Membrane Technology in Water Recycling

Principles and Challenges

Menachem Elimelech

Department of Chemical Engineering
Environmental Engineering Program
Yale University

Integrated Concepts in Water Recycling
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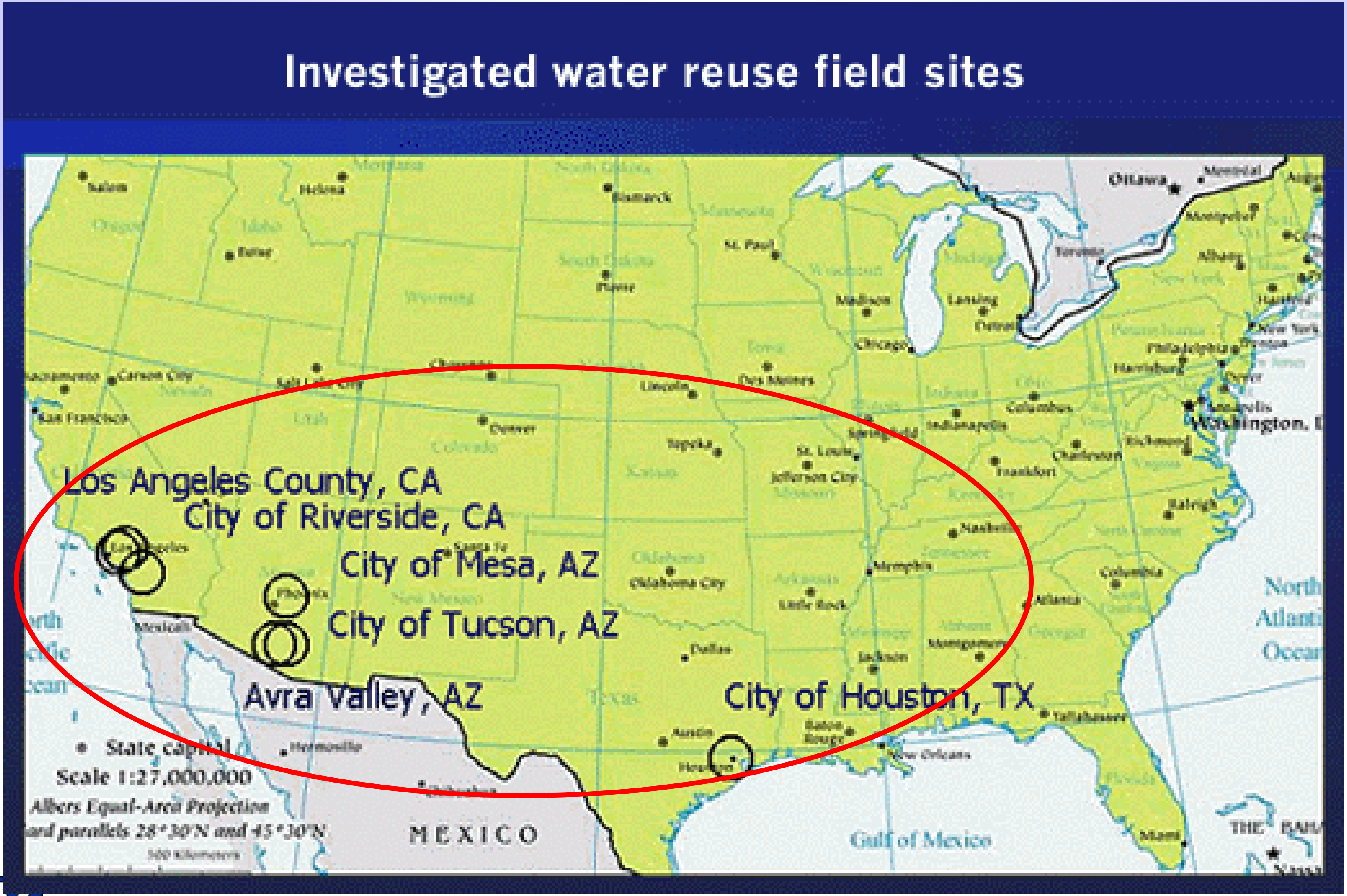
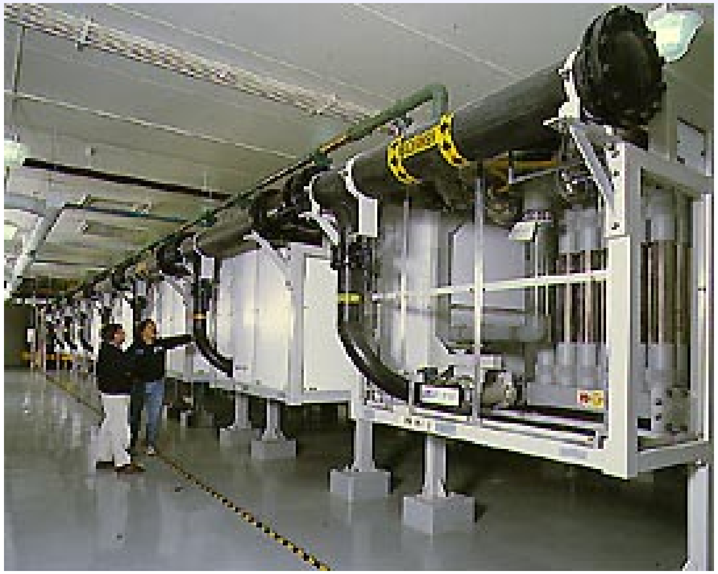
Water Reuse is Practiced Worldwide

Water Reuse in the USA



Membrane versus “Victorian” Plants

Membrane Plant



Conventional “Victorian” Plant

- Meets multiple water quality objectives
- Produces water of superior quality
- Physical separation
- Small footprint

- Poorer product quality
- Lack of flexibility
- Need to add chemicals
- Large footprint

Membrane Technology

- Best technology to produce high-quality water from non-traditional sources (wastewater, impaired/brackish water, and seawater)
- Can, in principle, provide an *absolute barrier* for microbial pathogens and chemical pollutants

Membrane Technology for Advanced Wastewater Reclamation

Secondary WW Effluent

Microfiltration (MF)

- Fouling
- Cleaning
- Membranes

Reverse Osmosis (RO)

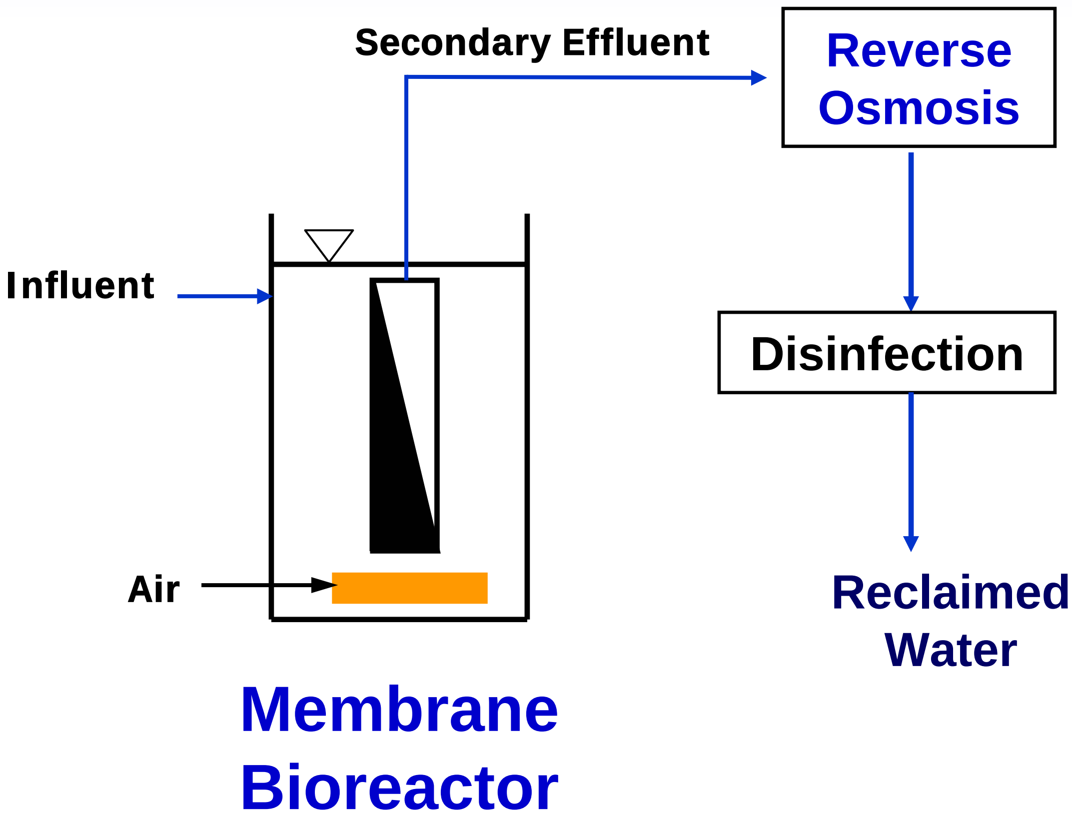
- Fouling
- Fouling Control
- Membrane Materials
- Absolute Barrier?

Disinfection (UV)

Purified Water

Potable?

MBR in Advanced Wastewater Reclamation



- Fouling
- Fouling control
- Membrane materials
- Absolute barrier?

Membrane Technology for Sea Water or Brackish Water Desalination

- Pre-treatment processes (several options)
- Chemicals (fouling control, cleaning)

Reverse Osmosis (RO)

- Fouling
- Fouling Control
- Membrane Materials
- Absolute barrier?

