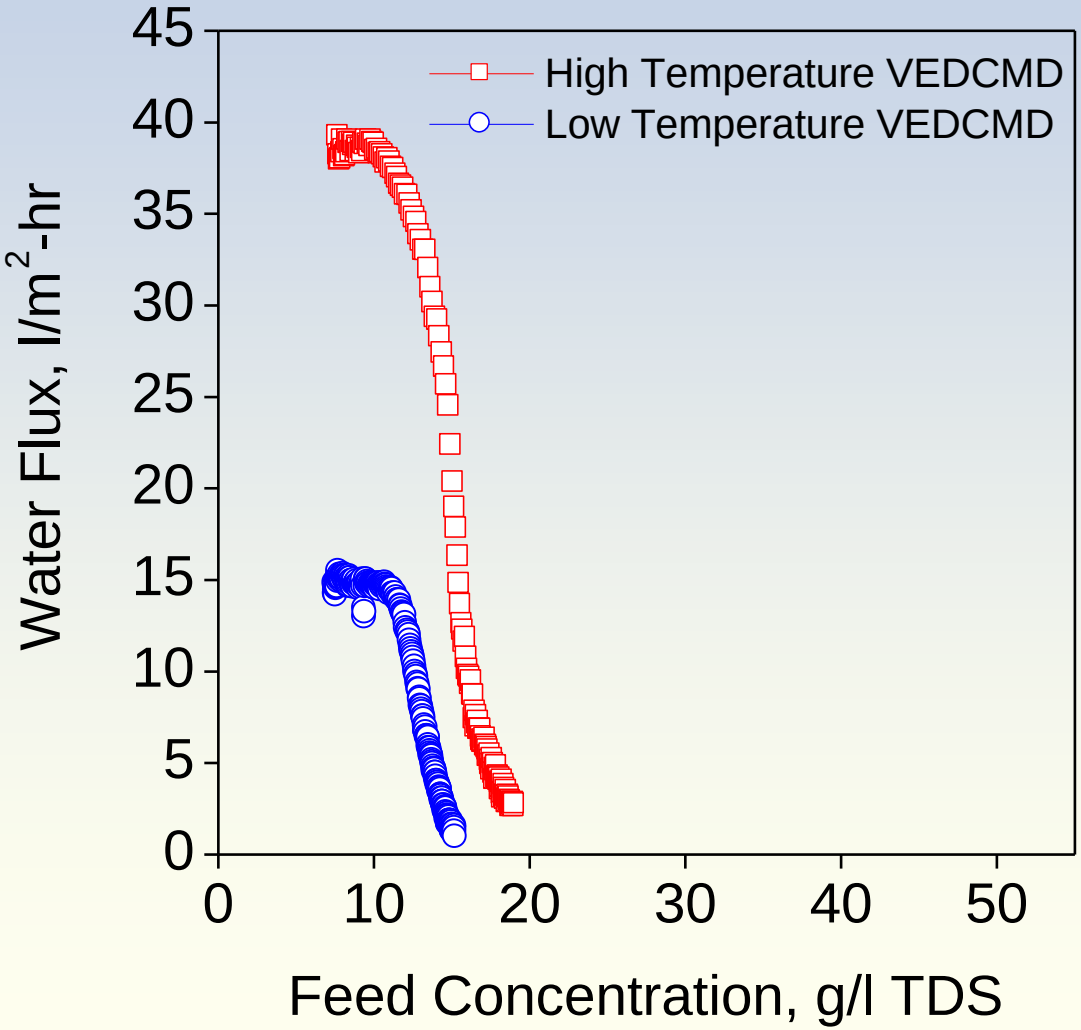
# Forward Osmosis vs. Reverse Osmosis



# FO for Brackish Water Desalination



# Performance of VEDCMD



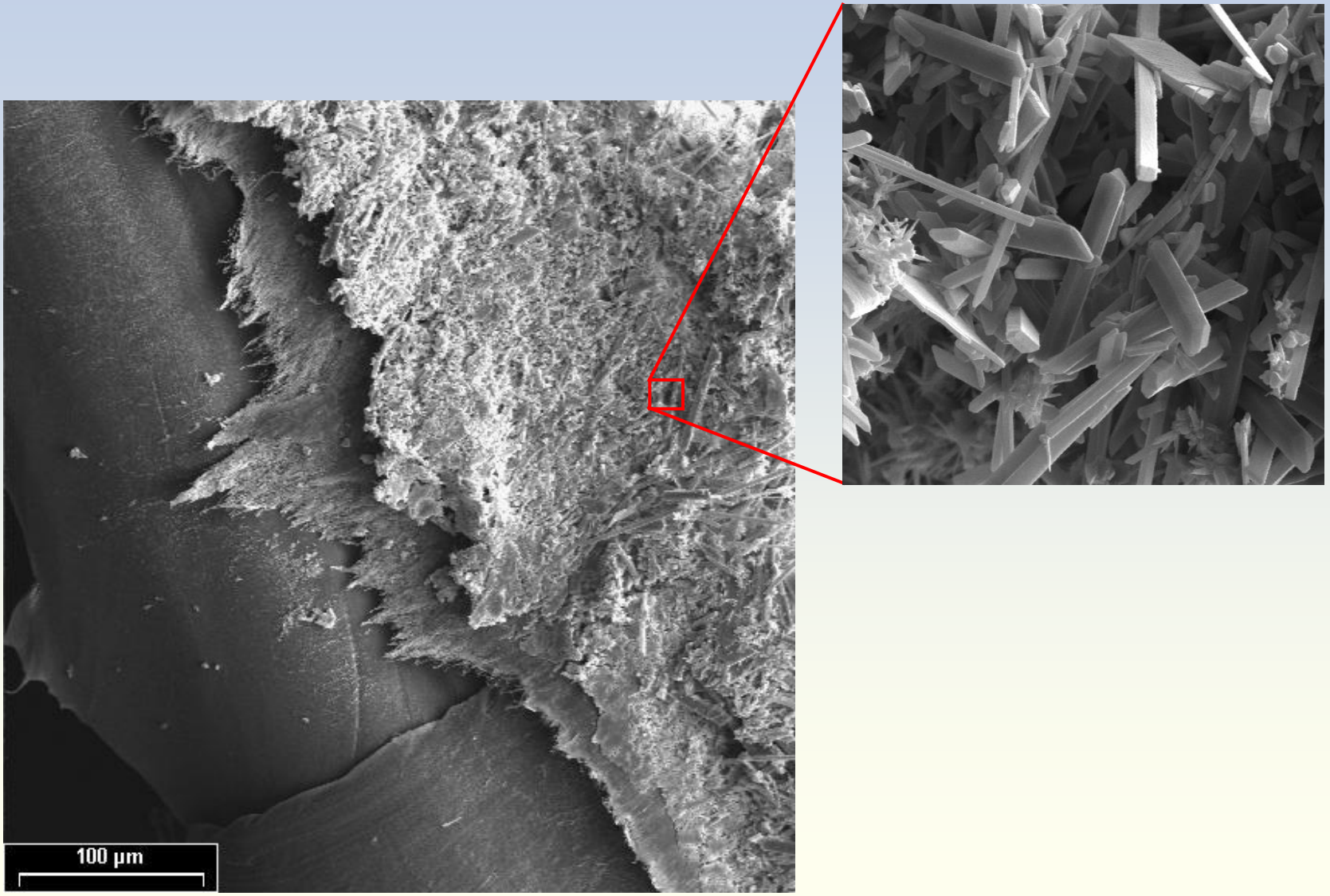

$C_{DS}$ = 55 g/l NaCl

$T_{feed}$ = 20°C

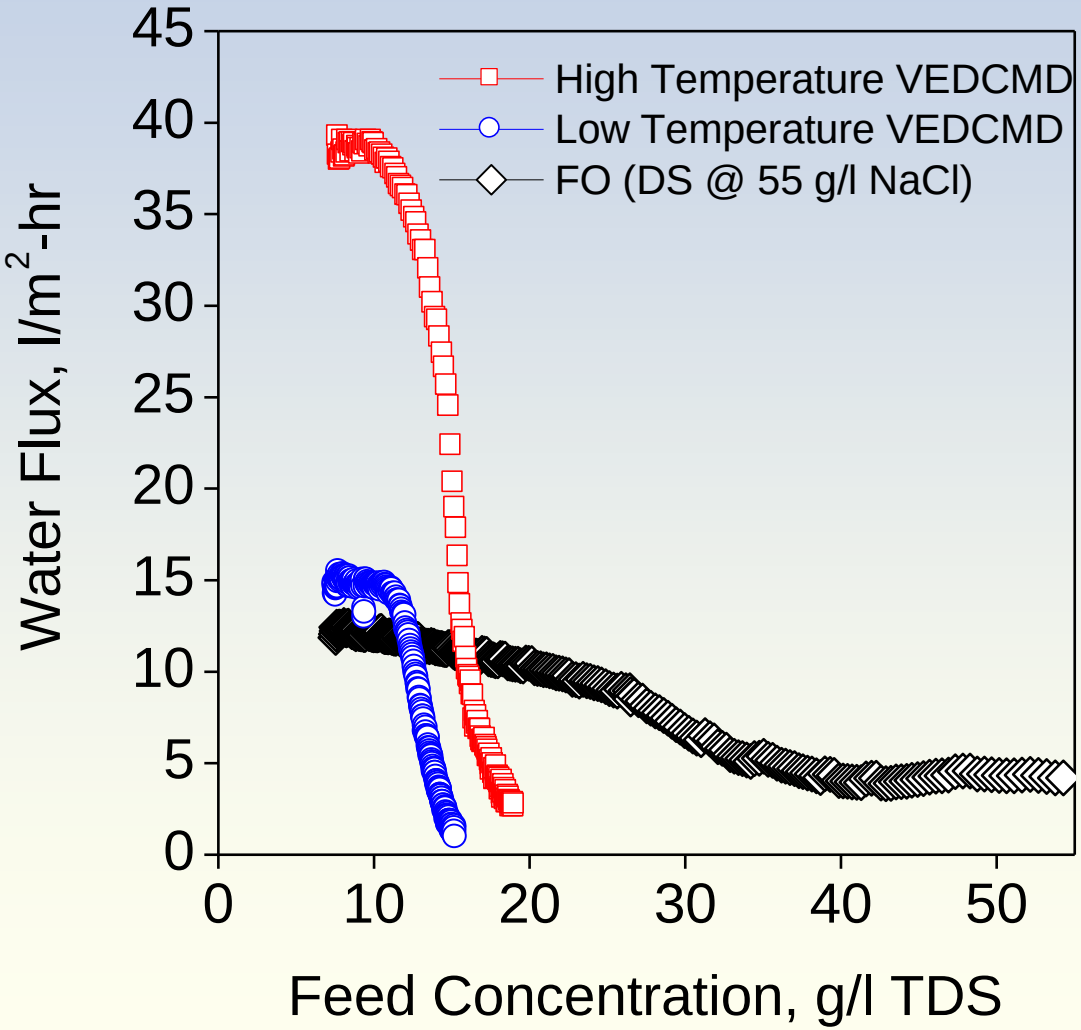
