

AP2XX Electrochemical Engineering Final Project: Design a Flow Battery

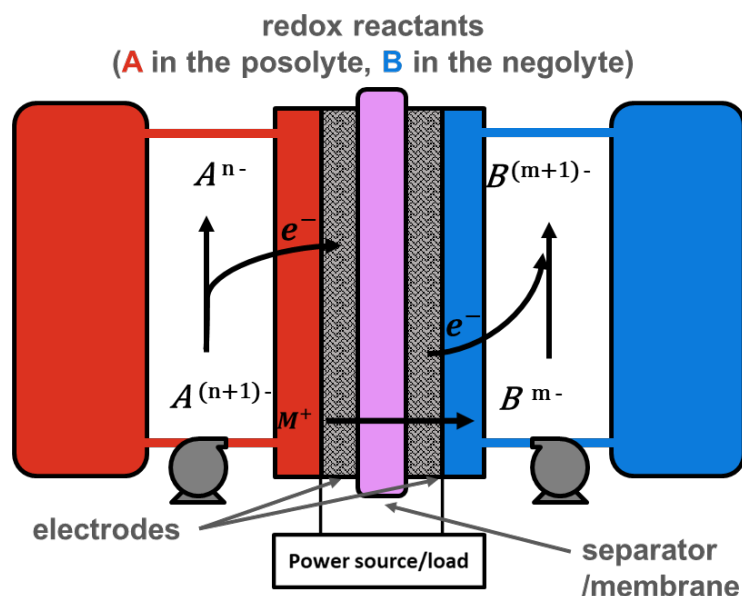
Over the course of this semester, you have learned the principles underlying the performance of electrochemical devices: electrochemical potentials; potential-dependent electrochemical reaction kinetics; mass transport phenomena under external electric fields. You have also analyzed case studies of different electrochemical systems for applications in energy and sustainability. **In this capstone project, you will apply your fundamental knowledge and engineering skills developed over the semester to design and test an electrochemical energy storage technology: the redox flow battery.**

Redox Flow Battery Background

Large scale energy storage plays an important role in decarbonization efforts, because the transition to intermittent sources of renewable energy (solar and wind) must be coupled with an expansion of energy storage to maintain stable supply of energy at the times when energy is most in demand. For example, energy demand peaks close to nightfall when many workers return home, turn on the lights, cook, et cetera, which is when solar energy is unavailable.

Redox flow batteries (RFBs) are of particular interest because their unique architecture is specialized for long-duration, large-scale energy storage. In an RFB, the redox active material is dissolved in liquid electrolyte: positive and negative redox reactants comprise the “posolyte” and “negolyte” respectively. The electrolytes may be stored in massive reservoirs and pumped to an electrochemical stack of membranes and porous electrodes, where charge/discharge reactions take place. Because the volume of the electrolyte reservoirs and the area of the stack may be scaled independently, the energy to power ratio of an RFB, i.e. the duration of discharge, may be chosen based on the needs of a given deployment.

A variety of electrolyte compositions and redox reactants have been developed as candidates for RFBs. **As part of this project, you and your team will down-select candidates for performance evaluation in your own lab-built flow battery.**



Assignment Overview

In this project, you and your team (2-4 students) will select among candidate redox reactants through literature review, measure the properties (redox potential, diffusion coefficient, electrochemical reaction rate constant) of selected candidates, down-select to one posolyte and one negolyte, and then evaluate the performance in a lab-scale flow cell. Each of these steps is broken into sub-assignments that, taken together, will build up to your final report.

PART 1: Materials Selection

You and your team will review the list of available candidates (Appendix A of the assignment handout), sort them into negolyte and posolyte candidates (you and your team will have to decide how to do this – *hint: look into reported redox potentials of the candidate species*), and select two posolyte and two negolyte reactants to evaluate in PART 2. Submit a brief report (no longer than one page including no more than one figure), along with the members of your team and your group's availability for scheduling the two lab components, at the form provided [here](#), by **Tuesday 4/9**. A member of the teaching staff will meet with your team individually in class on **Thursday 4/11** to finalize your electrolyte choices before moving on to the lab components of the project.

