Title: Flow Electrolyzers for Reaction Scaling

Author: Rachel N. Gaines

Affiliation: Department of Chemical and Biomolecular Engineering, University of Illinois Urbana-Champaign, Urbana, Illinois, United States

Email: rgaines3@illinois.edu

Main text:

Electrocatalytic reactions for the sustainable production of fuels and chemicals have been extensively studied in batch reactors, which provide insight on reaction mechanisms for development of advanced catalysts. However, scaling of electrocatalytic reactions requires use of large-scale, operationally-complex reactors known as membrane electrode assemblies (MEAs). Reaction kinetics, mass transport, and other fundamental reaction engineering parameters vary between batch reactors and MEAs. As a result, reaction conditions have to be reoptimized during scale-up.

Translation of information between batch reactors and MEAs can be done using macroscopic reaction engineering in benchtop-scale flow electrolyzers (FEs). FEs are derived from laminar-flow fuel cells and are modular, with parts that can be added or removed depending on the reaction and phenomena under investigation. For example, gas flow channels can be sealed when only liquid-phase reactions are of interest, and liquid flow channels can be removed when only gas-phase reactions are of interest. Generally, FEs have two current collectors made of a conductive metal (commonly stainless steel) that double as gas flow channels. Potentiostat leads are attached to the current collectors and can be configured in two-electrode (pictured) or three-electrode configurations, enhancing translatability of results from batch reactors while allowing for monitoring of full-cell performance parameters. Liquid-flow channels are separated by an ion-exchange membrane to limit crossover. The gas flow channels are separated from the liquid-flow channels by an electrode, which completes the circuit by contacting both the current collectors and the electrolyte.

A variety of electrochemical tests can be performed after setup, depending on the goals of the study. For example, macroscopic reaction engineering might require application of a pre-experiment cyclic voltammetry characterization and conditioning protocol, followed by application of chronoamperometry or chronopotentiometry to evaluate the reaction over time, and lastly a post-experiment voltametric characterization protocol. Electrochemical results (such as current density) can be combined with product analysis from chromatography or spectroscopy (such as Faradaic efficiency) to understand the reaction conditions. These conditions can then be correlated to fundamental engineering parameters, and improved prior to full scale-up.

Mechanism and catalyst development in batch reactors can be investigated in FEs prior to full scale-up in MEAs. For example, FEs are being used to optimize operating conditions for complex waste streams, such as the electroreduction of carbon dioxide in mixed-gas feeds and electrooxidation of waste biomass. Further work developing non-dimensional numbers describing the changes in mass transport and reaction kinetics between batch reactors, FEs, and MEAs could provide higher throughput of optimization and scaling of electrocatalytic reactions producing sustainable chemicals and fuels.

Competing Interests: The author declares no competing interests.