Managing Expectations for Graduate Students Involved in Nano-Related Sustainability Research

David Jassby
Department of Civil and Environmental Engineering
UCLA

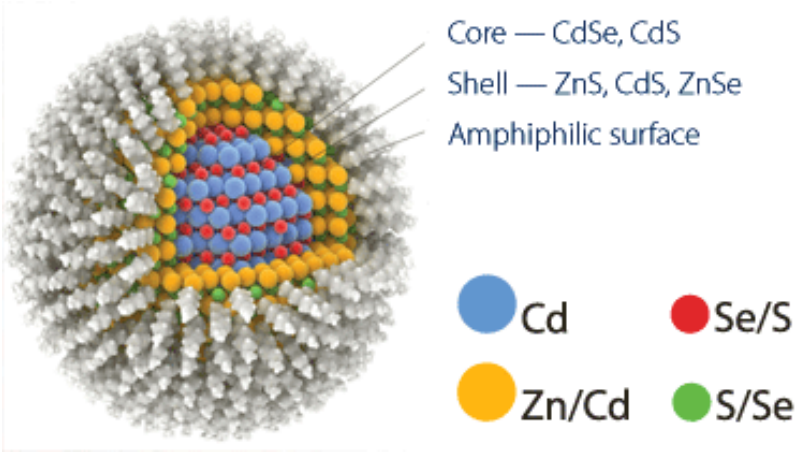
UCLA ENGINEERING
Civil and Environmental Engineering
Engineering Sustainable Infrastructure for the Future

Environmental (Sustainable?) Nanotechnology

- What is sustainability research?
  - US EPA: "…is to create and maintain the conditions under which humans and nature can exist in productive harmony to support present and future generations"
- What is Sustainable Nanotechnology?
  - From SNO: "Promote the advancement and application of scientific research related to nanotechnology, implementation of sustainable nanotechnology for environment, health, and safety, and the use of nanotechnology in policy and decision-making"
  - From Center for Sustainable Nanotechnology (UW-Madison): "…we aim to understand the molecular-level chemical and physical principles that govern how nanoparticles interact with living systems, in order to provide the scientific foundations that are needed to ensure that continued developments in nanotechnology can take place with the minimal environmental footprint and maximum benefit to society."

Environmental (Sustainable?) Nanotechnology

- While many NPs have been found to have toxic properties, to the best of my knowledge, NPs have not been demonstrated to be far more toxic than their elemental composition would imply
  - No dramatic environmental toxicity has been observed
  - Of course, there are unknown unknowns…
- This is good news!
  - NPs/nanotechnology: transition from implications to applications? Very carefully
  - The concept of sustainability has evolved



http://en.rusnano.com

Environmental (Sustainable?) Nanotechnology

- My personal history
  - Started PhD at Duke with Mark Wiesner in 2016
  - CEINT started in 2008
  - Worked on environmental nanotechnology projects
    - NP aggregation and reactivity
    - Was executive director of CEINT for a few months (2011-2012)
    - Pretty exciting place to be
      - Felt like a new frontier (for me)

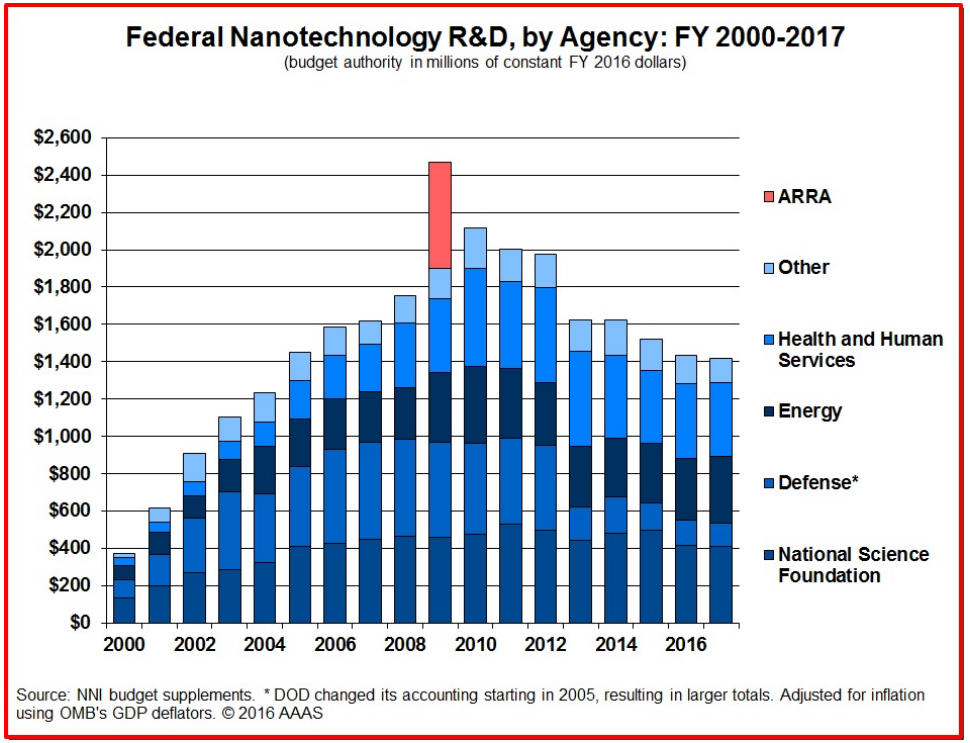
CEINT
Center for the Environmental Implications of NanoTechnology

