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Ultrasound for Remediation of Per- and Polyfluoroalkyl Substances (PFAS)

Considerations and Applications

Fiona Laramay

Background

Sono*lysis*: Sound waves passing through a liquid create cavities (bubbles) in the liquid

→ cavities collapse when size is no longer sustainable (*lysis)*

→ cavities collapse releasing high temperature vapor

***In situ* remediation**

→ Reduces likelihood accidental exposure or release

→ Options for low permeability settings

***Ex situ* remediation**

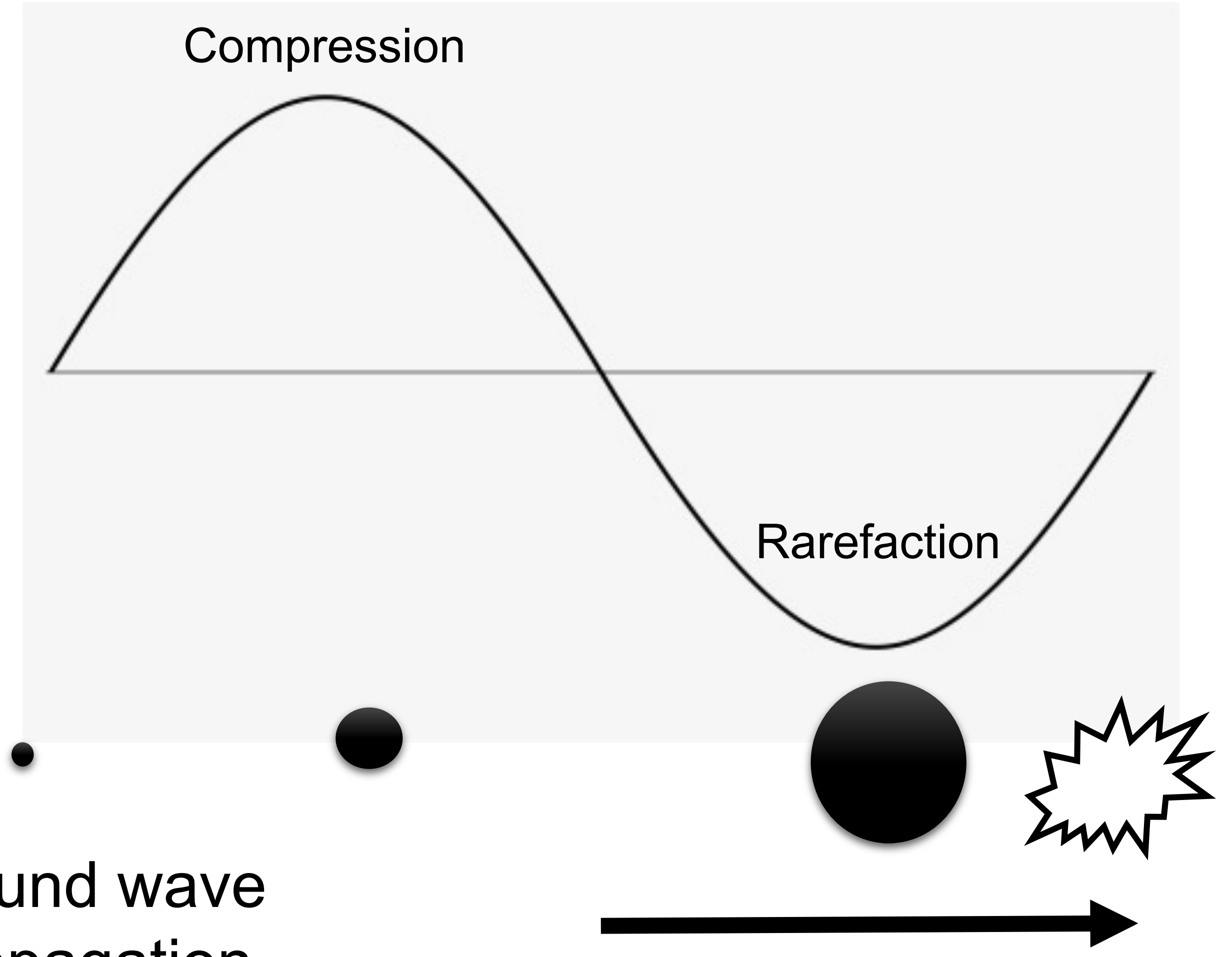
→ Modularity and scalability

→ (Relative) ease of installation

Knowns – PFAS with analytical standards available in “standard twenty-four” method

Unknowns- PFAS without analytical standards for method

Cavity growth and collapse



Sound wave propagation (19 kHz and above)

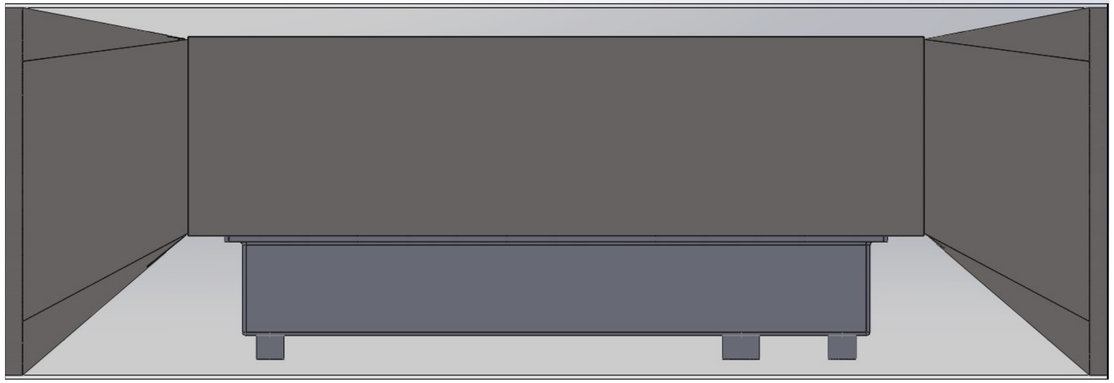
- **Types**: Acoustic and hydrodynamic
- **Created by**: Changes in pressure
- **Results in**: High temperature and pressure conditions
- → damage to surfaces
- → cleaner surfaces