Post-treatment

Challenges

- Membrane fouling and its effect on membrane performance
- Fouling control (cleaning)
- Brines and residual (concentrate) streams
- Removal of emerging organic contaminants by RO membrane. **Is the RO membrane "*an absolute barrier*"?**

Fouling of RO Membranes

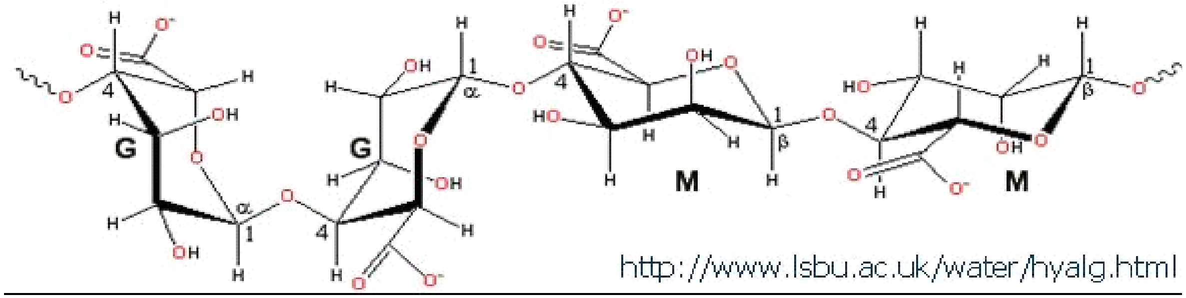
Suspected Foulants for RO in Advanced Wastewater Reclamation

Effluent organic matter (EfOM) that passes MF/UF pre-treatment:

- Soluble microbial products (polysaccharides, proteins)
- Other (natural) organic matter

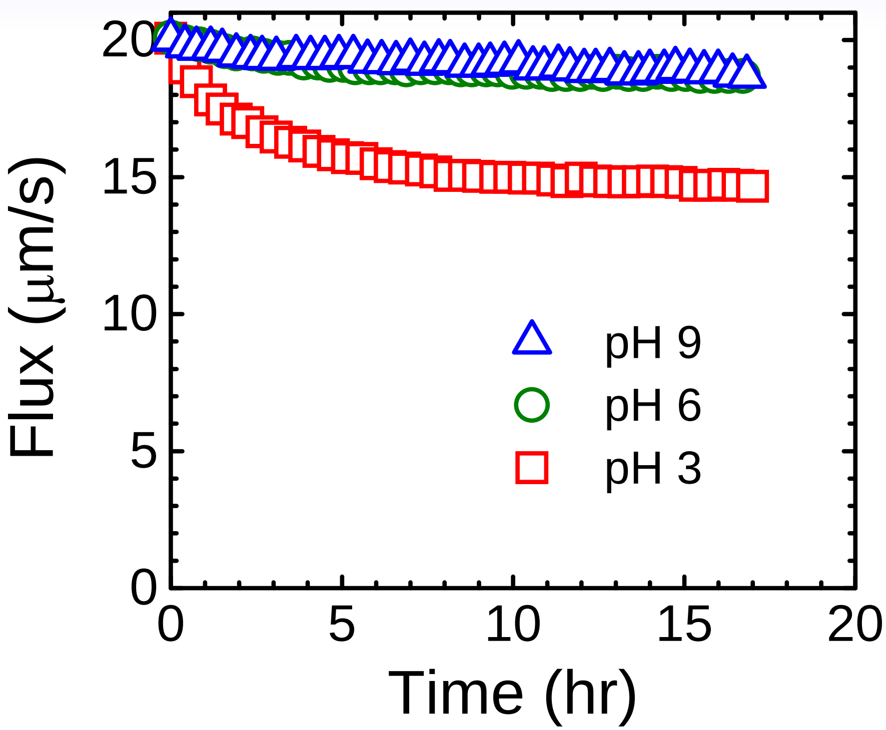
Model Effluent Organic Matter

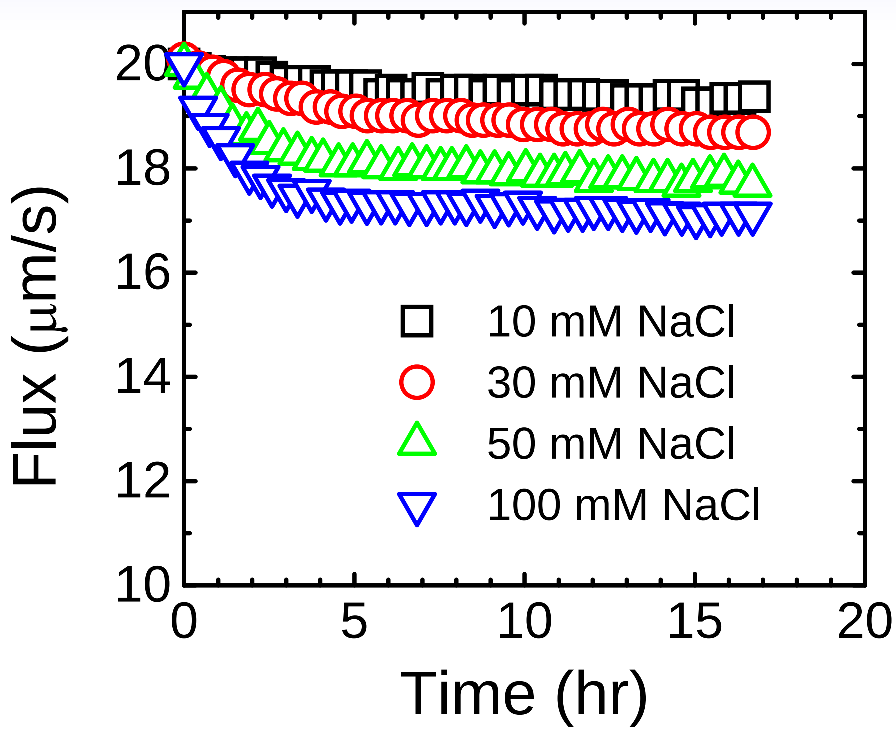
- Sodium alginate: represents hydrophilic fraction of EfOM (polysaccharides)



