



PROJECT OVERVIEW

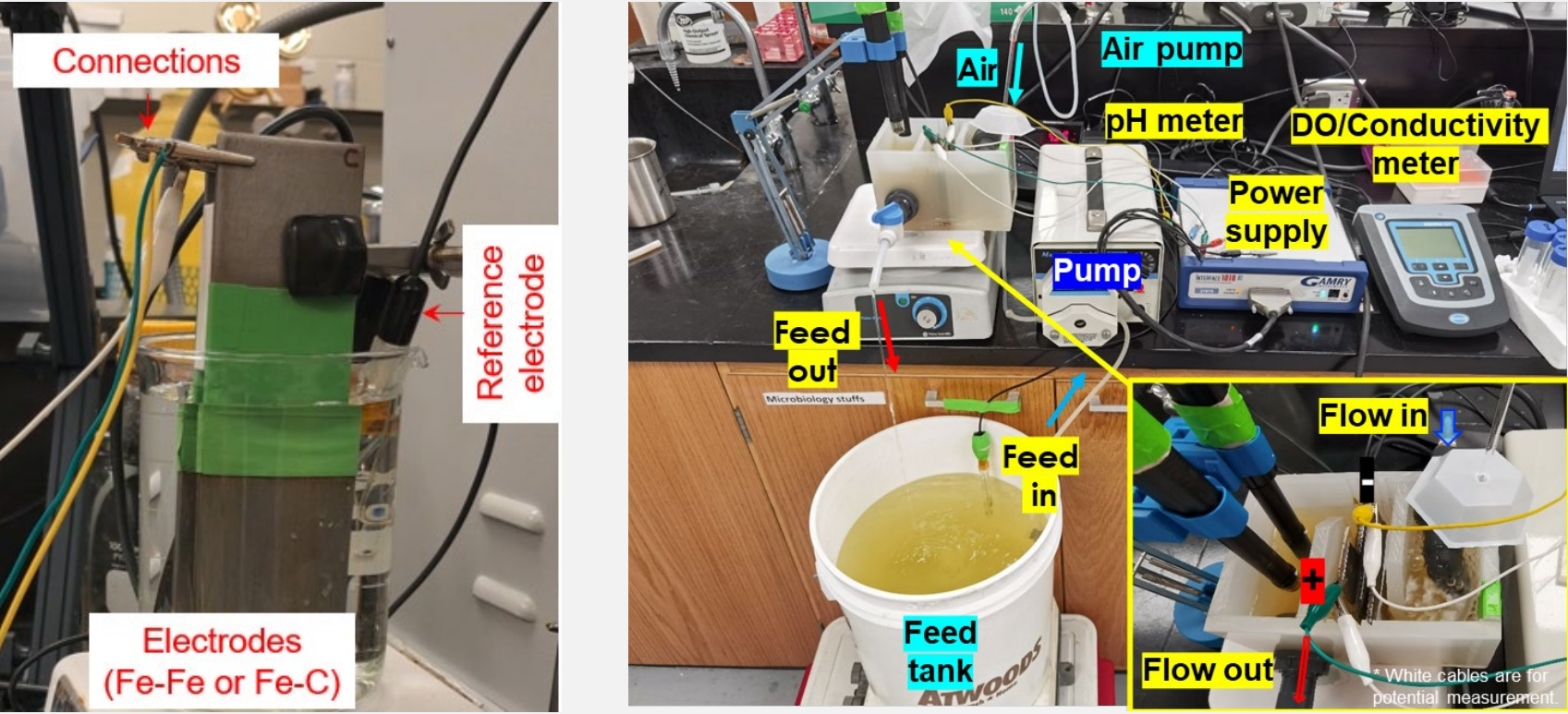
- ❖ **Research motivation, goal, and objectives**
- Motivation:** Develop a streamlined potable reuse treatment train.
- Current status:** Configurations for direct potable reuse still in development and existing ones for indirect potable reuse can be upgraded. Membrane fouling and virus log reduction values are key issues.
- Goal:** Incorporate iron electrocoagulation/electrooxidation (EC/EO) to enhance virus attenuation and mitigate ultrafiltration (UF) fouling.
- Objectives and approach:**

 - Implement iron EC/EO to increase virus attenuation and UF productivity.
 - Mitigate viruses upstream by EC/EO and decrease log reduction value (LRV) requirements of ultraviolet/advanced oxidation processes (UV/AOPs).
 - Enhance electro-Fenton reactions and virus inactivation by using a carbon cathode.
 - Boost UF productivity by EC/EO pretreatment.
 - Diminish passivation during long-term operation via polarity reversal.
 - Characterize electrode surfaces and demonstrate steady voltage profile.
 - Perform techno-economic analysis (TEA).