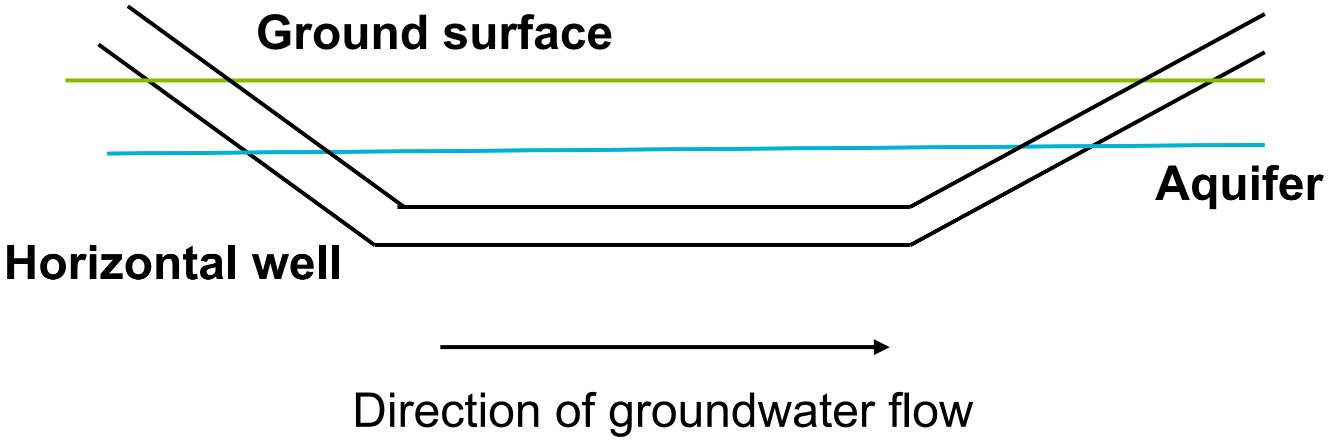
Sonolysis for water treatment

- Indirect: alleviation of membrane fouling (Qasim, Darwish, Mhiyo et al., 2018)
- Tandem system: Ultrasound and chlorination for bacteria inactivation (Zou and Tang, 2019)
- Dual frequency: Degradation of organic and microbial pollutants (Matafonova and Batoev, 2020)

Details of the design

- 12 L reactor with additional design for a horizontal well
  - Horizontal wells can passively capture water
- Operating at 430 kHz and 1000 kHz (alternating)
- Groundwater experiment durations were 24-36 hours total
  - 50% of that time reactor was off





How do PFAS respond to cavitation?

- PFAS align around the cavity interface

Mechanisms

- 1: Pyrolysis of the bond between head and tail group, followed by sequential or complete defluorination (Vecitis et al., 2008)

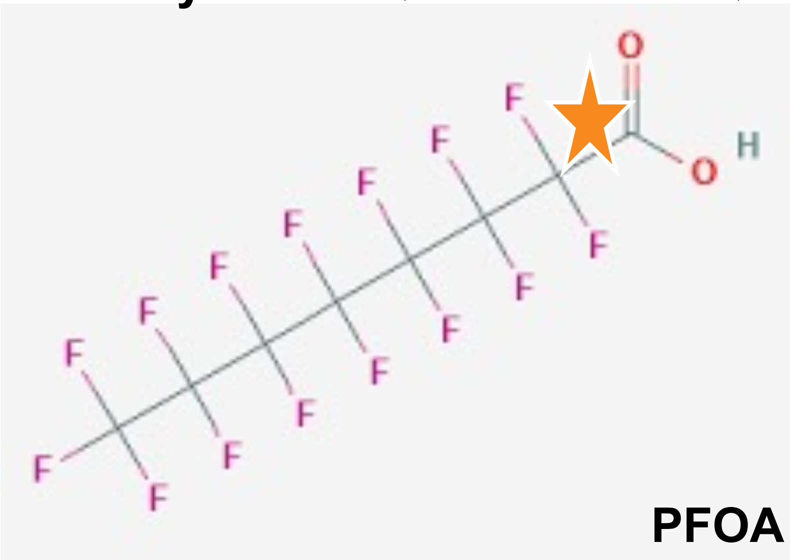
- 2: Aqueous electron attack between head and tail group followed by sequential defluorination via additional aqueous electrons and or other radical species (Wood et al., 2020)

- Possible byproducts: F-, CO_2, CO, H_2O, HF

→ Vecitis et al (2008) proposed that HF is formed under high temperature conditions in the cavity

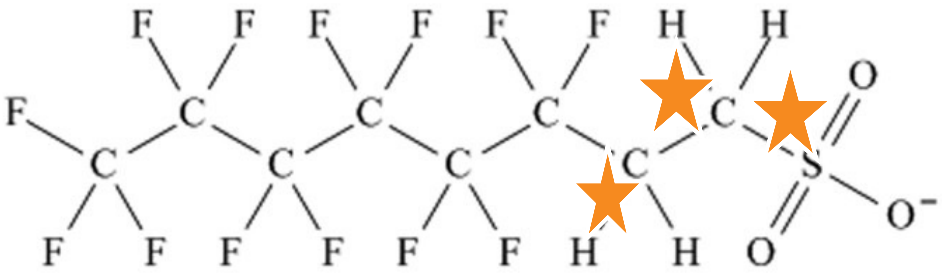
→ Dissolves into F- and H+ following cavity collapse