- Suwannee River NOM: represents hydrophobic fraction of EfOM

Chemical Aspects of Fouling
Influence of pH and Ionic Strength

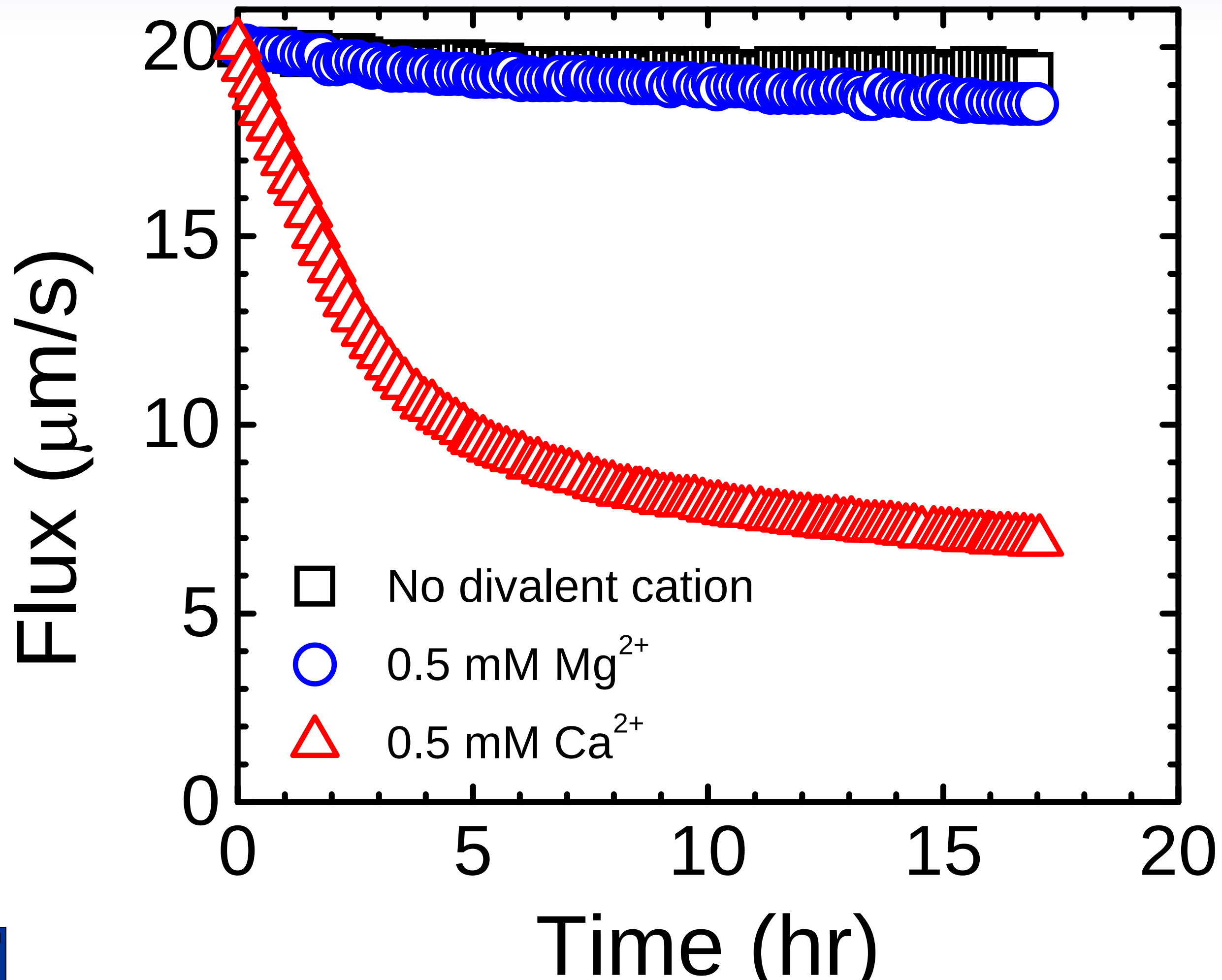




- LFC-1 RO membrane
- 20 mg/L alginate
- Cross-flow RO lab unit

Chemical Aspects of Fouling

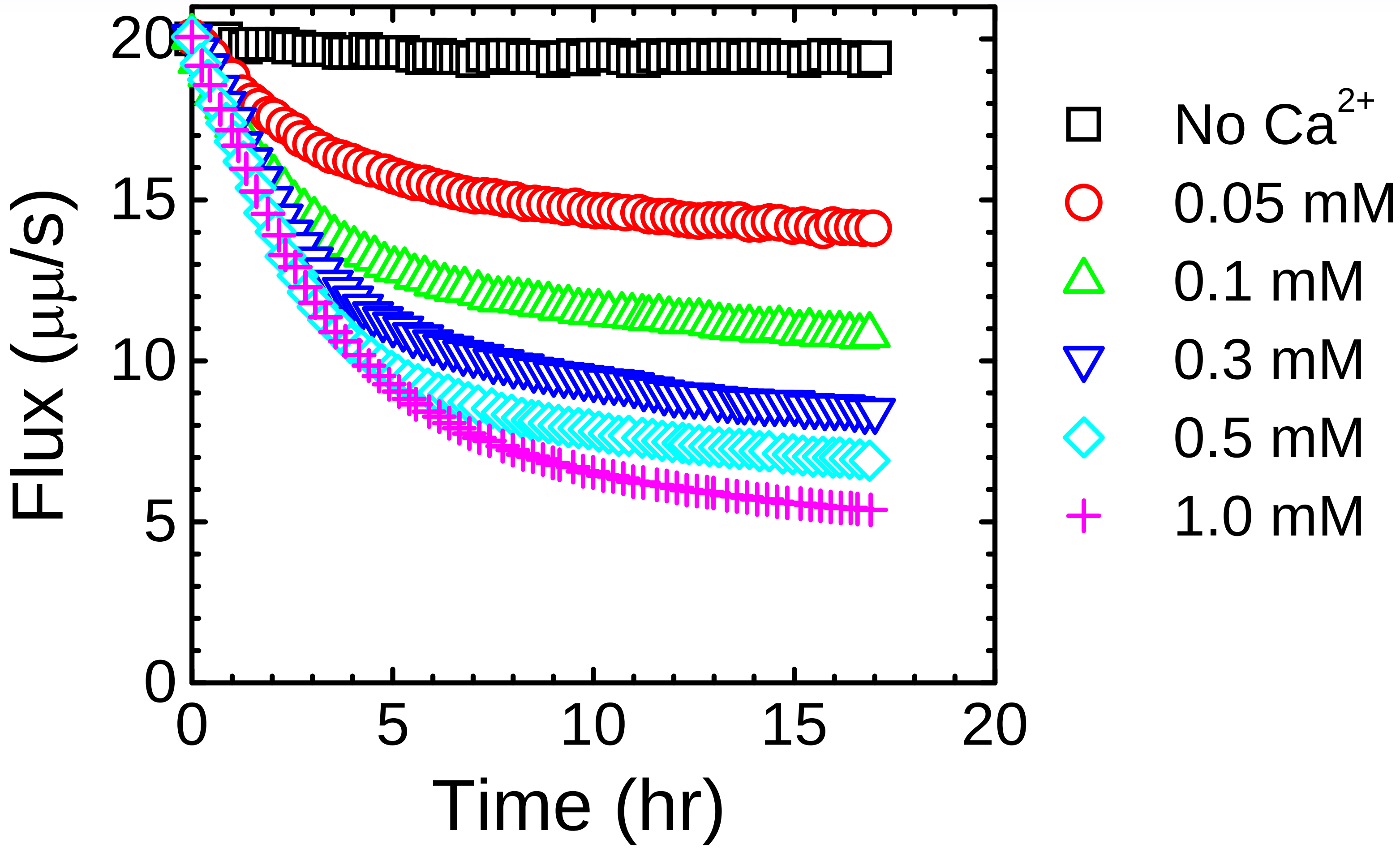
Influence of Divalent Ions (Ca^{2+} vs Mg^{2+})



- LFC-1 RO membrane
- 20 mg/L alginate
- Cross-flow RO lab unit
- Total ionic strength of 10 mM
- pH 5.6-5.8

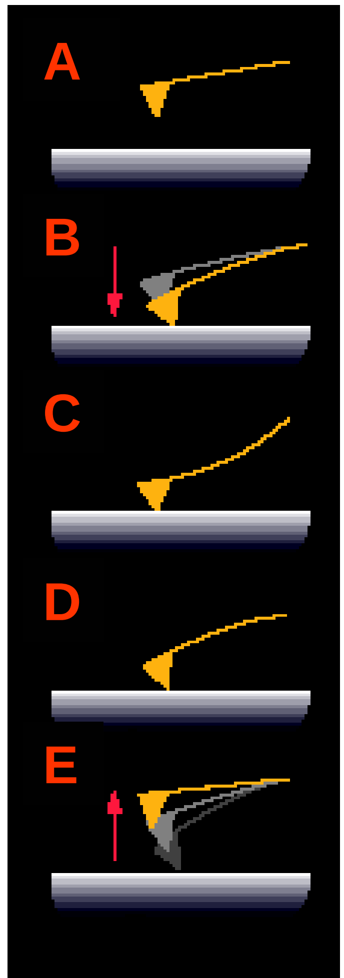
Chemical Aspects of Cleaning

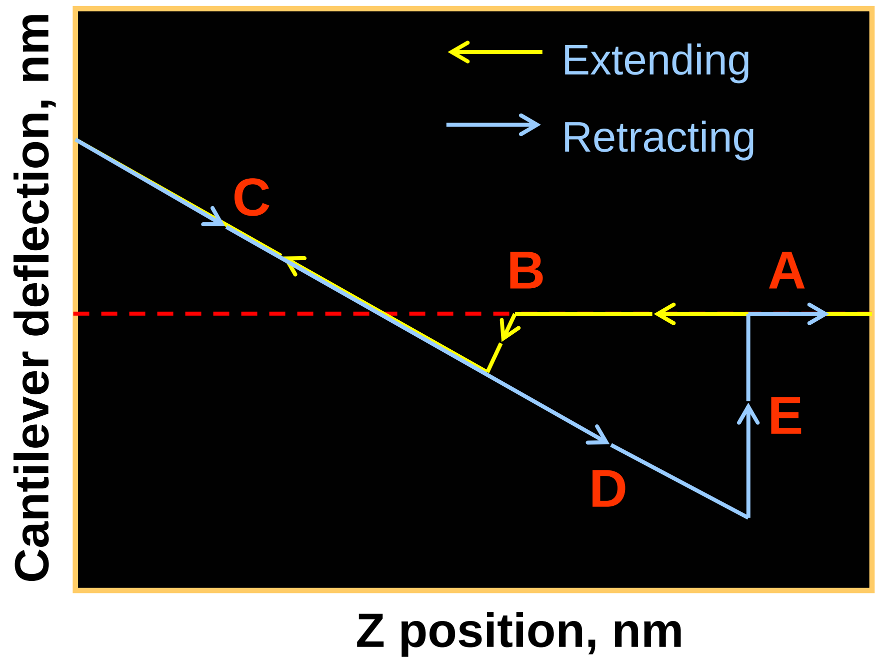
Influence of Divalent Ions (Ca^{2+})



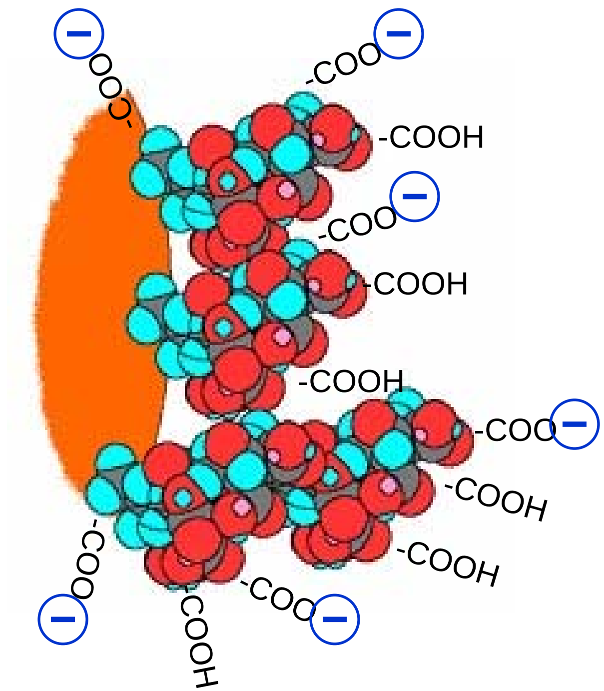
Relating Fouling to Interfacial Adhesion Forces

Force Measurement by Atomic Force Microscopy (AFM)