- ❖ **Team members and project support group**

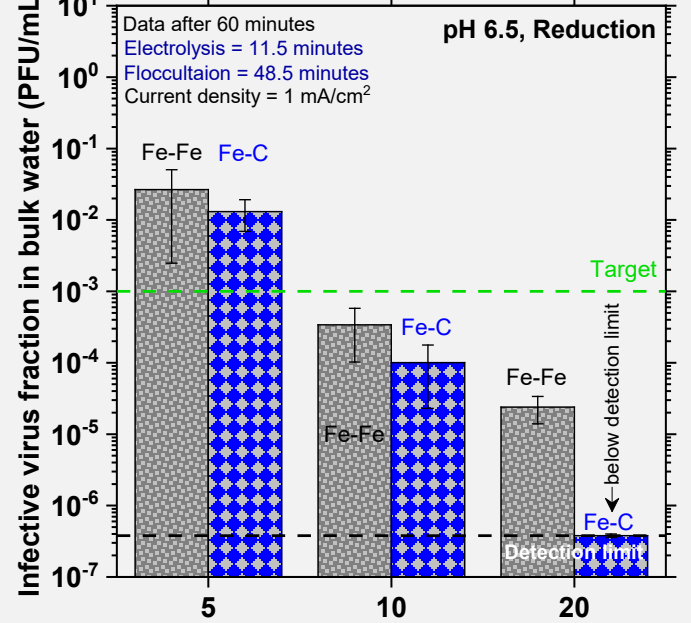
 - Members: Texas A&M University, Oak Ridge National Laboratory, Orange County Water District, Civitas Engineering, WaterTectonics, Lawrence Berkeley National Laboratory, and CAP Water & Power International
 - Project Support Group: Kushal Seth and Lisa Henthorne