Environmental (Sustainable?) Nanotechnology

- Many graduate students and postdocs trained through CEINT (38 PhDs, 21 postdocs) and CEIN (42 PhDs, 26 postdocs)
  - Both domestic and international
- More students/postdocs from other programs not affiliated with centers
- I Started a faculty position in 2012
  - Realized very quickly there is very little “nano” specific research
  - Even less “environmental nanotechnology” funding

How Research is Funded: Trends

- Funding is critical for research
- Funding under NNI peaked in 2010
  - ALL nano-related funding
  - Seems to be stabilizing, but…
- DOD dramatically decreased funding in 2013
- As more researchers conduct "nano" related research – more competition
- Majority of funding from "mission" agencies
- NSF is different from other "mission" agencies
  - basic research vs. applied
    - Sometimes….



www.aaas.org

Translating our Training

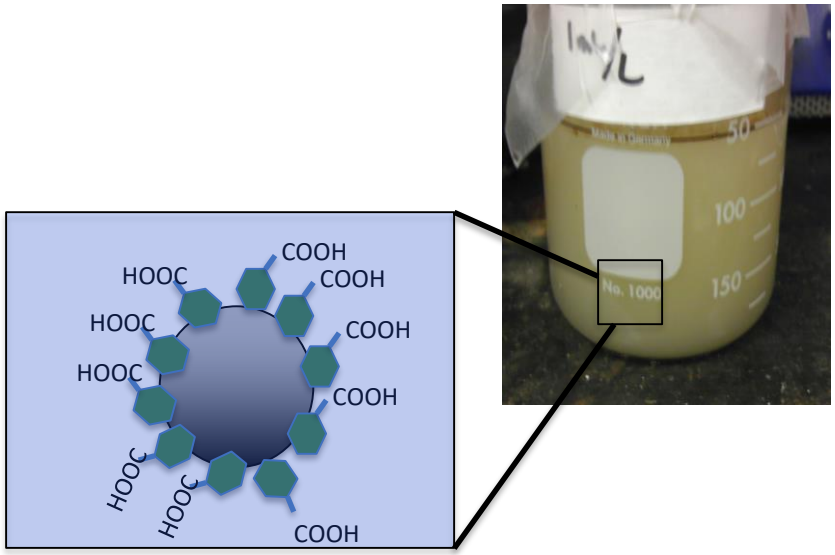
- Mission agencies and environmental issues
  - Have fairly specific research needs
    - Navy (through ONR) – desalination, oil/water separation
    - USDA – agricultural waste valorization
    - DOE – reducing water use in power generation
- I believe nanotechnology is a tool, not a discipline
  - Much like synthetic biology – a tool that can be applied to solve many problems
- Applying nanotechnology tools towards the needs of mission agencies
  - Can translate into innovative solutions
  - Must discuss impact of potential environmental release of these nanomaterials
  - Must address the needs of the agencies!
    - Requires an understanding of environmental processes and treatment technologies

Translating our Training

- Back to my nanotechnology training
  - Learned how to make and characterize nanomaterial suspensions
- Once I became faculty – needed to translate this knowledge to funding
- Many organizations need help with oil/water separations
  - Navy (bilge water treatment)
  - Department of Interior (oil spill cleanup)
  - Oil companies (wastewater treatment)