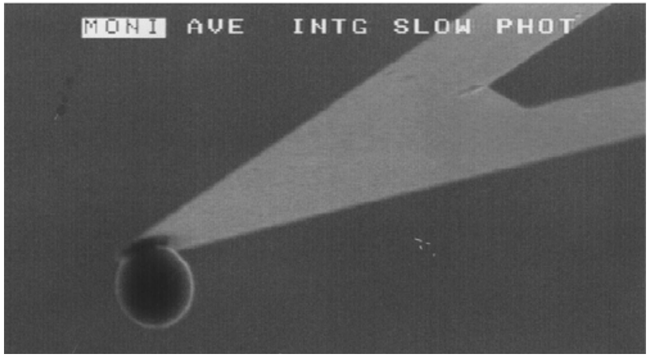


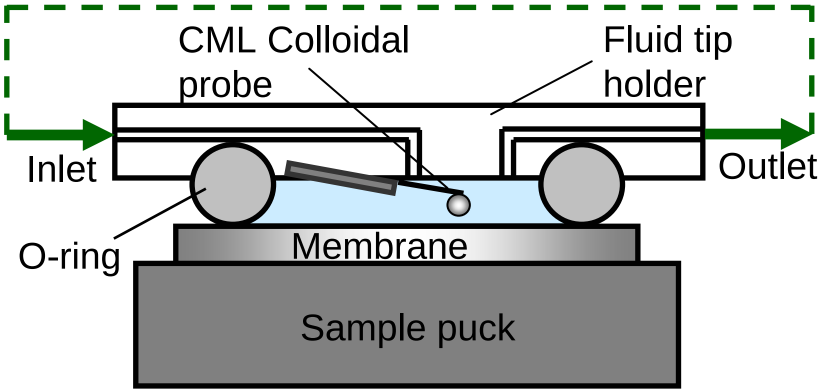


Functionalized Colloidal Probe



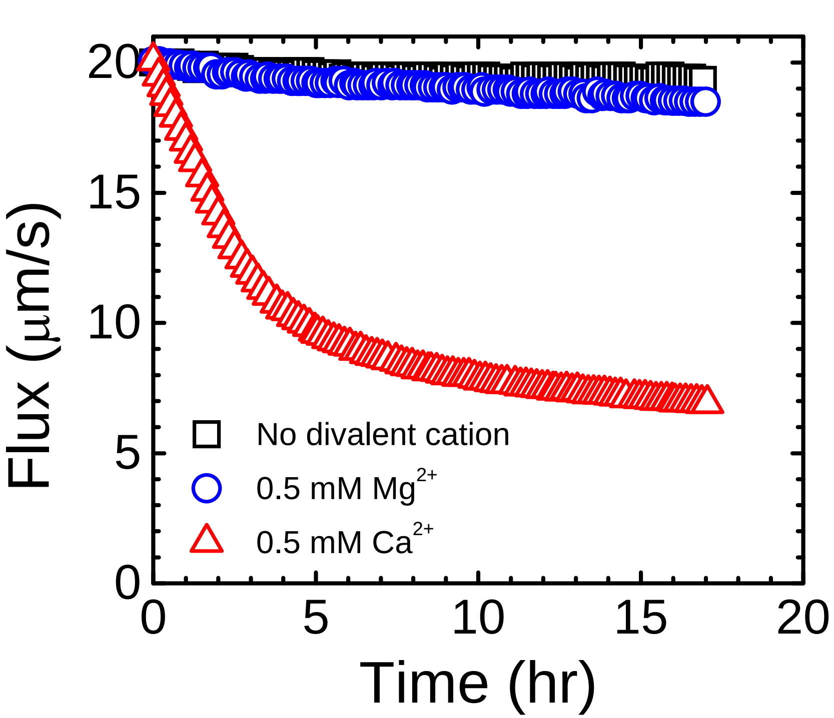
Carboxylate modified latex (CML) particle

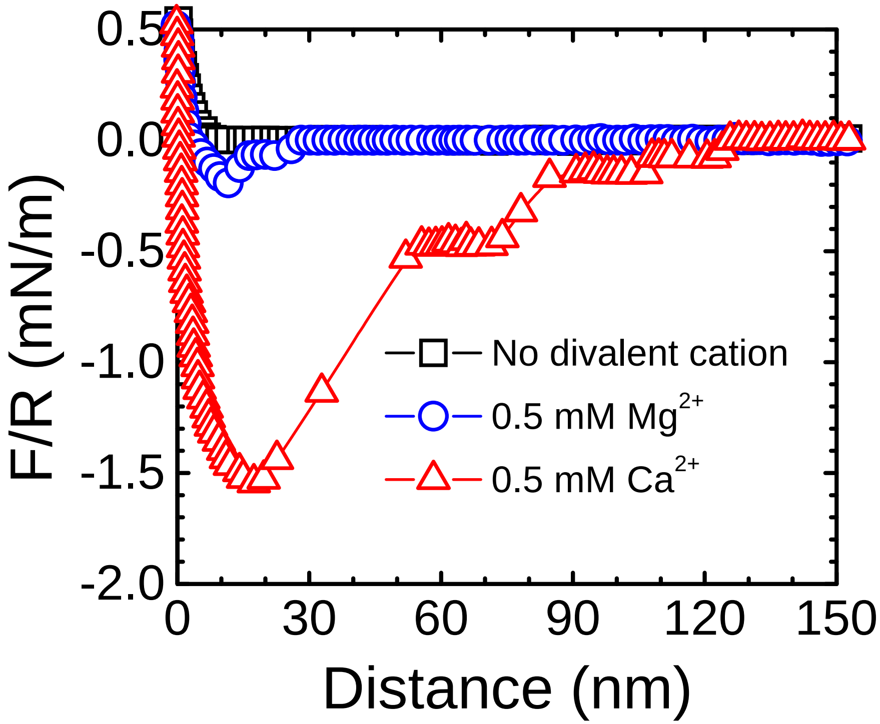




AFM fluid cell

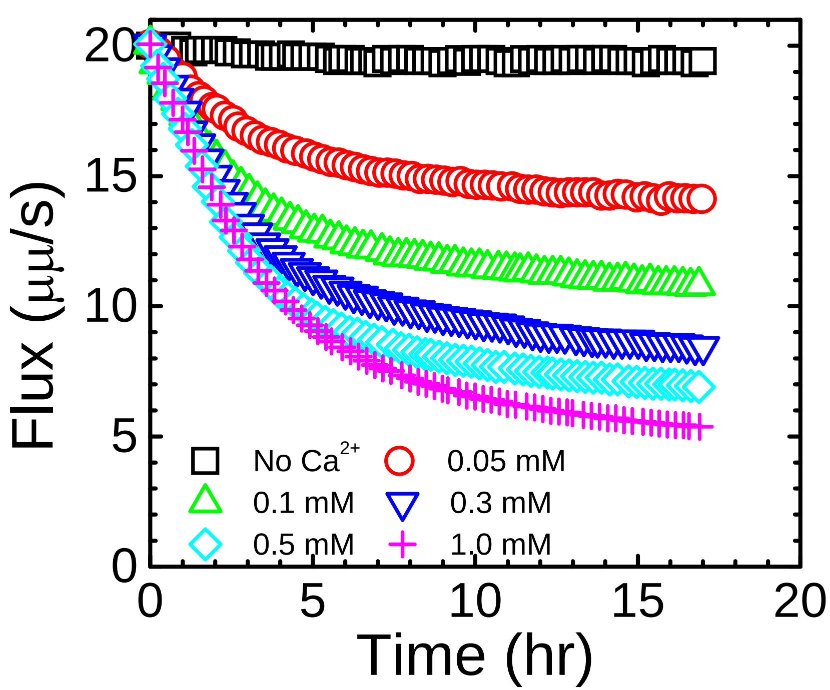
Relating Fouling to Adhesion Force
Influence of Divalent Ions (Ca^{2+} vs Mg^{2+})