EXPERIMENTS

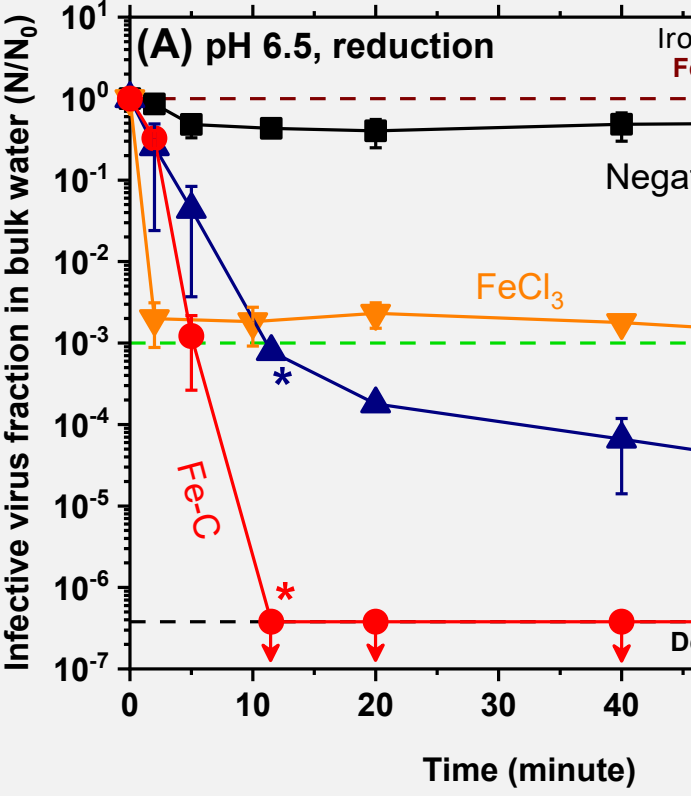
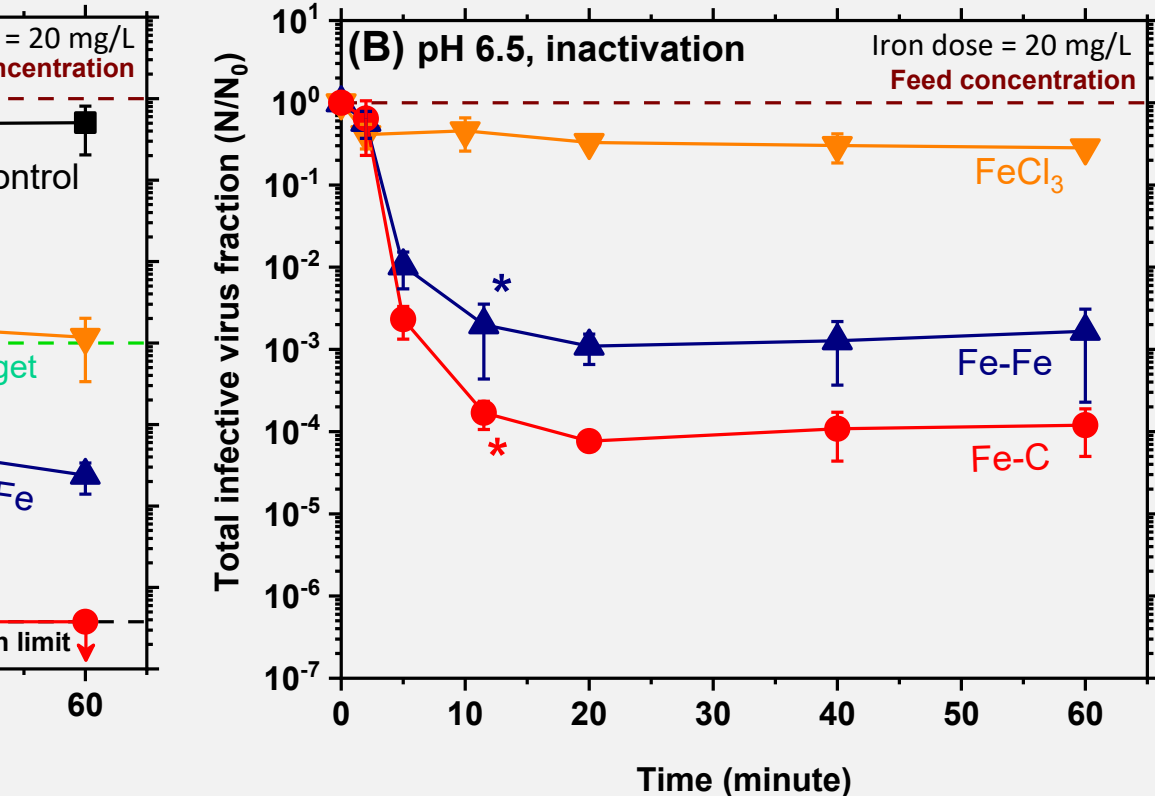
- ❖ **Batch and flow-through EC/EO systems**
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- First study to assess virus control using batch and flow-through system using Fe-Fe and Fe-C electrode systems.
- Monitor water quality and electrolysis parameters.
- ❖ **Synthetic municipal secondary effluent**

 - Mimics composition of secondary wastewater effluents in an indirect and a direct potable reuse plant.
 - Contains all important inorganic components including sodium, calcium, magnesium, silicon, chloride, alkalinity, and sulfate, but effluent organic matter was excluded.