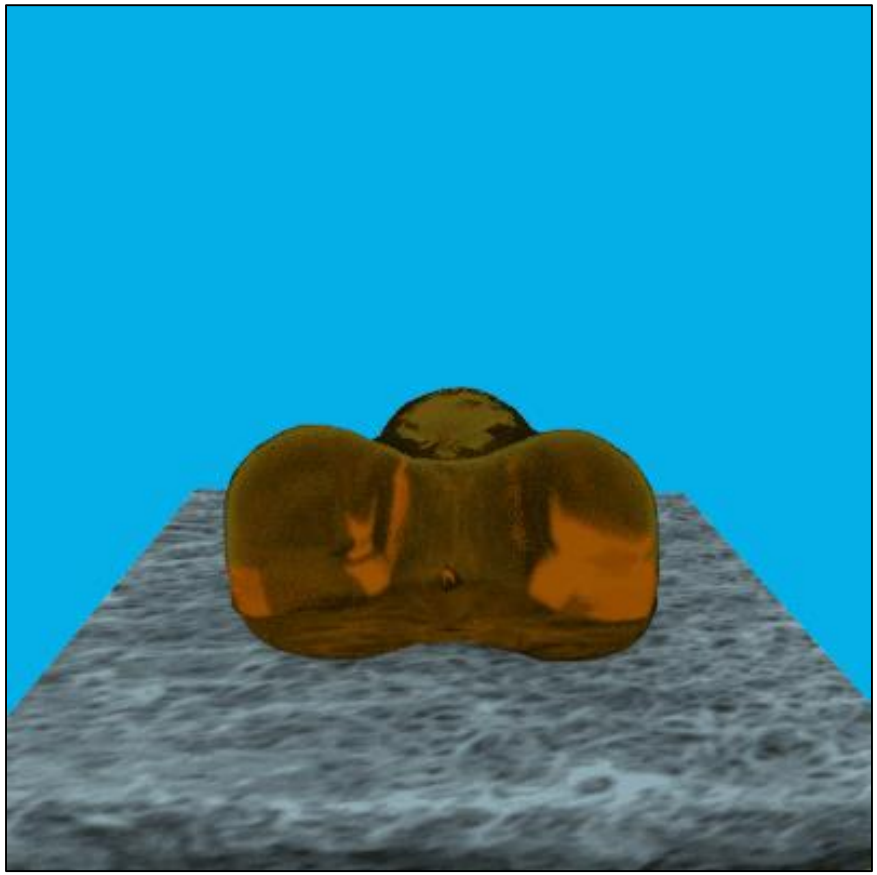
Translating our Training

- The separation of oil from water remains one of the biggest challenges in water treatment
  - Gravity-based methods can be effectively used to remove “free” oil
  - Crude oil forms natural emulsions – naphthenic acids
  - Further polishing steps are required to remove emulsified oil and produce oil-free streams



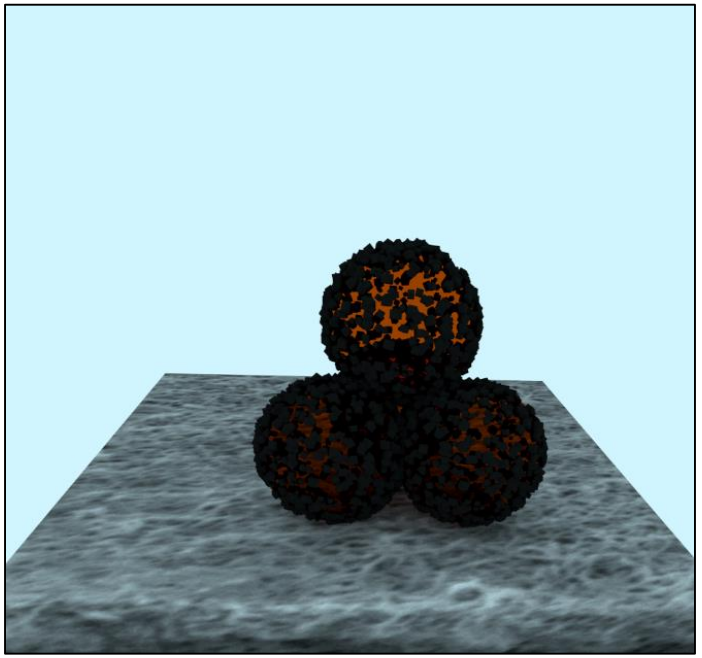
Translating our Training

- Membranes have been demonstrated to be very effective at separating oil from water
- Oil is incredibly fouling on membranes (even emulsified)
  - Once oil droplets accumulate along the membrane surface they can coalesce to form a continuous phase, which sticks to the membrane
  - Results in drastic flux decline