Cavity interior ↔ Bulk fluid



PFOA

https://pubchem.ncbi.nlm.nih.gov/image/imgsrv.fcgi?cid=9554&t=l



6:2 FTS

https://media.springernature.com/lw685/springer-static/image/art%3A10.1038%2Fs41598-017-17515-7/MediaObjects/41598_2017_17515_Fig1_HTML.jpg

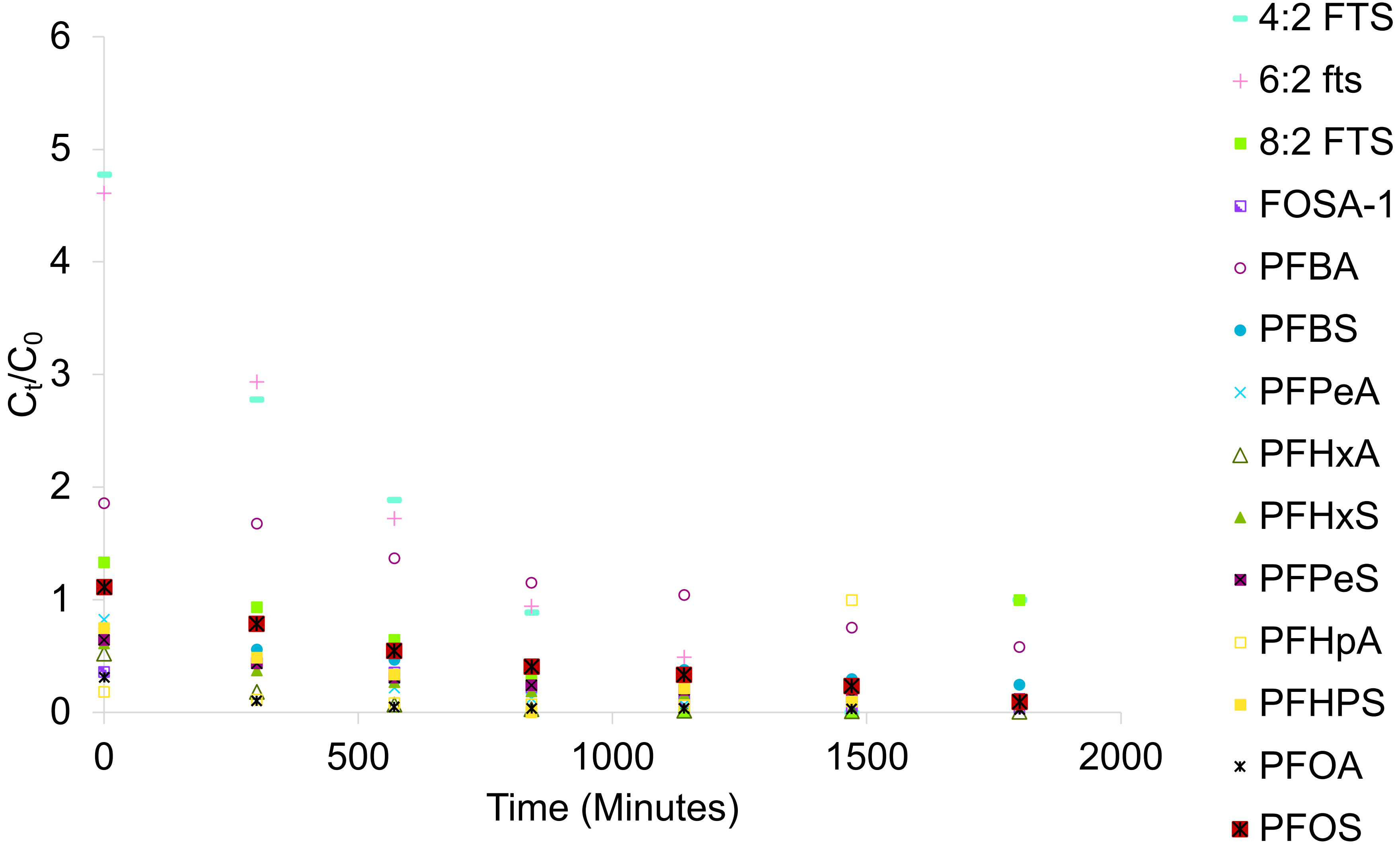
Considerations to optimize system design