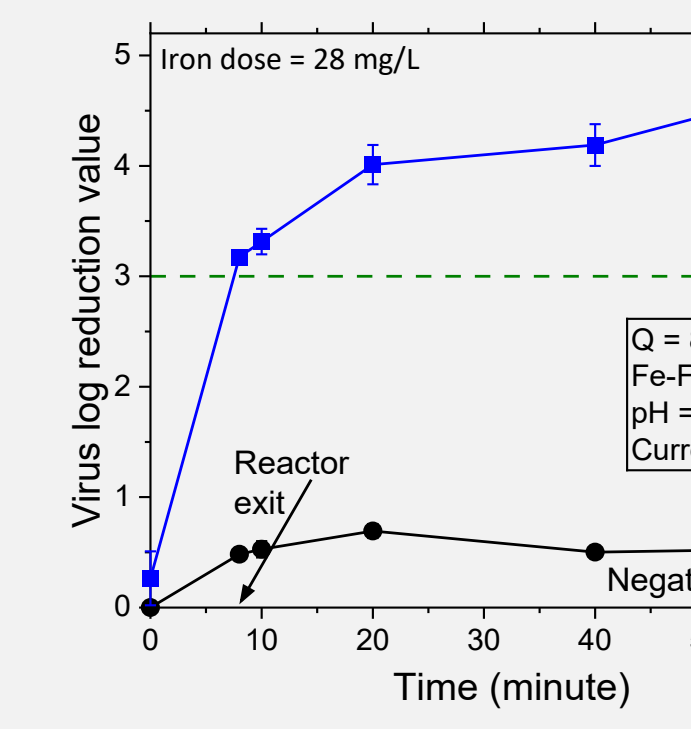
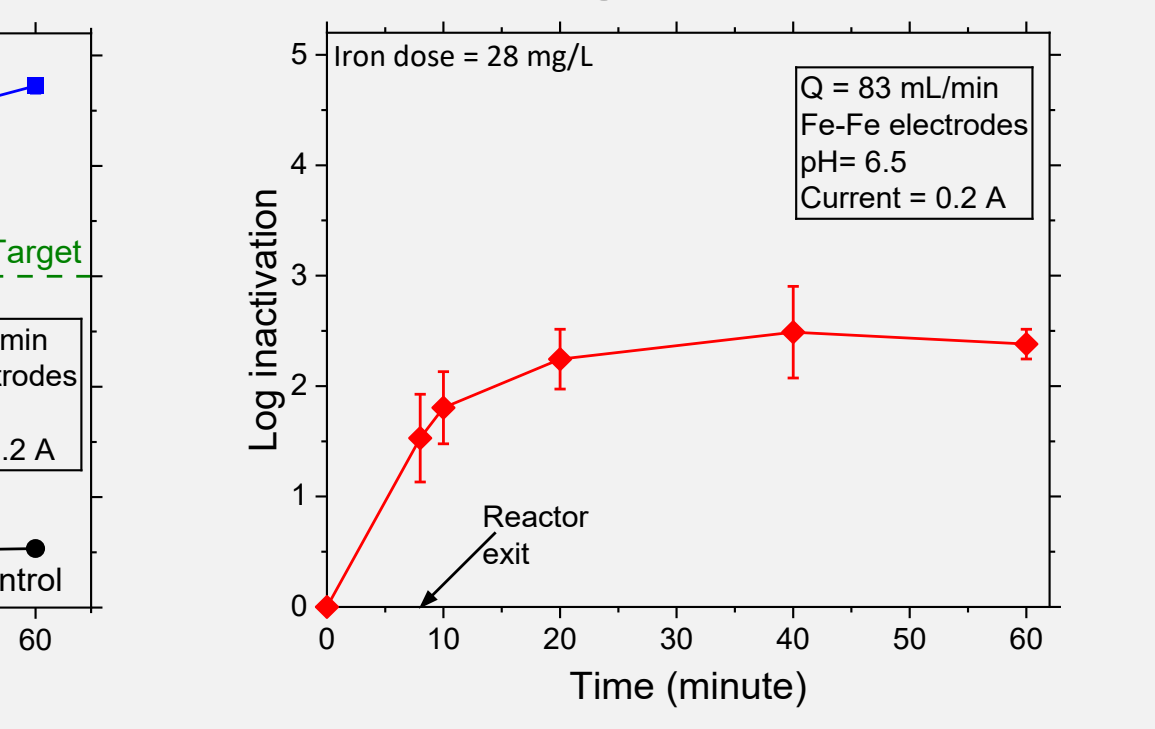
KEY RESULTS

- ❖ **Fe-C EC/EO outperformed Fe-Fe EC and FeCl₃ coagulation for virus attenuation**
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 - Fe (anode) – C (cathode) EC/EO outperformed Fe-Fe EC in all cases.
 - LRV exceeded detection limit for Fe-C EC/EO at 20 mg Fe/L dosage.
 - ≥ 3 LRV by Fe-C in < 5 minutes but Fe-Fe needed ~10 minutes.

