RESEARCH BRIEF
Start Date: Oct 1 2020 | Duration: 15 months

NAWI
National Alliance for Water Innovation

Platform Process for Electrified Pretreatment

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Challenge

Chemicals used in desalination are mostly generated off-site using energy-intensive methods and, when accounting for the transportation costs, account for a significant fraction of the operational and greenhouse gas emissions.[1] Processes such as electrocoagulation have shown promise as substitutes for chemical addition, but their exact mechanism of action is poorly understood. Developing a thorough understanding of how these electrochemical processes work will allow researchers and engineers to optimize the processes and ultimately displace chemical use.

Research Approach

In this project, we have developed an experimental methodology that combines probing electrochemical reactions and surfaces at the atomic, nano, and micron scale using an array of characterization tools, and use these observations/insights to better understand macro-scale (i.e., system-wide) electrochemical characterization methods. While these characterization methods have been applied to other systems (e.g., energy storage), they have never been applied in a concentrated effort to characterize reactions and electrode surfaces during the electrochemical treatment of water.

Impact

The long-term goal of the NAWI research on electrified treatment processes is to establish the scientific foundation of electrified processes and research opportunities for highly energy-efficient water treatment and pretreatment for NAWI's Electrification theme. The outcome of this project will provide unique insights that will enable the wide-scale adoption of these treatment methods across multiple treatment scenarios. It is expected that the tools and insights developed in this work will pave the way towards a deeper understanding of other electrochemical platforms and processes for water treatment.

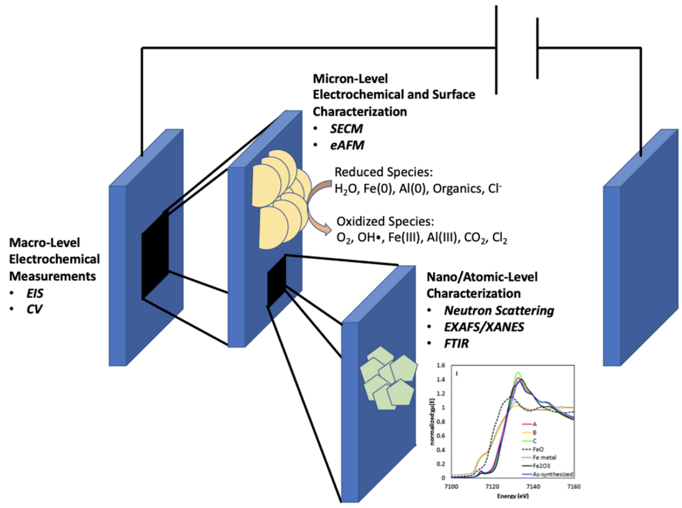

Figure 1. Investigation of electrochemical reactions from the macro to the atomic scale utilizing a range of advanced characterization methods. The combination of these methods will enable more efficient operation, as well as identify limitations, and potentially open up completely new areas of application.

RESEARCH PARTNERS

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1. Liu, Y.-H. et al. Electroprecipitation Mechanism Enabling Silica and Hardness Removal through Aluminum-Based Electrocoagulation. ACS ES&T Engineering (2022).
2. Khor, C. M. et al. Performance, Energy and Cost of Produced Water Treatment by Chemical and Electrochemical Coagulation. Water 12, 3426 (2020).

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Accomplishments & Findings

One important initial discovery was that the assumption that the anode in an EC system would have the most observable chemical phenomena that we could use to optimize performance.1 We found that the anode is "boring", as the rapid electrochemical dissolution process continuously renews the anode surface. In contrast, the cathode was the site of a range of illuminating phenomena that govern EC performance. For example, it has been empirically observed that, after an initial break-in period, EC systems "ripen" – showing improved electrochemical efficiency with time and that the amount of coagulant produced by EC seems to exceed what would be predicted from a simple application of Faraday's Law. We discovered that one reason is that aluminum oxide on the cathode surface is transformed into aluminum hydroxide (gibbsite), which has lower electrical resistivity and results in a lower resistance to charge transfer.1 Furthermore, under the localized high pH on the cathode surface, Al oxide(hydroxides) solubility increases, leading to pitting and "sloughing" of aluminum ions, which contribute to the coagulant dosage, and removes scale-forming materials that form on the cathode (e.g., Mg(OH)2).1 We developed a statistical analysis that enabled us to predict EC performance under real-world conditions.

Another practical goal of our research was to establish a more rigorous methodology for conducting EC research experiments. Many past EC academic studies have been conducted in batch mode – whereas practical EC systems operate in continuous flow mode. Our experiments were designed and operated in continuous flow mode and we developed a standardized flow cell that other researchers have adopted.

Related Accomplishments

Electrocoagulation (EC) is a promising pretreatment technology, especially for small-scale desalination systems for which conventional chemical coagulation (CC) can be impractical to implement and maintain. But uncertainties in the fundamental electrochemical processes that control EC performance, as well as explanations for other reported treatment benefits (e.g. virus inactivation, softening and silica removal) have impeded the adoption of EC by treatment system designers. To some, EC still seems a "black art". Our main accomplishment in this 1-year "seedling" project was to establish some rigorous foundational understanding of the processes that control EC performance and optimization.

Opportunities for Further Research

Our project points to several important new areas for further investigation. EC has also been claimed to be effective for partial removal of hardness and silica – two very challenging pretreatment objectives that are not accomplished with chemical coagulation. We confirmed the effectiveness of aluminum EC for hardness and silica removal, but further study (now underway in our group) will illuminate the specific chemical reactions responsible and where these problematic scale-forming constituents end up in the EC process. The role of trace organics in the EC process is also an important frontier requiring investigation.

Overall, our project significantly advanced the understanding of EC as a reliable, deterministic water treatment process and confirmed that there are some treatment objectives for which EC will be significantly superior in cost and performance to conventional chemical coagulation, especially for small-scale, autonomous, electrically-driven treatment trains.1,2

Publications and Reports

1. Liu, Y.-H. et al. Electroprecipitation Mechanism Enabling Silica and Hardness Removal through Aluminum-Based Electrocoagulation. ACS ES&T Engineering (2022).
2. Jang, G. G., et al. Neutron Tomography of Porous Aluminum Electrodes Used in Electrocoagulation of Groundwater. Frontiers in Chemical Engineering, vol. 4, (2022).

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