$T_{low}$ = 40°C

$T_{high}$ = 60°C

# Performance of VEDCMD



# Forward Osmosis vs. VEDCMD

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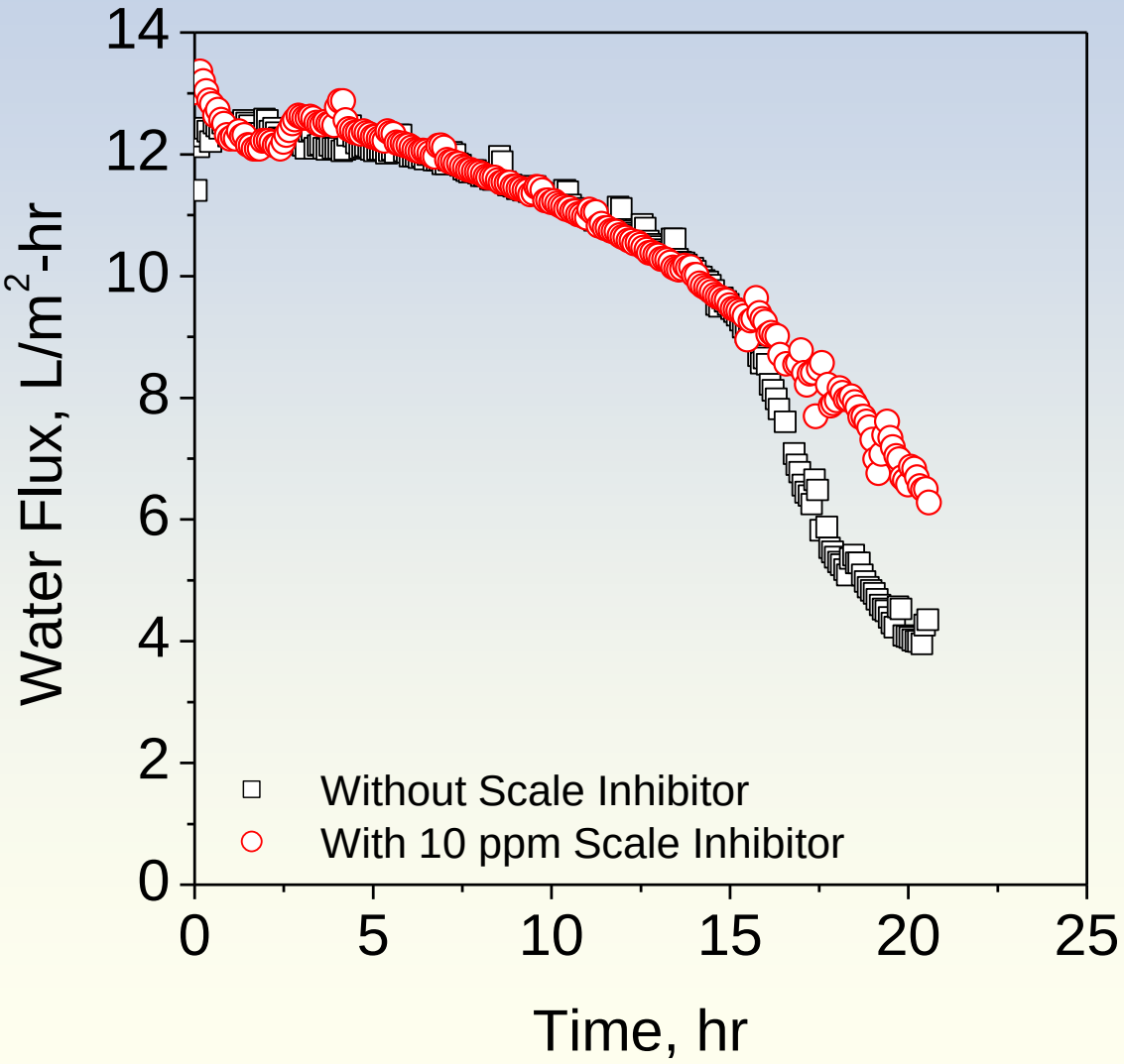
# Scale Inhibition Study



# Summary and Future Directions

- Membrane contactors perform very well and are suited for unique applications as the treatment process or as pretreatment
- Integration of membrane contactors or membrane contactors with pressure-driven membrane processes can lead to process enhancement
- Further development of membranes for MD and FO is crucial for future advancement of these processes and their potential applications

# Acknowledgements


- NASA, Ames Research Center
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- Joshua Cartinella, Ryan Holloway, Riz Martinetti

# Thank You