Method Development for the Analysis of Electrochemical and Transport Processes in Redox Flow Batteries at Practical Operating Conditions

by

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Technical Summary:

At high penetration levels, intermittent energy sources can destabilize current grid infrastructure, but their pairing with energy storage systems can ameliorate this issue through the storage of energy during times of high production and releasing energy at times of low production. Redox flow batteries (RFBs) are nascent electrochemical energy storage technology which utilize liquid-phase charge storage materials, enabling circumvention of some scaling challenges associated with conventional enclosed batteries (e.g., Li-ion, Pb-acid). Merits of these flow systems, including simplified manufacturing, inherent safety aspects, and the potential for cost savings on reactor components, make them very promising as technical symbionts with emerging intermittent sources of renewable energy. In particular, use of a flowable redox-active material enables infinite capacity per unit of reactor area, contrasting both Li-ion and Pb-acid, where the resistance contributions from spatially anchored components limit the practical electrode thickness, effectively bounding the energy-to-power ratings of these enclosed systems. Use of a liquid-phase charge storage material also allows the system energy capacity to be scaled with tank volume; whereas, the system power can be scaled independently via adjustment of the reactor area for a specified application. At present, commercial installations of flow batteries are still limited, and few system chemistries have advanced sufficiently to merit their scaled installation within the near-term.

The focus of this thesis is the development and assessment of techniques for the analysis of electrochemical and transport processes in RFBs at moderate to high active species concentrations under direct current conditions. At its core, all thesis projects are aimed at enabling the development of component descriptions that enable material properties (e.g., viscosity, conductivity), geometry (e.g., flow field design), and operating parameters (e.g., flow rate, current density) to be directly related to battery performance metrics, such as cycle efficiencies and area-specific resistance. The investigation is divided into three primary projects: the development and assessment of a research-scale flow cell; measurements of mass-transfer coefficients; and integration of a polarization model into a standalone application which can be used to assess system performance.

The research-scale flow cell is developed with validation material from industrial collaborators and the performance of the 2.55 cm^2 is consistent with that of the larger cell, but its smaller design enables material assessment investigations as only 10 mL of redox active electrolyte (RAE) is needed per side of the cell. Mass-transfer coefficients are then measured using this cell with a well-behaved RAE, in which glucose is added in various amounts to modify the system

viscosity with minimal changes to other material properties. The results or methodology presented could be extended other similar systems either as preliminary estimates of mass-transfer performance or as a protocol for carefully evaluating new system parameters on mass-transfer. The third project then incorporates the results of this mass-transfer analysis into a standalone application, which can be used to estimate stack or cell performance as a function of these key properties of interest.

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