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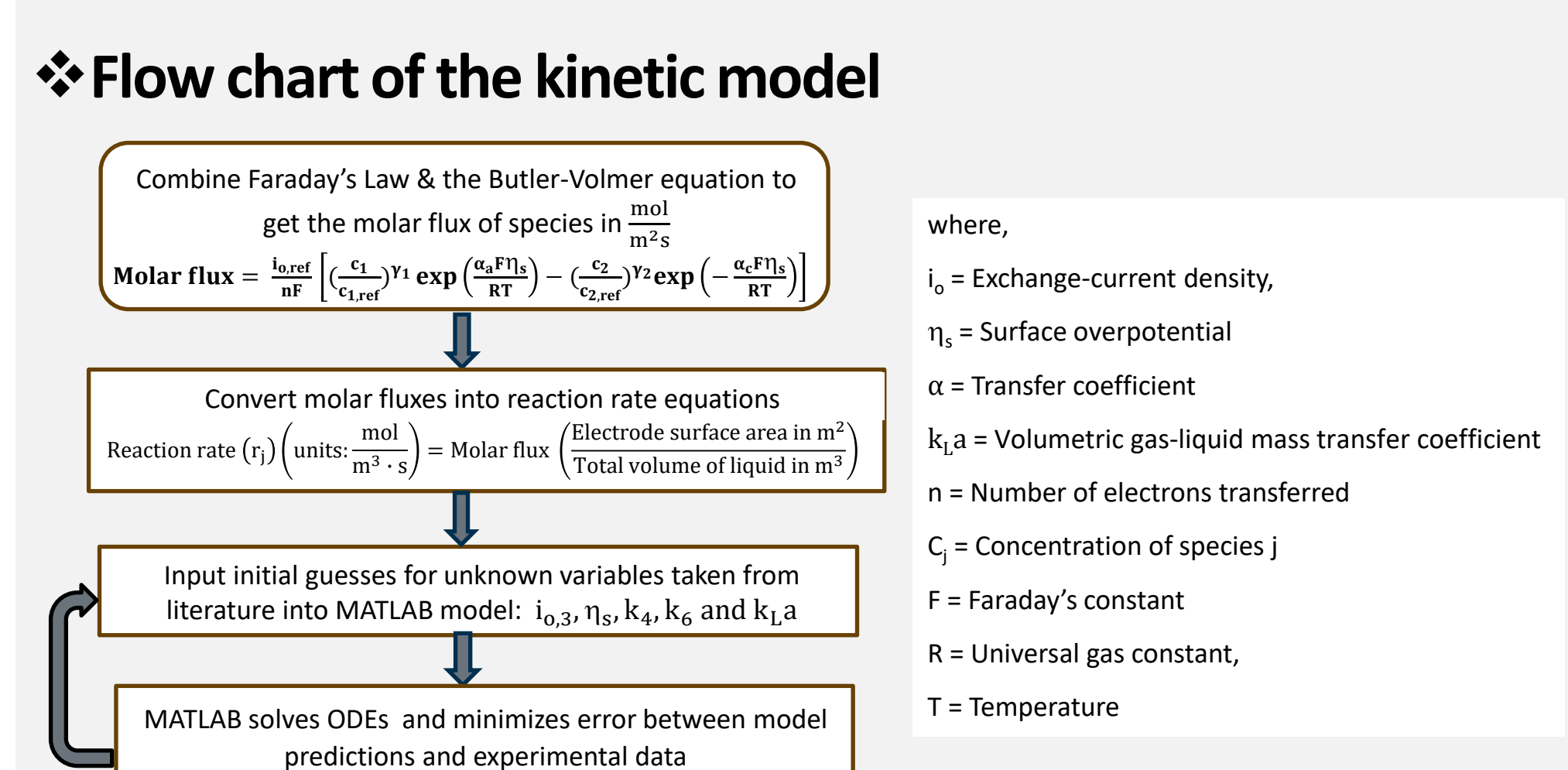
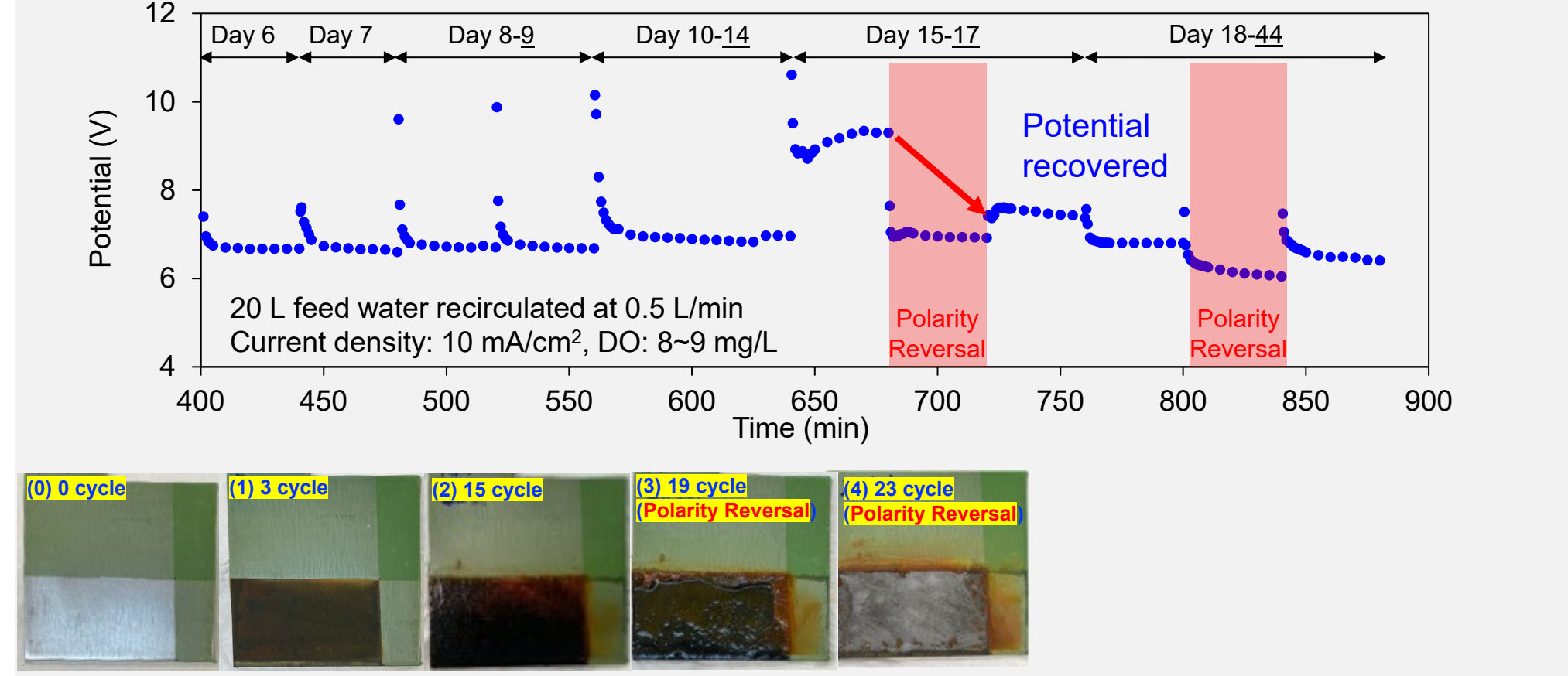
 - Fe-Fe and Fe-C systems removed **and** inactivated viruses.
 - Peroxide and Fe(II) measurements signify electro-Fenton activity at pH 6.5 contributing to virus inactivation.