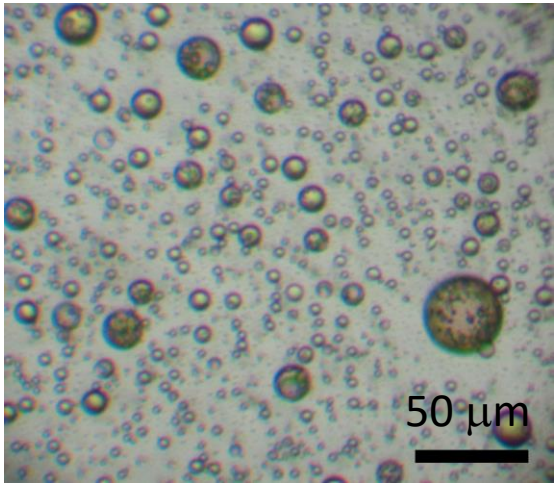
Translating our Training

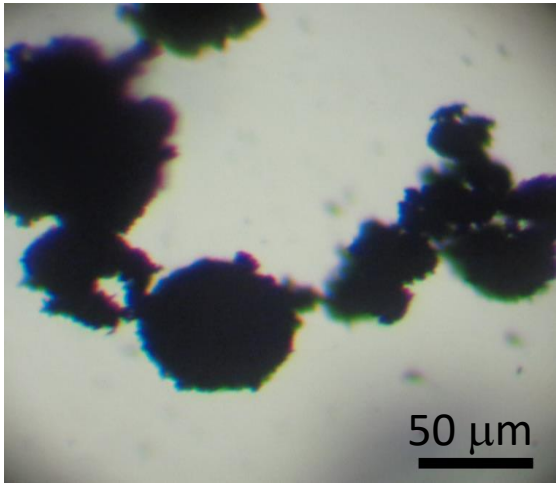
- We have developed an oil/water separation methods that eliminates membrane fouling
  - Use nanoparticle-stabilized oil (Pickering emulsion) to prevent oil coalescence and fouling
- Required understanding of:
  - Why NPs partition to the oil/water interface
  - Ability to functionalize NP surface
  - How NPs behave under different salinity, pH, and mixing conditions
  - How NPs interact with surfaces
  - How oil interacts with surfaces



Translating our Training

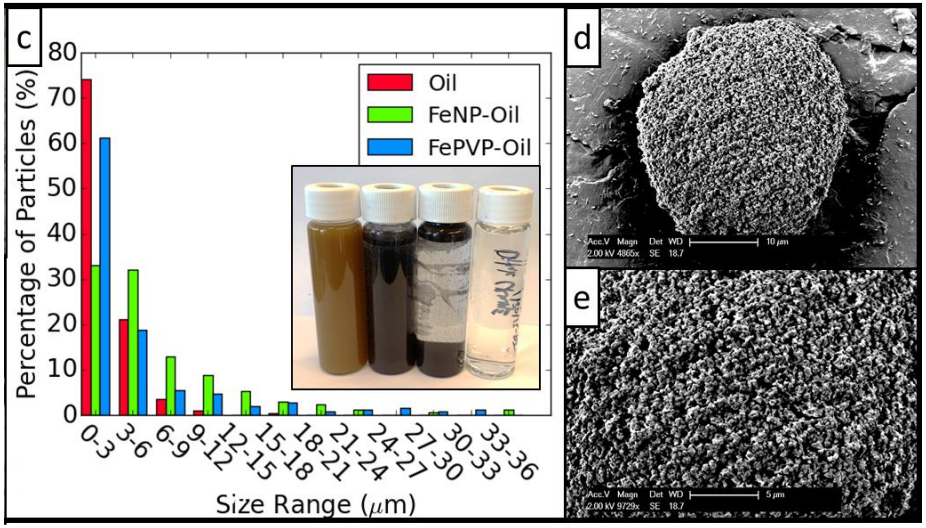
- Pickering emulsions have been around for a long time (1923)
  - Instead of a surfactant molecule, use a particle that partitions to the oil/water interface
  - Degree of adhesion to interface
    - Particle contact angle
    - Particle size
- Iron oxide NPs naturally partition to the oil/water interface to form stable oil droplets
  - Form long-lived emulsions at very high concentrations (>100 g/L)
- Salt concentration and species do not impact emulsion stability