1. **Energy consumption**
   a) Increased consumption as flow rate increases
2. **Cost**
   a) Transducers
3. **Influent constituents**
   a) Organic matter
   b) VOCs
   c) Polyfluorinated precursors and intermediates
   d) Abundance of sulfonates vs carboxylates
4. **Reactor configuration**
   a) Volume
   b) Materials
   c) Frequency(ies)
   d) Power density
   e) Temperature

Can PFAS-contaminated groundwater by treated with ultrasound?

Results

- 3 % of initial PFOA concentration remaining
- 10 % of initial PFOS concentration remaining



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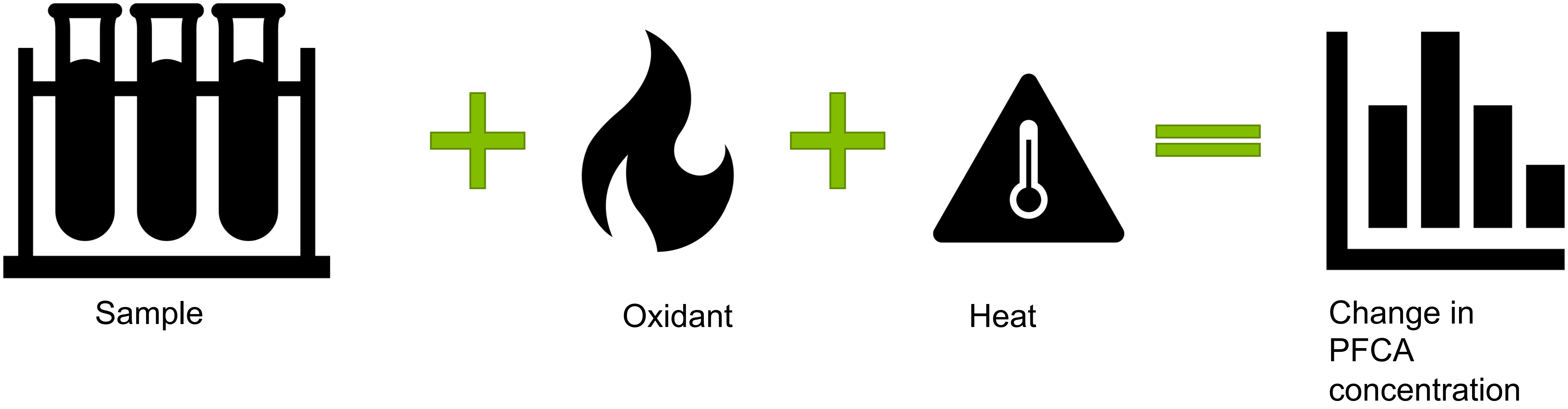
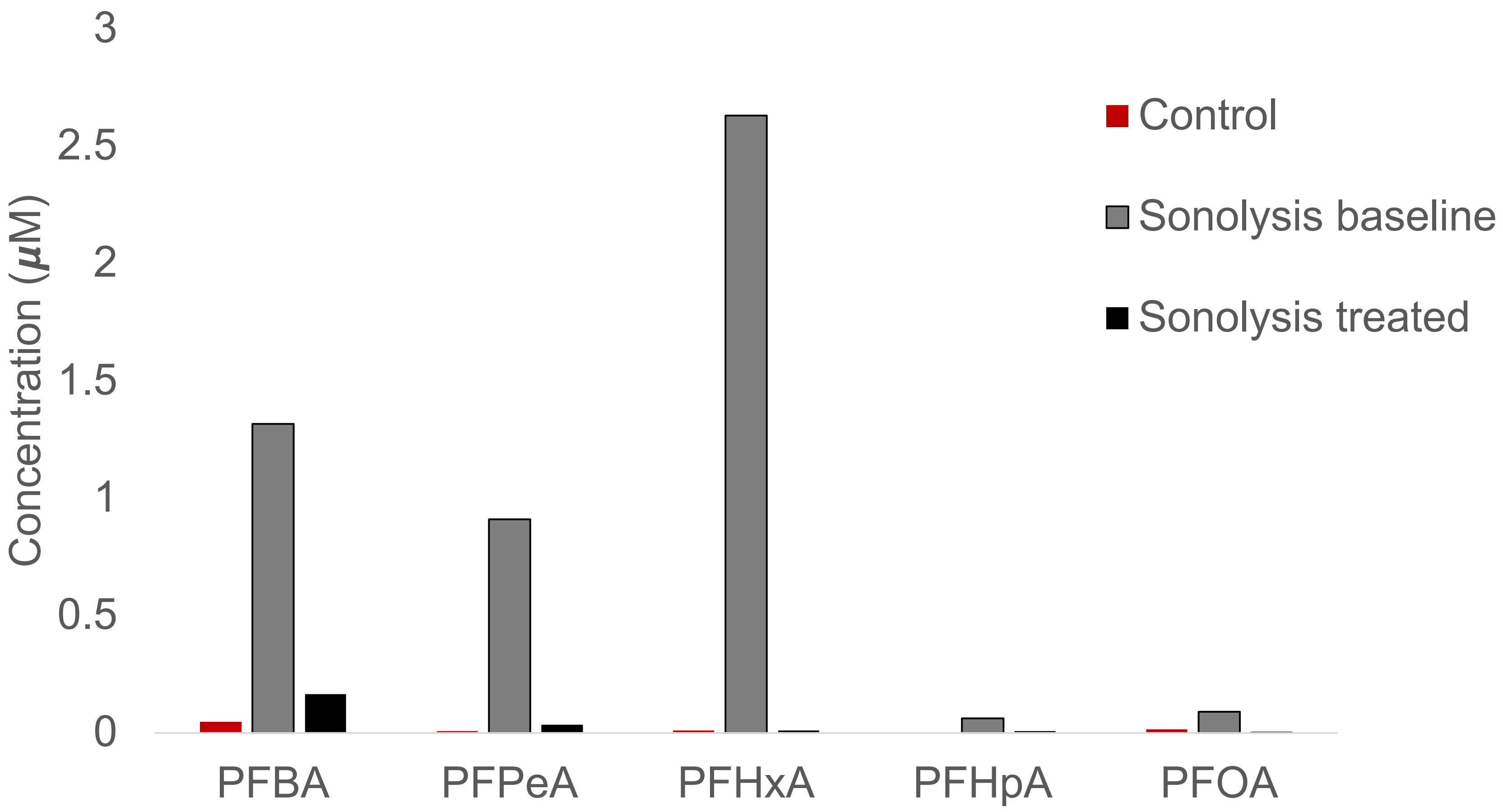
Total Oxidizable Precursor Assay (TOPA)

Houtz and Sedlak (2012)



