Water-Energy Nexus: Technological Hurdles and Opportunities

David Jassby
Department of Chemical and Environmental Engineering
UC Riverside
Introduction

• Water and Energy are intimately related
  – It takes water to produce energy
  – It takes energy to produce/treat/move water
Introduction

- Water for energy (not exhaustive...)
  - Fracking water and enhanced oil production
  - Coal mining
  - Hydroelectricity
  - Cooling water and steam generation
  - Biofuel production (energy crops)
  - New tech (e.g. PRO?)

water.usgs.gov
www.cdc.gov
www.ghdlivingun.com
Introduction

• Energy for water (also non-exhaustive)
  – Pumping and moving (32% of CA State Water Project costs)
  – Treatment
    • Pressure for membrane processes
      – Reverse osmosis (desalination + wastewater reuse)
      – ~3 kWh/m³ for seawater desalination
    • Aeration (wastewater treatment)
    • Electrocoagulation
      – Hydraulic fracturing
Water Treatment Technologies

• Whether water is used for energy production or wastewater is produced as a byproduct of energy production/extraction, water must meet certain QUALITY standards before it can be used/reused/discharged

• To meet these quality standards, water often requires TREATMENT
Treatment Technologies – Water for Energy

• Make-up water for steam generation
  – Power plants burn fossil fuels, generate steam, and drive turbines
  – Most power plants recycle their water, but losses always occur
  – Make-up water must meet strict quality standards
  – Mineral scaling on heat exchangers is a serious issue
  – Divalent ions must be removed from water stream
    • Nanofiltration, reverse osmosis, or ion exchange
  – Biofouling is also a big problem
    • water must be bacteria-free
Membranes are often used to ensure water quality.

Unfortunately, biofouling and scaling are a problem in membrane separation processes:
- Ions accumulate on the membrane surface, which leads to precipitation and clogging of the membrane surface.
- Anti-scaling agents (small organic chelators) are typically used to prevent scaling:
  - Expensive, can clog membrane
- Biofilm formation on desalination membranes is considered the “Achilles heel” of the process:
  - Can’t disinfect feed water due to membrane sensitivity to chlorine.
We have created a range of electrically conducting membrane materials:
- Ultrafiltration (bacteria/organic molecules)
- Reverse osmosis (desalination)
- Nanofiltration (softening/organic contaminants)
- Forward osmosis (desalination)
- Membrane distillation (desalination)

Membranes are formed by pairing appropriate polymers with CNTs:
- Polymer selection depends on application

Membrane sizes range from lab-scale to “mini-pilot”:
- Spiral-wound elements (in progress)
Treatment Technologies – Water for Energy

- By applying an electrical potential to the membrane surface we can change the morphology and deposition rate of mineral scale
  - Significantly reduce membrane fouling

Duan et al., (2014)
Electrically conducting membranes have also been demonstrated to prevent microbial attachment and biofilm formation.

Dissolved oxygen in the water is electrochemically reduced to $\text{H}_2\text{O}_2$, which creates unfavorable conditions on the membrane surface.

- Bacteria “move on”

![Deposition and Detachment Step Diagram](image)

Ronen, et al. (2015)
Treatment Technologies – Energy Related Wastewater

• Produced water contains many hazardous compounds
  – Hydrocarbons and small organic molecules
  – Radioactive elements
  – Very high salinity (geology dependent)

• Water can be reused, but requires treatment
  – Scaling again...
  – Water softening

• Discharge of this water to a receiving body requires a very significant amount of treatment
  – Salinity is typically a limiting factor
  – Requires desalination
    • High salinity can limit technology options
    • Requires thermal desalination – very expensive
Treatment Technologies – Energy Related Wastewater

• A portion (~1 g/L) of hydrocarbons in produced water form natural emulsions
  – Gravity separation will not remove emulsified fraction
  – Ultrafiltration is an excellent way to remove emulsified oil
  – Emulsified oil can foul membranes
    • Oil droplets coalesce on the membrane surface
  – Would be nice to recover oil...
We have developed a new oil/water separation method to remove emulsified oil from water.

- Oil is stabilized with magnetic nanoparticles, AKA Pickering emulsion - prevents oil droplets from coalescing.

Dudchenko et al., 2015
• NP-stabilized oil does not foul the membranes
• Once oil is concentrated (by pushing out most of the water through the membrane), NPs can be separated and recycled through the use of an external magnetic field (oil can be recovered, too)
Conclusions

• Water and energy are intimately related to one another

• Water treatment technologies are a critical component of the water-energy nexus

• Water treatment technologies are critical for:
  1. Optimal operation of energy production and energy extraction activities
  2. Ensuring no environmental damage is caused from energy production/extraction
Acknowledgements

• **Postdocs:**
  – Avner Ronen (BARD)
  – Adam Slade
  – Binod Chaudhary

• **Graduate Students:**
  – Alexander Dudchenko
  – Wenyan Duan
  – Xiaobao Zhu
  – Katherine Muller
  – Caroline Kim
  – Quynh Tran