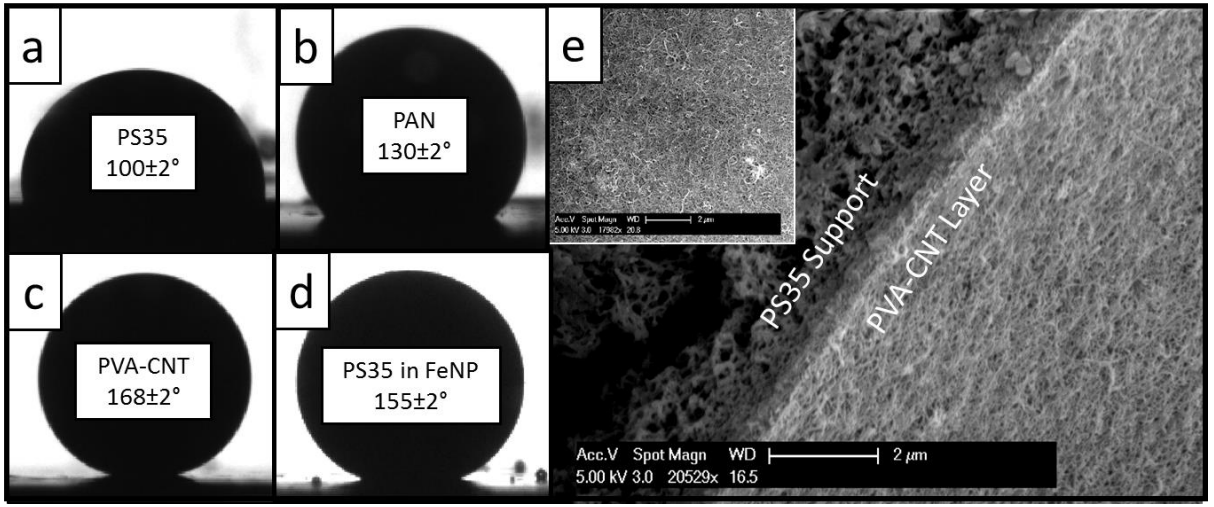




Translating our Training

- The addition of magnetite NPs forms very stable Pickering emulsions
  - Solid coating around oil
  - No significant change in size
- Contact angle of oil with membrane is material dependent
  - NPs increase contact angle

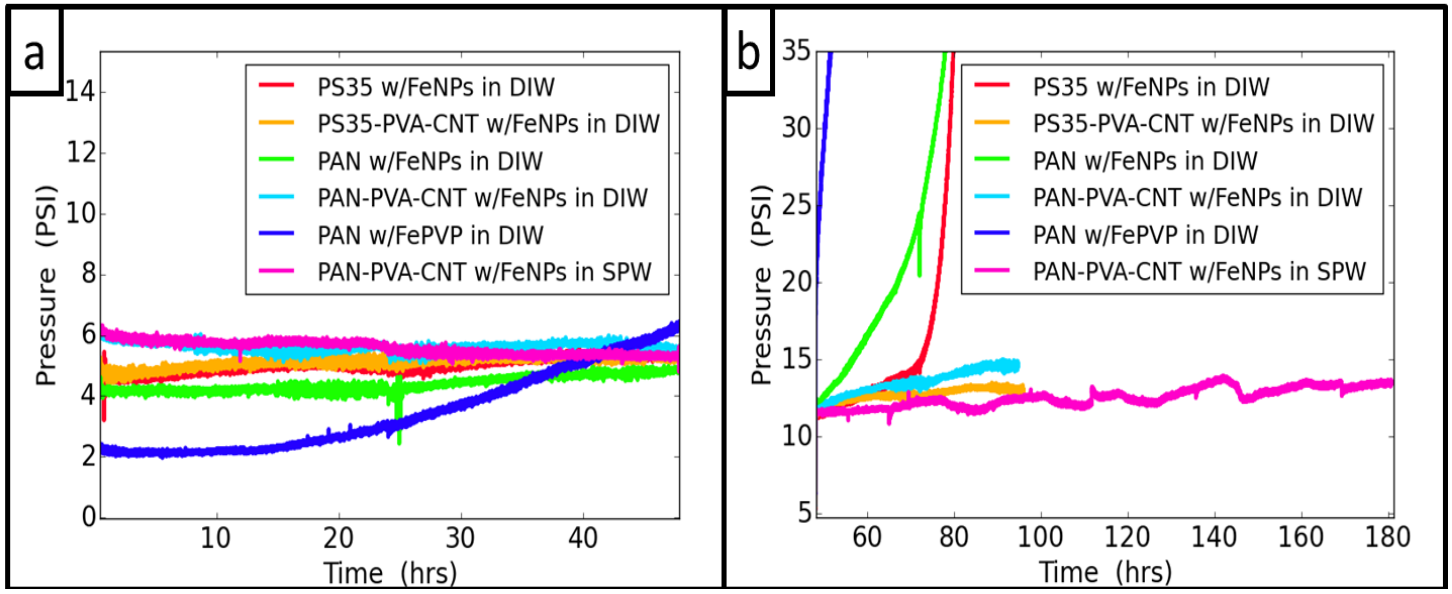




Dudchenko et al., 2015 (ACS Nano)