- ❖ **Effective virus control via flow-through EC**
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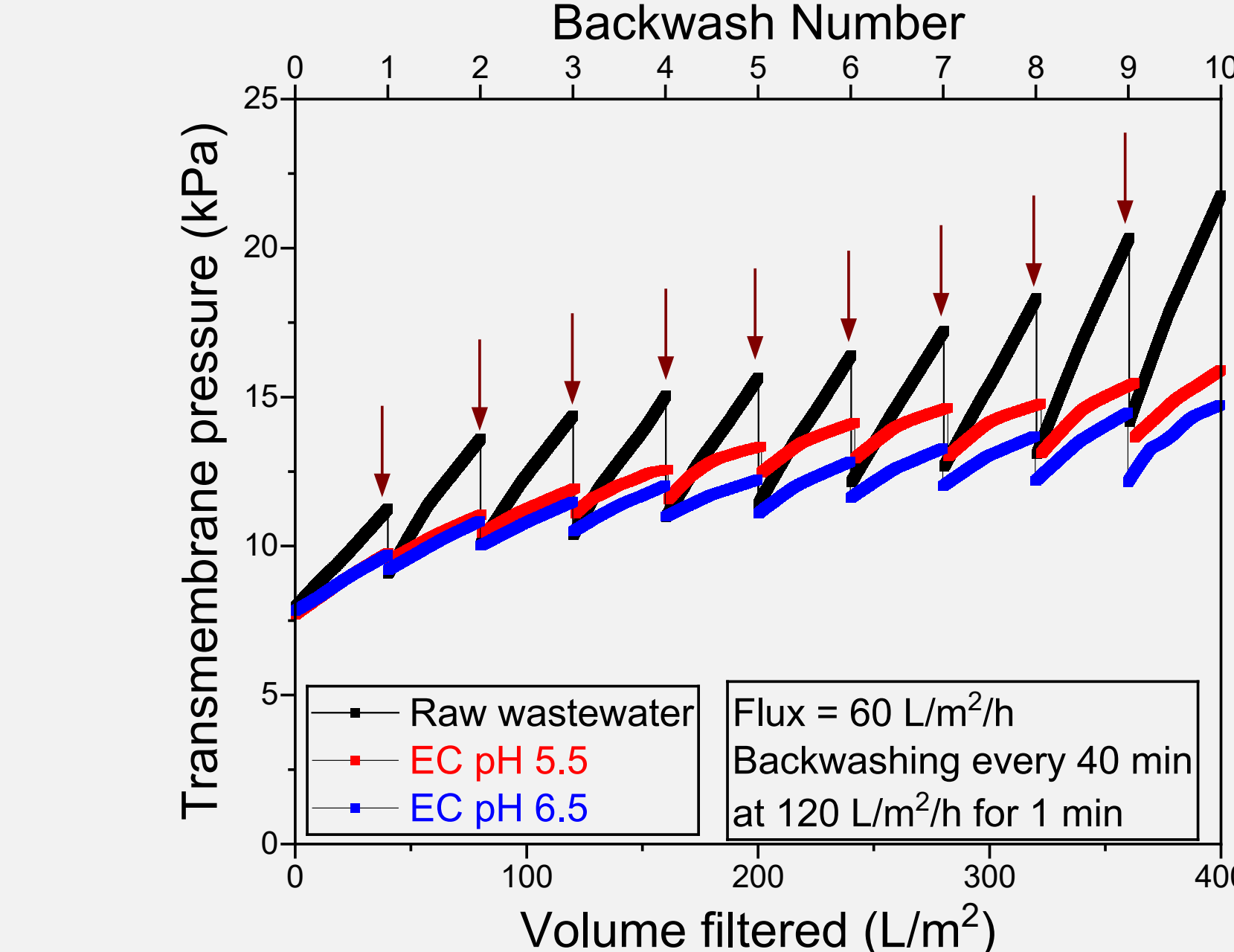
 - LRV > 4 possible with just 20 minutes flocculation.
 - Higher dosage needed than batch EC.