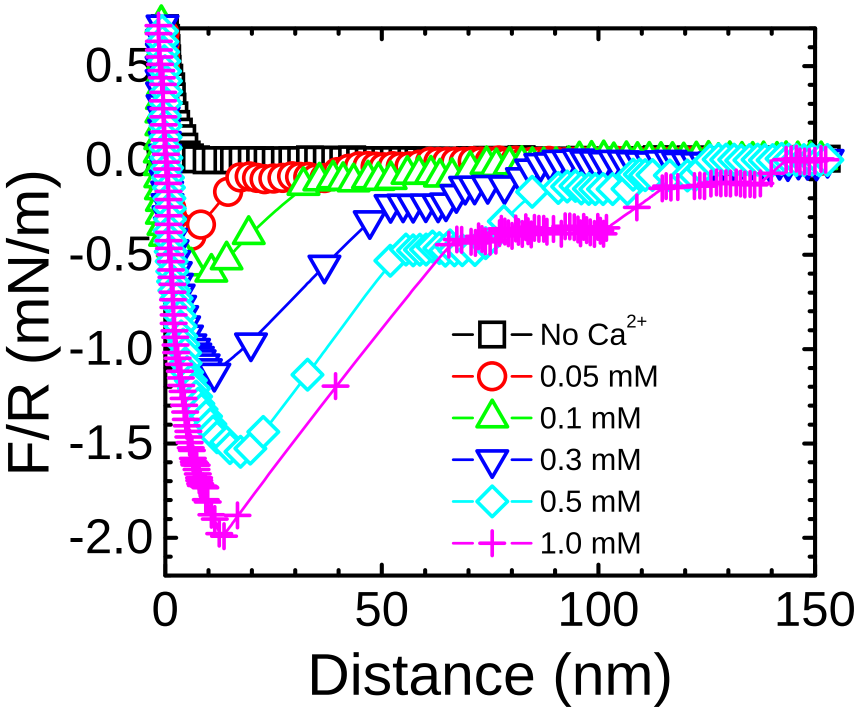




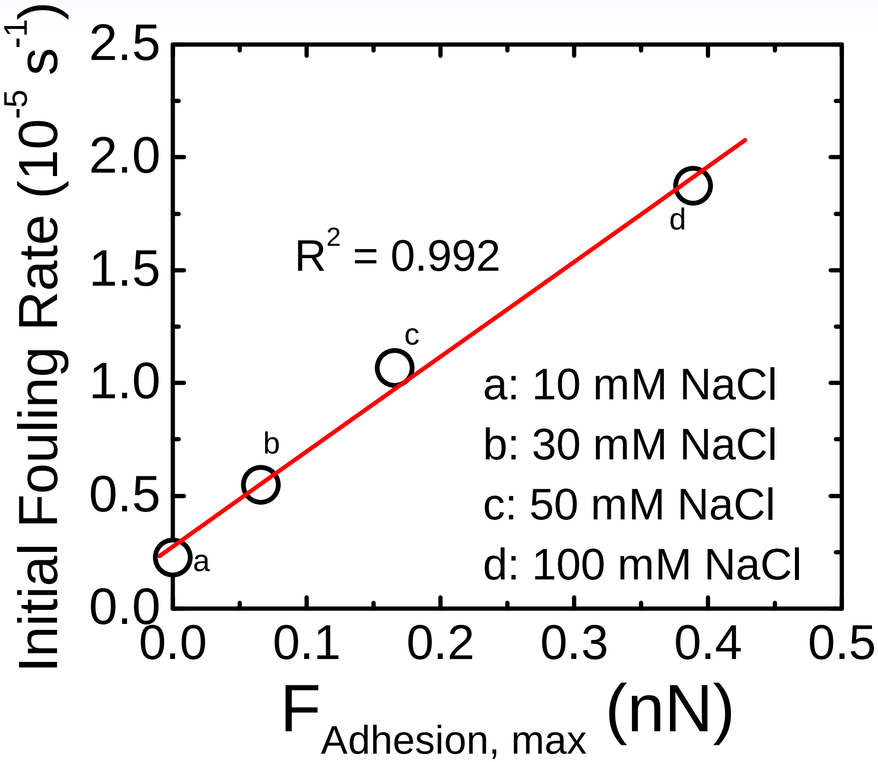
Relating Fouling to Adhesion Force

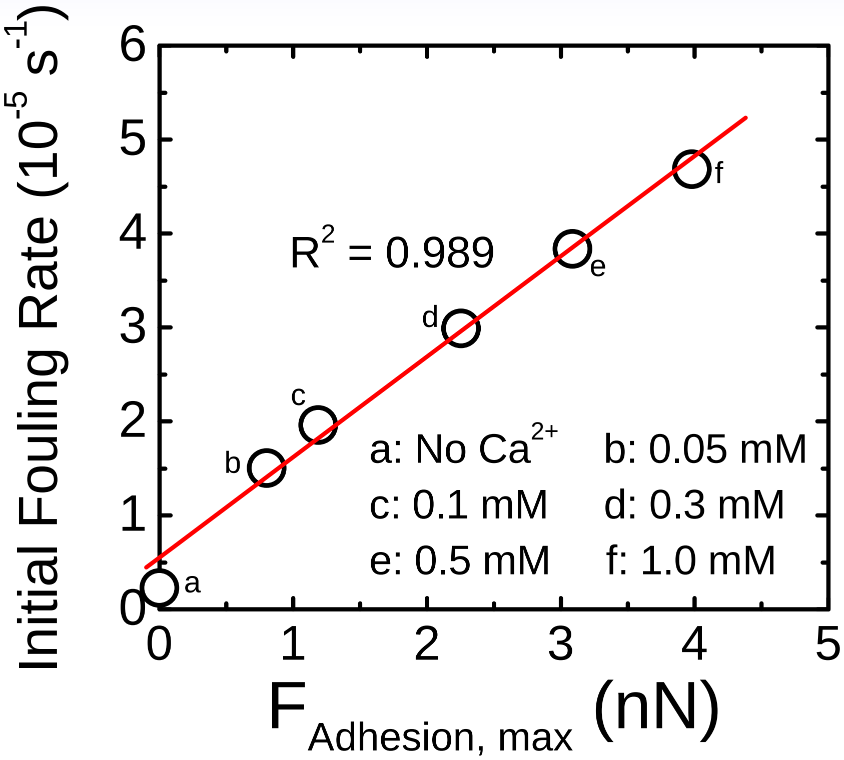
Influence of Divalent Ions (Ca^{2+})