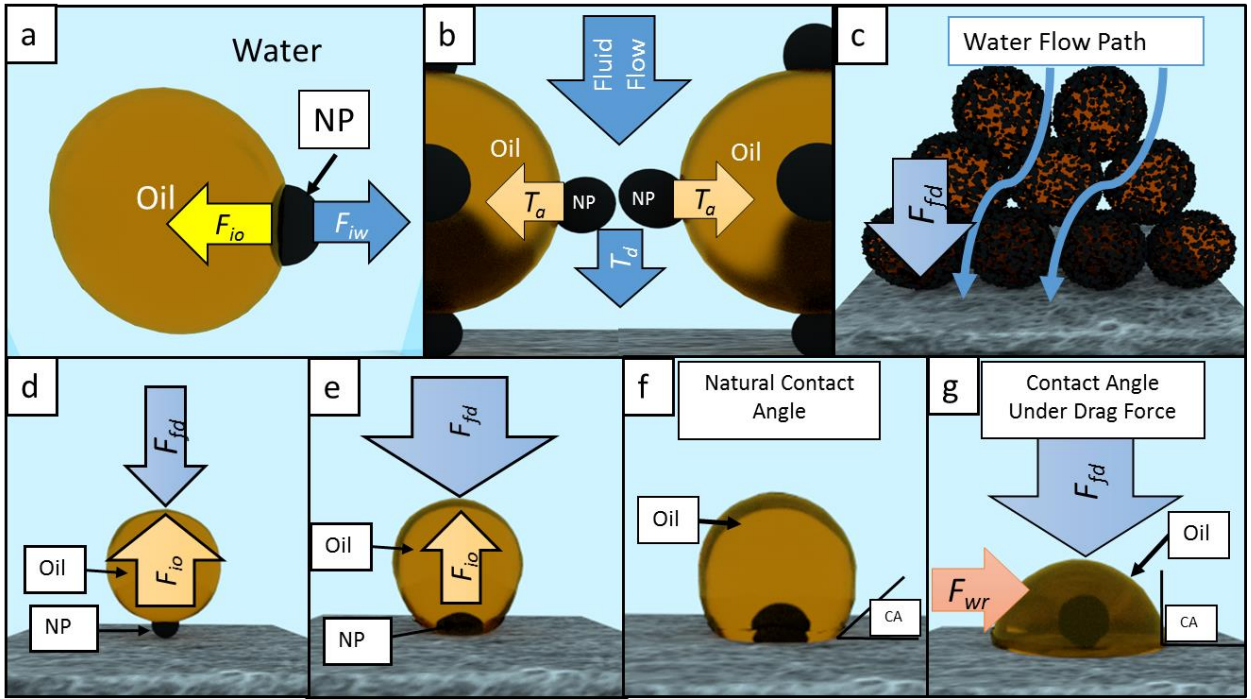
Translating our Training

- System was operated in constant flux mode (10 g/L crude oil + 10 g/L Fe_3O_4 NPs) at 15 cm/s
  - Increase in pressure signifies fouling
  - Bare Fe_3O_4 and PVP-coated Fe_3O_4 (hydrophilic)
- At 50 L/m^2 hr no fouling was observed with bare Fe_3O_4
  - PVP-coated Fe_3O_4 stabilized oil fouled
- At 100 L/m^2 hr, the PSF and PAN membranes fouled rapidly
  - The CNT-PVA membranes did not foul