Change in oxidizable precursor concentration from ultrasonic treatment



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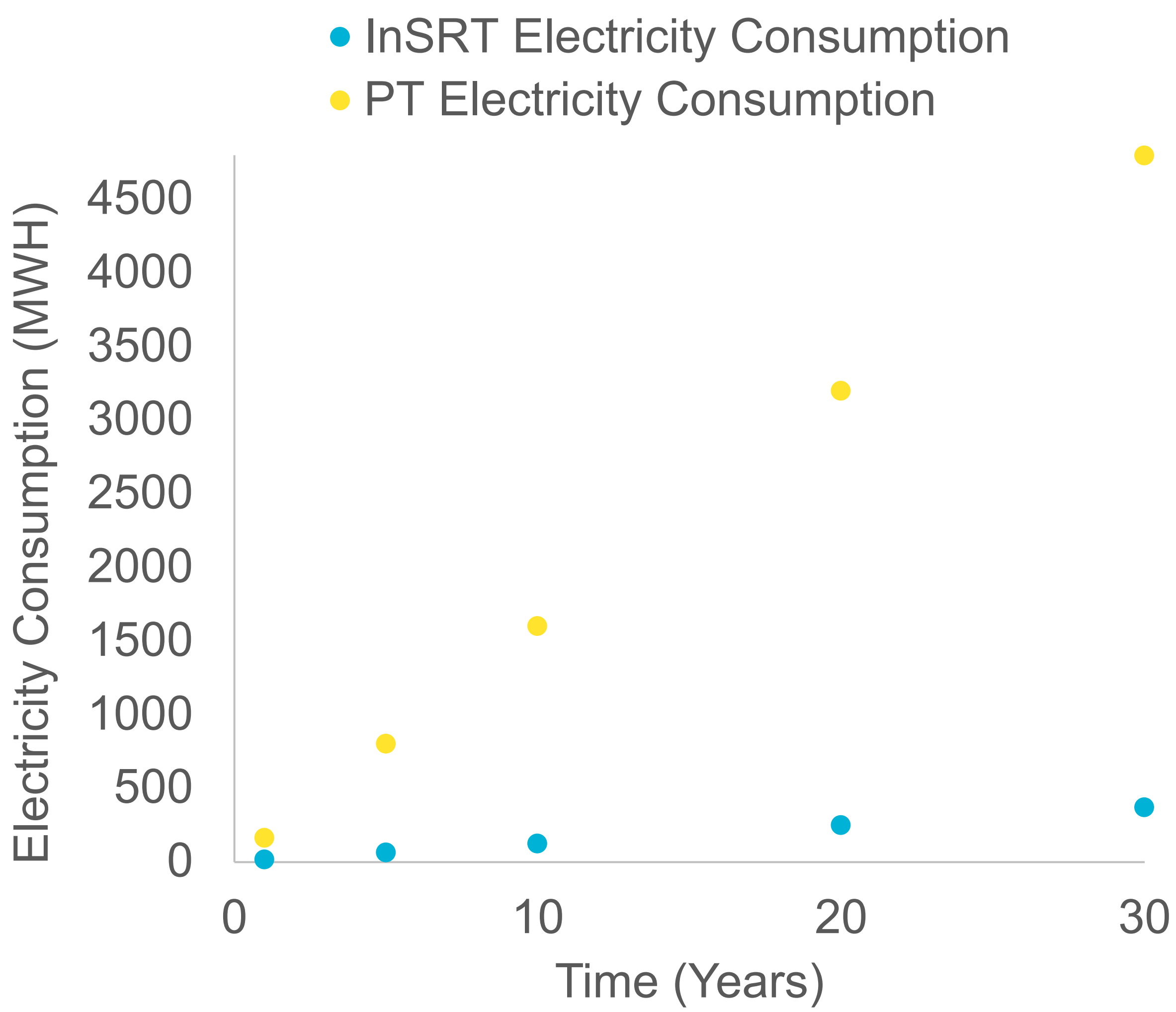
How much energy is consumed during treatment?

- InSRT- ultrasonic reactor in low permeability setting
- PT- refined pump-and-treat scenario using GAC
- Used SiteWise to estimate energy consumption



Takeaways

Ultrasound can be used to treat PFAS in groundwater, however…

1. The mechanism(s) are not yet thoroughly understood and are system dependent
2. Designs benefit from having a thorough assessment of the contaminants present
3. Reaction rate constants tend to favor lower flowrate systems
4. Energy consumption is a barrier to developing larger reactors
5. *In situ* treatment is probably feasible but still need a field pilot test to verify

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Questions?

fiona.laramay@aecom.com

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