- ❖ **EC performance restoration by polarity reversal**

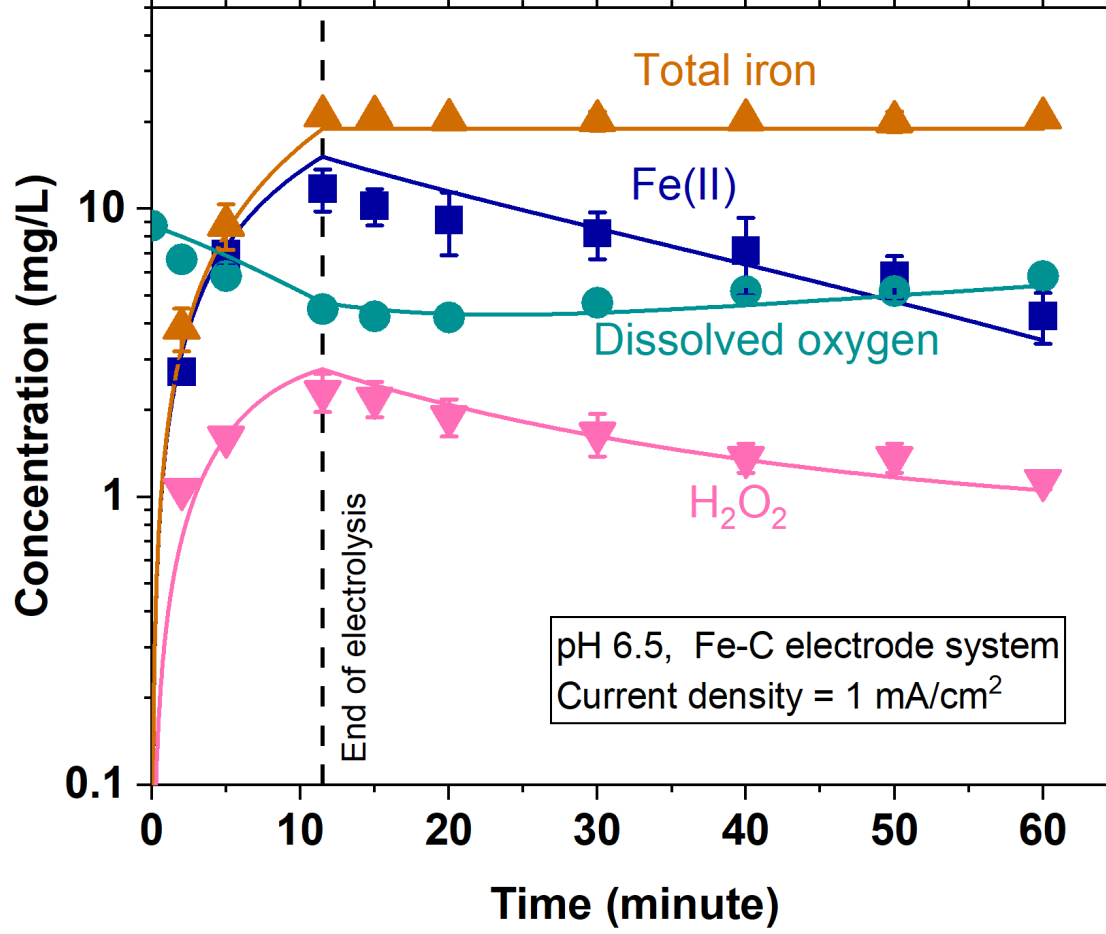
 - Polarity reversal largely dislodged the passivation/foulant layer and recovered operational voltage (potential).