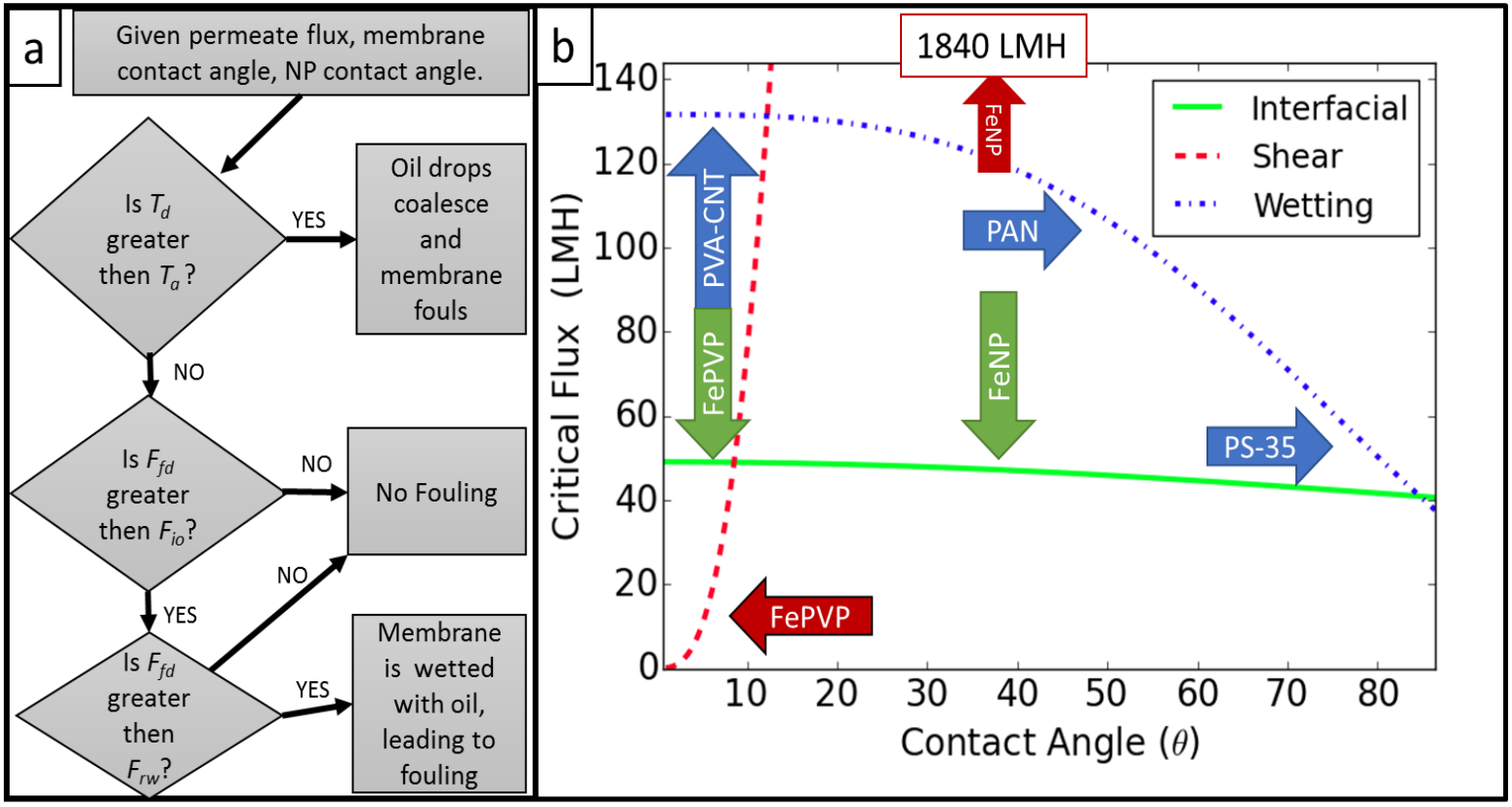
Translating our Training

- We developed a model to describe our experimental observations
  - Calculates the energy required to pull off/push in NPs from interface
  - Calculates the forces acting on NPs
    - Shear forces from constrained flow through cake layer
      - If NPs are sheared, neighboring drops will coalesce and membrane fouls
    - Pressure drop across cake layer pushing NPs into oil
      - Oil comes in contact with membrane