Correlating Fouling Rate to Adhesion Force



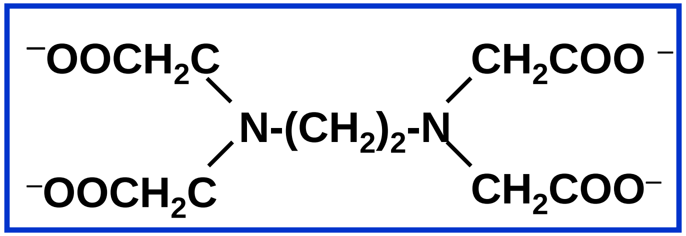


Fouling Control:
Chemical Cleaning of RO Membranes

Cleaning Chemicals

Alkaline: NaOH, pH 11

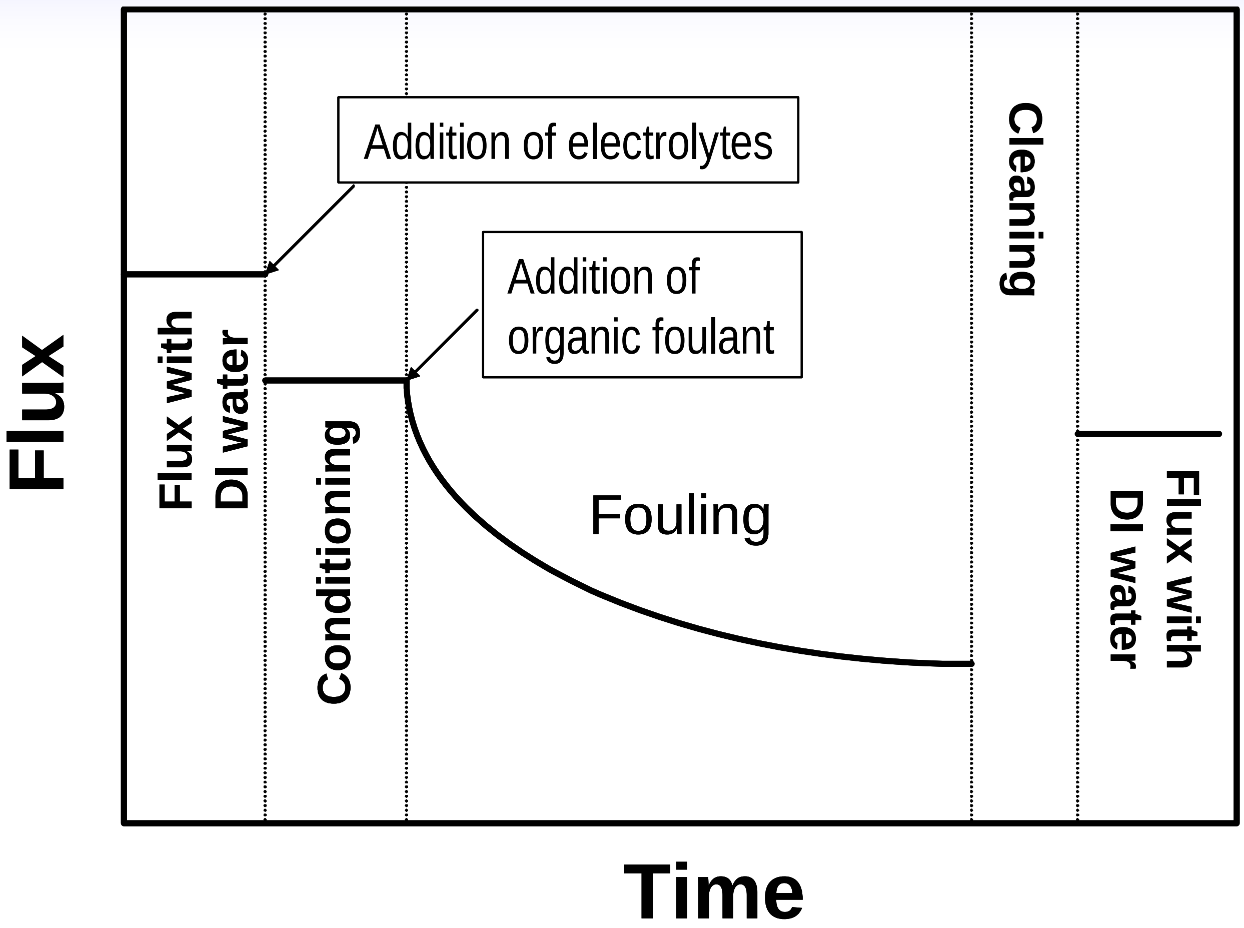
Metal chelating agent: EDTA



Anionic surfactant: SDS

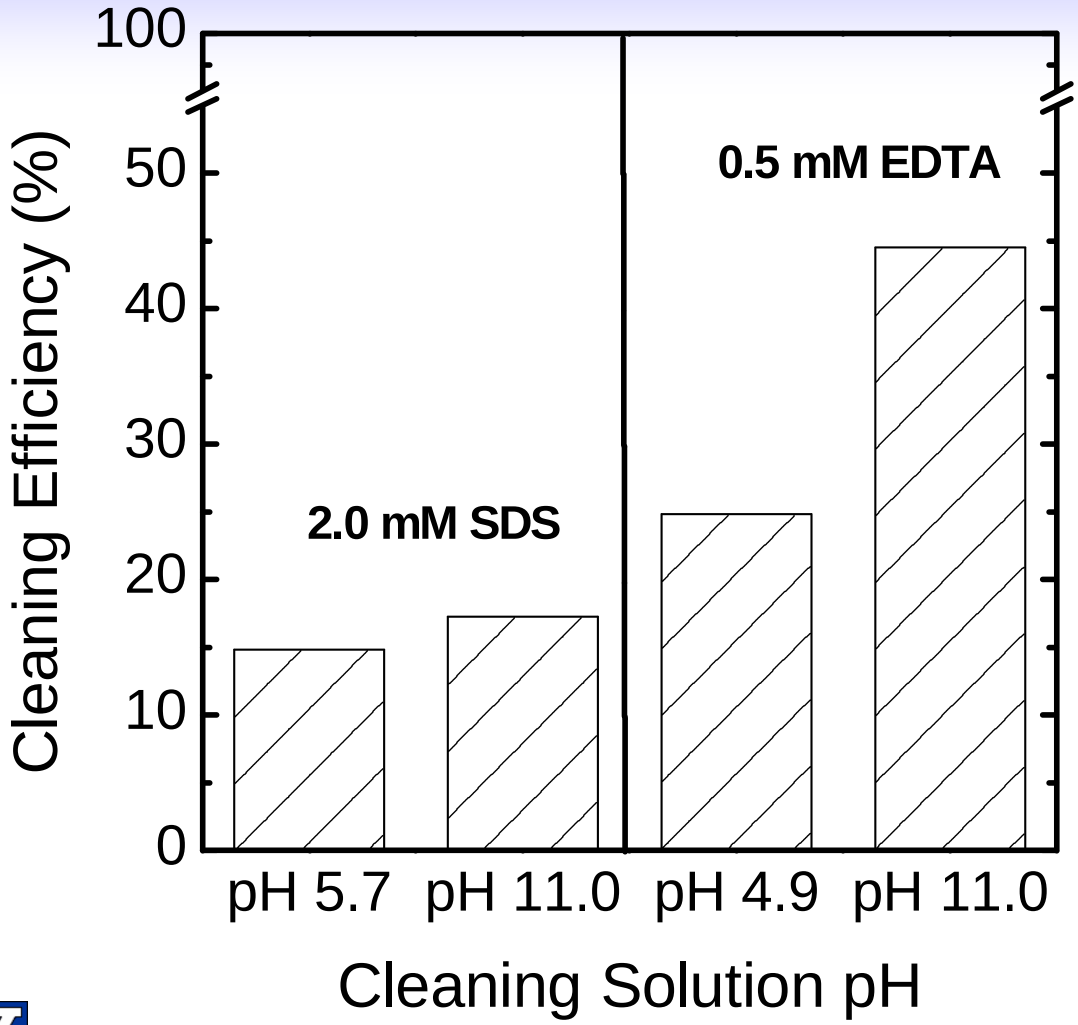
$CH_3\text{-}(CH_2)_{10}\text{-}CH_2\text{-}\ O\text{-}SO_3^-\ \ Na^+$

Fouling/Cleaning Protocol



Chemical Aspects of Cleaning

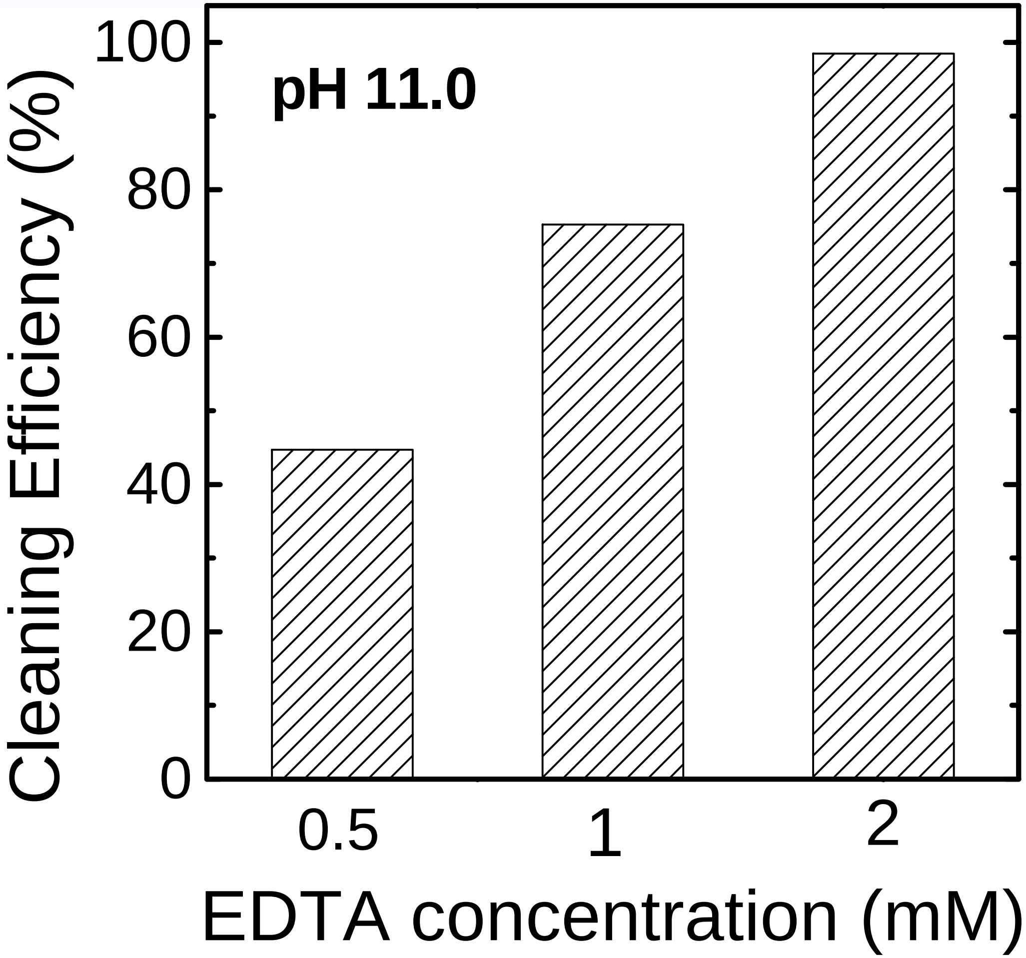
SDS and EDTA as a Function of pH



- **Fouling:** 20 mg/L alginate, 0.5 mM Ca^{2+}, total ionic strength of 10 mM, pH 5.6-5.8
- LFC-1 RO membrane
- Cross-flow RO lab unit