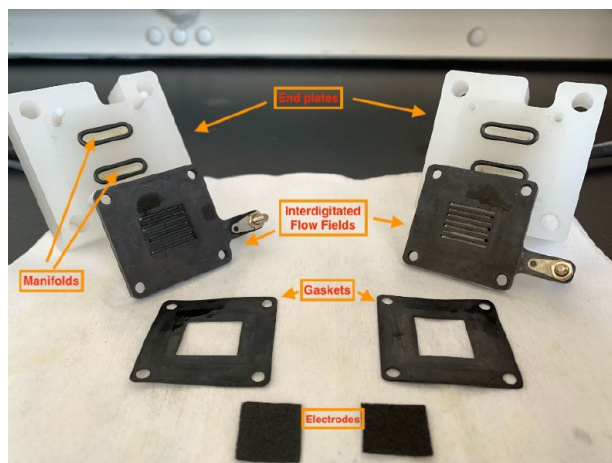
PART 2: Cyclic Voltammetry

This portion of the project involves one 90-minute lab session at the Active Learning Labs in the Allston SEC, for which all team members must be present. The Active Learning Lab staff will prepare your four electrolyte candidates, for your evaluation with cyclic voltammetry. It is recommended to review the *Practical Beginner's Guide to Cyclic Voltammetry* resource on Canvas, as well as lecture notes from class on Thursday 4/4. Bring a flash drive or use email/Dropbox/Google Drive to take home data to analyze. You and your team will analyze the cyclic voltammetry data using the `CVsim` Jupyter notebook, download link provided [here](#). Instructions for making your own local copy of the notebook in Google Collab are provided in Appendix B of the assignment.

You will fit the experimental CV data with `CVsim`, following the instructions in the notebook. Print your completed notebook as a .pdf (Appendix B), which will include a discussion of your four candidates properties (redox potential, diffusion coefficient, electrochemical reaction rate constant), comparison to literature values, and selection and justification for your negolyte and posolyte (one each) for the flow cell polarization lab (PART 3); submit the document on Canvas.

PART 3: Flow Cell Polarization

This portion of the project involves one 2-hour lab session at the Active Learning Labs in the Allston SEC, for which all team members must be present. In the lab, you will build a redox flow battery cell utilizing your chosen electrolytes. You will measure the open-circuit potential, the maximum theoretical voltage the battery can deliver upon discharge. Further, you will measure voltage as a function of applied current density, enabling you to determine maximum power output of the battery. **Complete experimental protocol for flow cell assembly and testing will be provided as an additional PART 3 Lab handout.** A photo of the flow cell setup is provided below:



Plotting the experimental data as voltage vs. current, you will construct a polarization curve for the redox flow battery designed by you and your team. Then, you will break the polarization curve into contributions of ohmic resistance, electrochemical reaction kinetics, and mass transport limitations. To do this, review the **ideal polarization model derived in Problem Set 6**. As model inputs, you will use the kinetic rate constants and diffusion coefficients of your redox reactants measured in PART 2, and cell resistance and open circuit potential measured in PART 3. Determine which electrolyte, posolyte or negolyte, has a more significant impact on cell polarization – which side of the battery incurs the largest **overpotentials**? Compare the results of the model to the experimental data and consider sources of discrepancy. All of these results will be synthesized in your **final report**.

Final Report

To culminate your efforts designing, testing, and analyzing a redox flow battery, you and your team will submit one written report in the style of an academic journal article – see for example the formatting guide supplied by *The Journal of the Electrochemical Society* linked [here](#).

Your report must include the following sections: introduction (motivate the research topic and scientific approach, citing relevant literature), methods (both theoretical and experimental), results and discussion (the most substantial part, see requirements below), and conclusions.

In your results and discussion, please include:

- ✓ Cyclic voltammograms with `CVsim` fits of four redox reactant candidates, and results for redox potential, kinetic rate constant, and diffusion coefficient, from PART 2
- ✓ Experimental polarization curve of PART 3 flow battery
- ✓ Measured ohmic resistance of PART 3 flow battery
- ✓ Ideal polarization model of the flow battery using inputs from PART 2
- ✓ Discussion of battery performance – what are the most significant overpotentials and why? Cite relevant literature here.
- ✓ Discussion of errors between experiment and theory, and comparison to literature results (if relevant)
- ✓ Given your results, how can this redox flow battery be improved? Consider proposed directions for further research