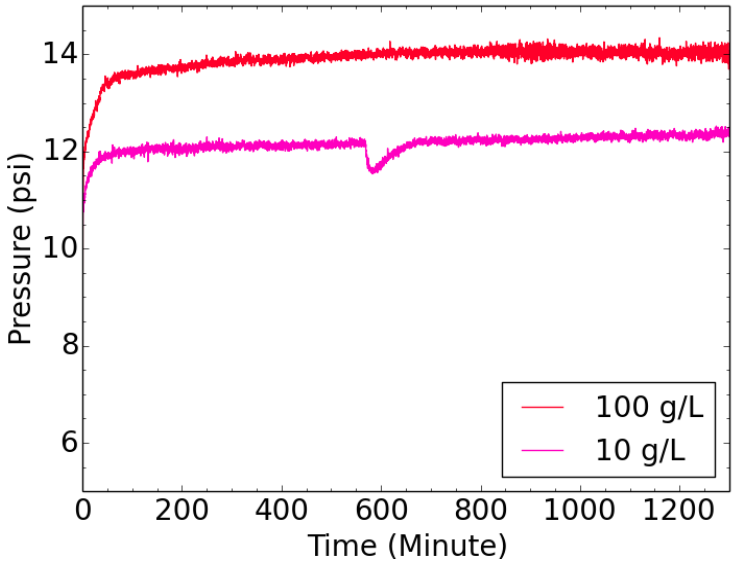
Translating our Training

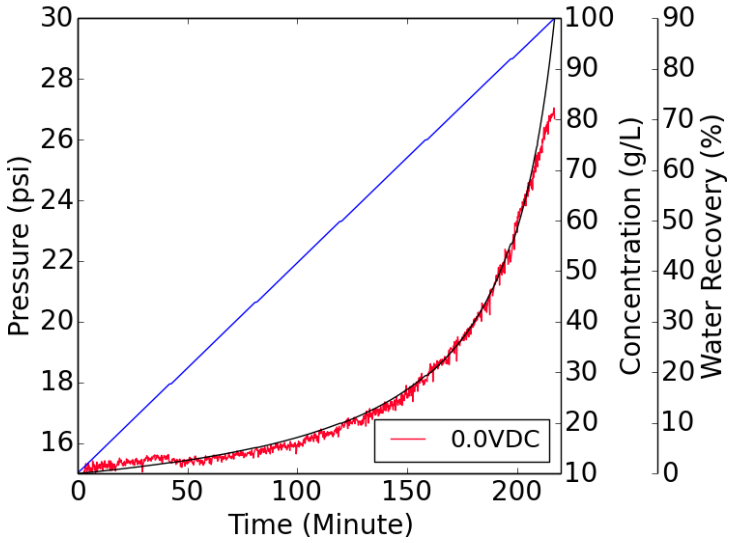
- Using the model, a framework was created to assess system performance

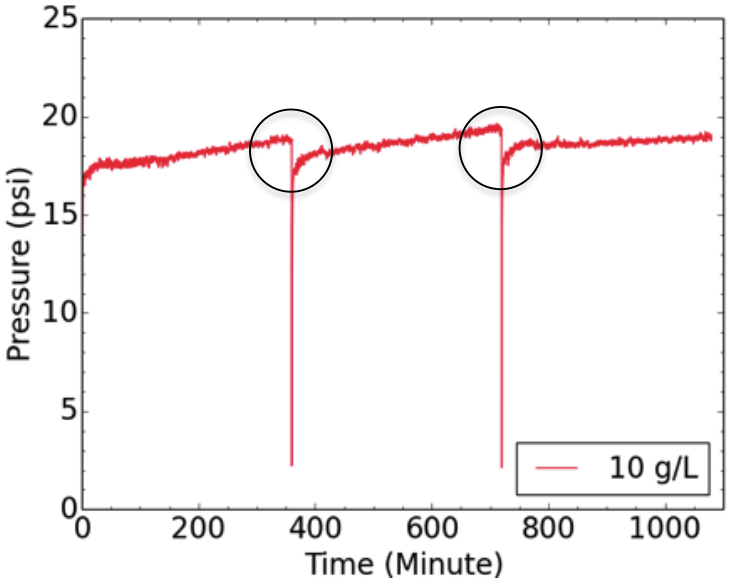


Translating our Training

- We did similar work meant to simulate oil spills in the arctic
  - CNT-PVA membrane
  - 10 g/L and 100 g/L of crude in seawater at 2°C
  - 100 LMH, 15 cm/s – no fouling
  - Backflushing can remove cake







Conclusions

- To me, it seems like environmental nanotechnology is transforming into a useful tool to solve pressing societal problems
  - Point-of-use water treatment
  - Wastewater treatment
  - Groundwater remediation
- Very exciting developments in agricultural applications
  - Anti-microbial agents in citrus
- Must address concerns about exposure
- For successful funding (mission agencies) – must understand how nanotechnology can be used to solve broader societal needs
  - Use tools acquired during graduate school to address new challenges

Acknowledgements

- **Postdocs:**
  - Yiming Su
- **Graduate Students:**
  - Xiaobo Zhu
  - Caroline Kim
  - Quynh Tran
  - Unnati Rao
  - Arpita Idya
  - Khor Chia Miang
  - Bongyeon Jung
  - Shengcun Ma