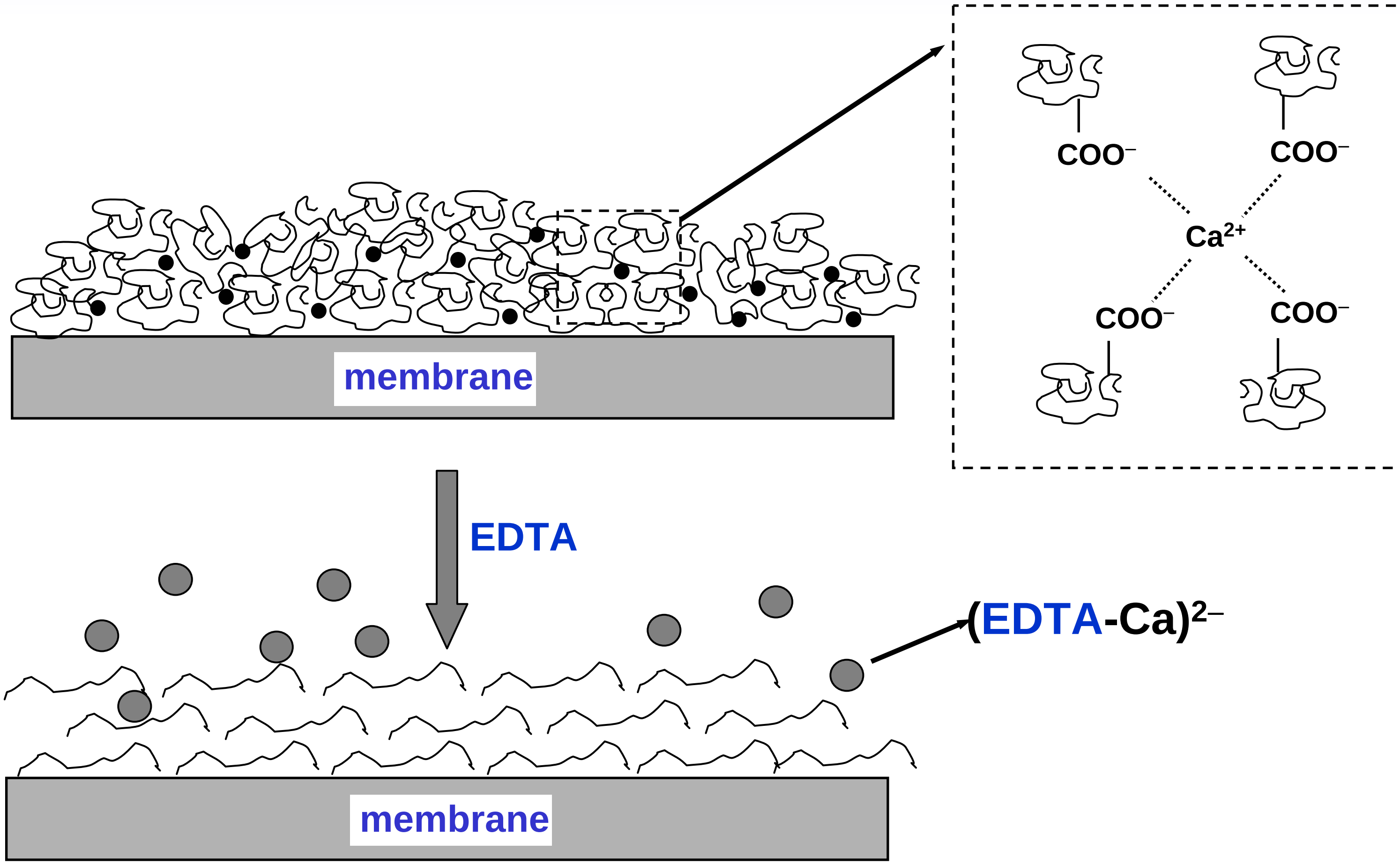
Chemical Aspects of Cleaning

Influence of Cleaning Agent Dose

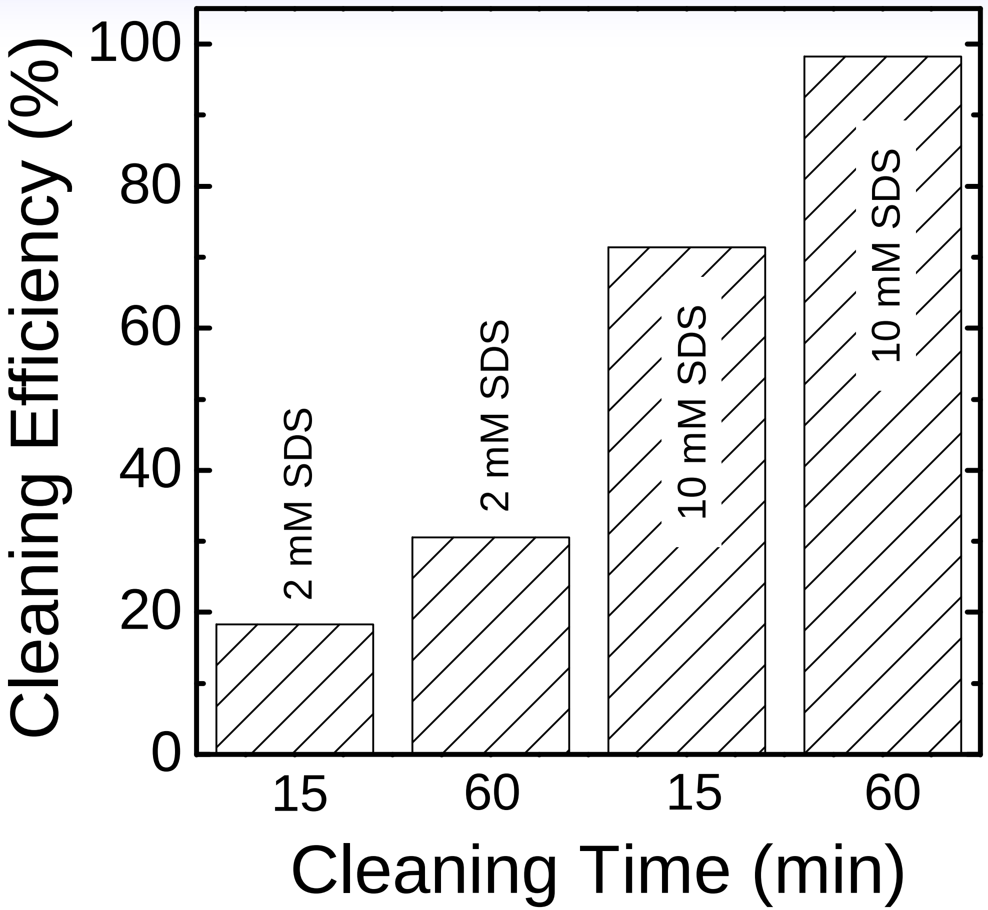


- **Fouling:** 20 mg/L alginate, 0.5 mM Ca^{2+}, total ionic strength of 10 mM, pH 5.6-5.8
- LFC-1 RO membrane
- Cross-flow RO lab unit

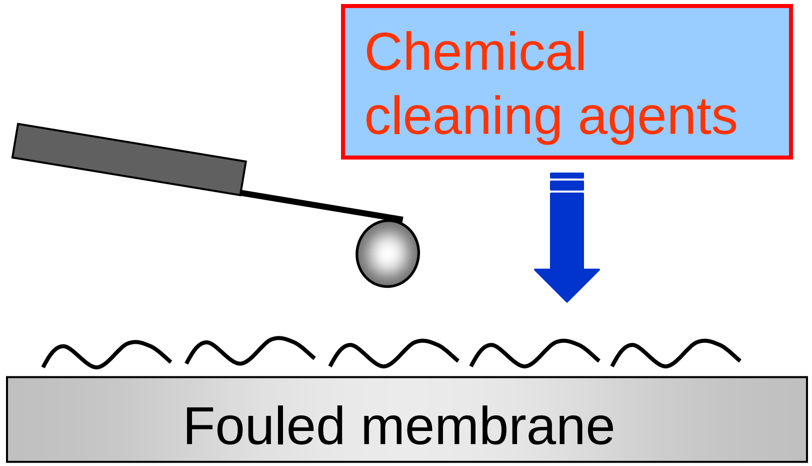
EDTA Cleaning:
A Ligand-Exchange Mechanism



Physical Aspects of Cleaning

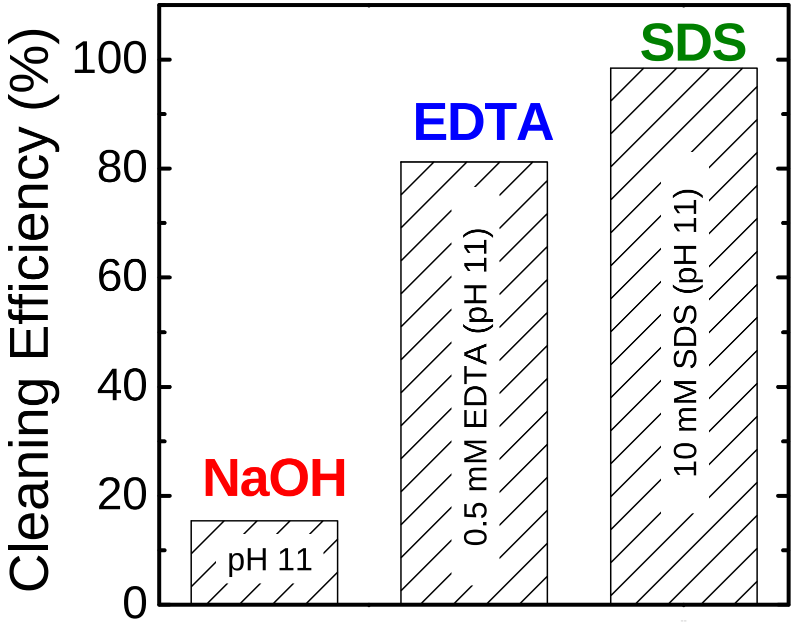


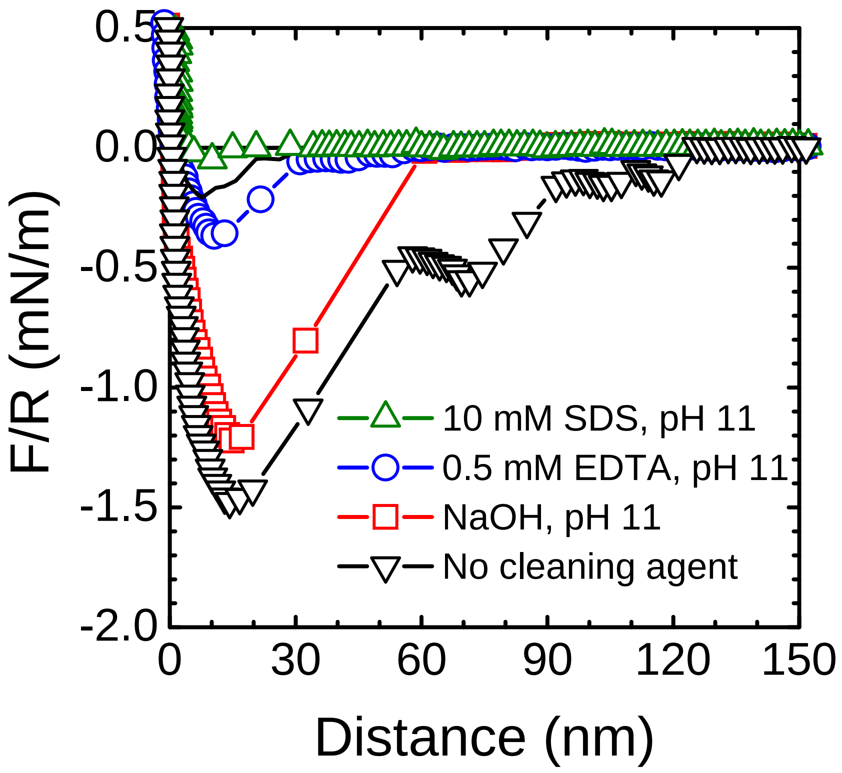
Interfacial Force Measurement



Foulant-foulant interaction

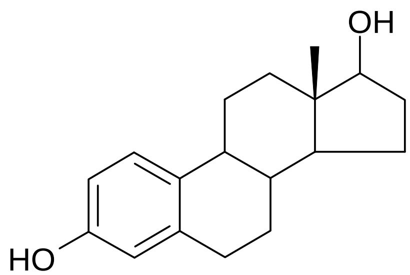
Relating Cleaning Efficiency to Adhesion Force