ON-GOING TASKS

- ❖ **Electrocoagulation pretreatment mitigates UF fouling**
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 - Significant role of flocs in reducing fouling.
 - Better fouling control at pH 6.5 than pH 5.5 due to larger and more flocs (better Fe precipitation).

- ❖ **Kinetic modeling**
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 - Modeling of Fe-C system well-predicted Fe(II), total Fe, dissolved oxygen, and H₂O₂ concentrations at pH 6.5.

FUTURE PLANS

- ❖ **Develop electrocoagulation guidebook**

 - Summarize shared experiences and connect EC/EO results to various aspects of water reuse (Marta Hatzell – lead).

- ❖ **Intensify virus removal and inactivation**

 - Perform experiments at a lower pH value (= 5.5) to further increase attenuate virus by enhancing Fenton reactions.

- ❖ **Electrochemical modeling of EC systems**

 - Reduce discrepancies between experimental data and model predictions.
 - Validate the model at other pH values.
 - Combine simulations for electrolysis and flocculation.
 - Expand the use of the model to an Fe-Fe configuration.

- ❖ **UF membrane fouling with pretreated wastewater**

 - Measure and mechanistically interpret reversible and irreversible fouling.
 - Analyze UF fouling behavior after pretreatment with iron anode + carbon cathode EC/EO.

NAWI CONNECTIONS

- Period of Performance:** April 2022 – March 2026 (with 1-year extension)
- Challenge Area/Topic Area:** Process Innovation and Intensification
- Successful application of electrocoagulation and (indirect) electrooxidation for potable reuse of municipal wastewater will lower pretreatment costs, improve resiliency, and reduce the risks of hazardous chemicals used for conventional coagulation and disinfection.
- NAWI Leverage**

 - ORNL: Electron microscopy, neutron scattering, X-ray spectrometry.
 - LBNL: Technoeconomic analysis with Water-TAP3.

KEY FINDINGS AND CONCLUSIONS

- Iron (anode) – carbon (cathode) EC/EO outperformed iron-iron EC and conventional iron coagulation by > 2 order of magnitudes for LRV and appears to be a promising technology.**
- Other key findings:**

 - Iron EC achieved ≥ 3-LRV in ~10 minutes in a synthetic secondary effluent at pH 6.5 and 20 mg/L Fe in the absence of organic matter.
 - LRVs were due to both removal and inactivation and increased with iron dosage.
 - Effective production of Fenton's precursors, viz. H₂O₂ and Fe(II).
 - Batch experiment data were validated with flow-through cell.
 - Electrochemical modeling of the Fe-C EC/EO system quantitatively predicted trends of Fe(II), total Fe, DO, and H₂O₂ concentrations.
 - Polarity reversal successfully restored EC performance (Faradaic efficiency and contaminant removal) and decreased energy consumption.
 - Porous iron electrodes reduced energy consumption.
 - Preliminary techno-economic analysis suggest that while EC/EO can improve CAPEX appreciably, those improvements are offset by an increase in OPEX.
 - Both Fe-Fe EC and Fe-C EC/EO are promising technical alternatives to conventional chemical coagulation because they increase virus attenuation.

Concluding remarks: Iron EC/EO behavior is strongly dependent on aqueous chemistry necessitating control of feed water pH and electrolysis parameters. Ongoing work targets better virus attenuation, electrochemical modeling, UF pretreatment, and fine-tuning TEA analysis.

REFERENCES

Kim et al., *ACS ES&T Engineering* (2024) 4(10) 2573-2584. <https://doi.org/10.1021/acsestengg.4c00317>
 Jang et al., *ACS ES&T Water* (2024) 4(6) 2390-2402. <https://doi.org/10.1021/acsestwater.3c00741>

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