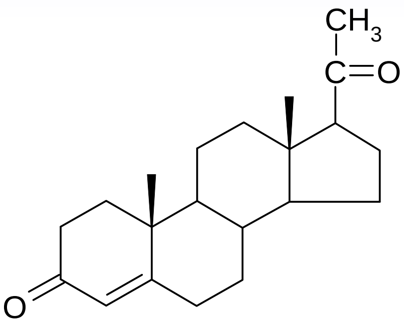


Removal of Trace Organics by RO Membranes

Representative Natural Hormones



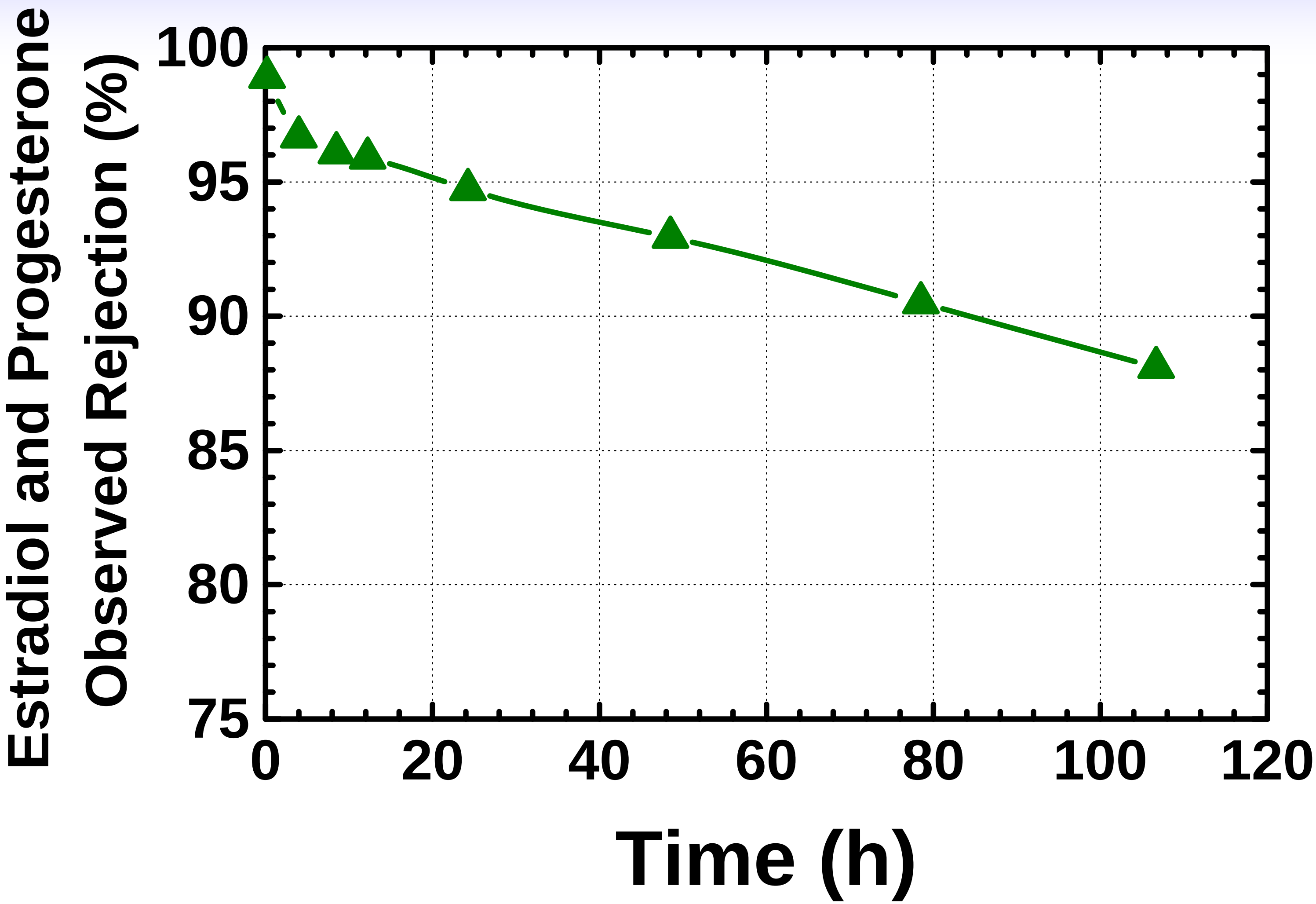
Estradiol



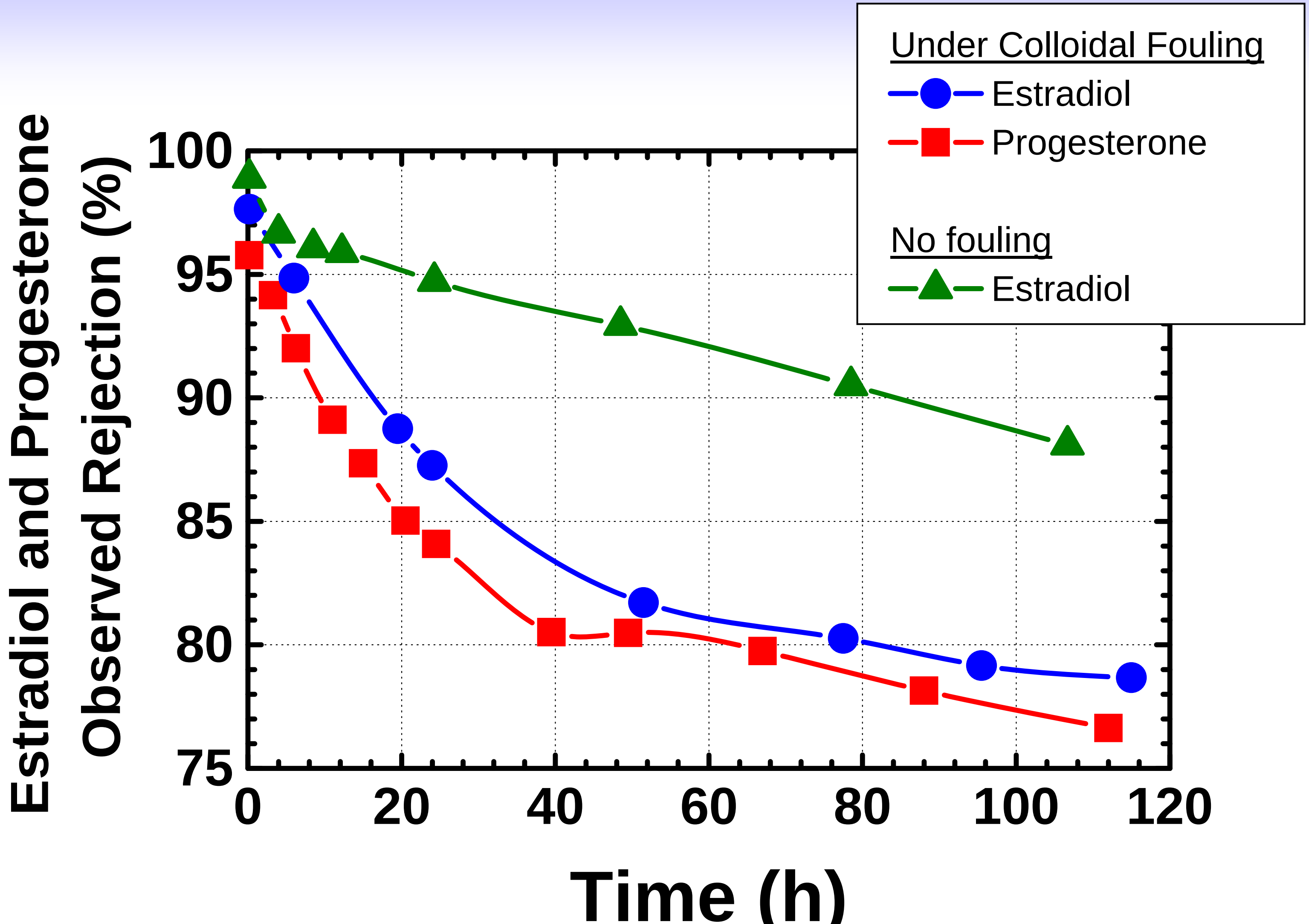
Progesterone

Hormones	**MW (g/mol)**	**log K_{ow}**	**Solubility (mg/L)**	**pK_a**
Estradiol	272.4	4.01	13	10.4
Progesterone	314.5	4.63	NA	-

Hormone Rejection



Hormone Rejection



Concluding Remarks

- **Current Status:** pressure-driven membrane processes are widely used in water recycling and desalination applications
- **Challenges:** fouling, fouling control, concentrates/brines, membrane materials, passage of trace organic contaminants, energy requirements
- **Fundamental Research:** will provide scientific base for optimizing membrane performance
- **Prospects:** technologies requiring less energy (membrane distillation, forward osmosis)

Acknowledgment

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- How Ng (post-doc, now at NUS)
- Funding: NSF, US Bureau of Reclamation