Vanadium Pentoxide Cathodes in Aqueous Zinc Ion Batteries

Alexander Braga, YSP Student, *John D. O'Bryant School of Math and Science*
Tarun Kannan, YSP Student, *Acton-Boxborough Regional High School*
Surafel Mustefa Beyan, Department of Chemical Engineering, *Northeastern University*
Professor Joshua Gallaway, Department of Chemical Engineering, *Northeastern University*

Northeastern University College of Engineering

Northeastern University Michael B. Silevitch and Claire J. Duggan Center for STEM Education

Abstract

With inconsistent renewable energy sources increasing in investments and production, there is a need for efficient and safe grid storage solutions (batteries). Current market options (lithium-based batteries) rely on non-readily available materials and can be extremely dangerous and costly. During our time, our goal was to determine how variations in cathode preparation techniques and electrolyte concentration affect cell performance. We determined that higher concentrations of $ZnSO_4$ resulted in higher achievable specific capacity across all cathode preparation methods. Additionally, we observed the greatest consistency and data quality when using ball milling, the vacuum oven, and a sieve to prepare the V_2O_5 active material.

Background

The increased usage of renewable energy sources directly correlates with demand for safe, low-cost grid energy storage systems. Lithium-ion batteries are the current standard, yet rely heavily on expensive and limited materials. Vanadium pentoxide as a cathode material has proved promising but still falls short of industry standards. Current research is trying to improve V_2O_5 but has high costs and manufacturing complexity. Our research investigates and optimizes the compound by reducing particle size and improving processing techniques to determine whether battery performance can be enhanced using simpler, more scalable methods. It is hypothesized that these modifications will improve specific capacity and cycle stability, making V_2O_5 a more practical and cost-effective cathode material for grid-scale energy storage.

Cell Composition

- Negative Cap — ➢ Forms base of the coin cell (Negative Terminal)
- Spring — ➢ Maintains constant pressure, ensuring contact between components
- Spacer — ➢ Evenly distributes pressure throughout cell
- Zn metal — ➢ Anode where oxidation occurs during discharge
- Separator (Glass Fiber) — ➢ Prevents short-circuiting; allows ions to pass
- Cathode — ➢ Prepared V_2O_5 cathode, site of reduction.
- Spacer — ➢ Evenly distributes pressure throughout cell
- Positive Cap — ➢ Top of the coin cell (Positive terminal)

Experimental Methods

Active Material Preparation:

Goal: reduce V_2O_5 particle size and improve electrode preparation

- Trial 1: FlackTek + SS mixing media → grainy and imperfect cathode
- Trial 2: Added 212 µm sieve + vacuum oven → smoother, but not perfect
- Trial 3: Swapped to ball milling + zirconia balls → smoothest and most stable

Cathode & Cell Preparation:

Combine V_2O_5, acetylene black, and PVDF → FlackTek w/ 8 SS balls (• 30 minutes) → Coat w/ DoctorBlade (• 20µm foil, 150µm clearance) → Dry on heat plate (• 30 minutes at 60°C) → Dry in vacuum oven (• 960 minutes at 80°C) → Punch cathodes w/ die press → Flatten cathodes with metal cube → Assemble cell + seal with crimper

FlackTek | Ball Milling

Electrolyte:

Compare different molar concentrations of $ZnSO_4$: 0.5 M, 1.0 M, and 2.0 M

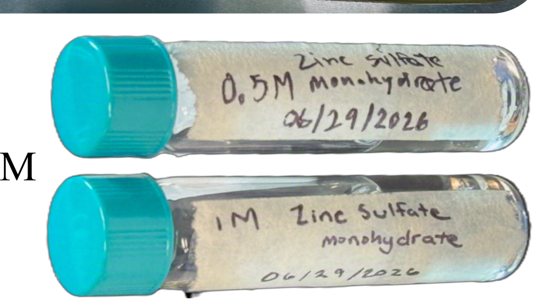
Electrochemical Analysis:

- Galvanostatic charging and discharging (cycling) in ARBIN
- Cyclic Voltammetry with BioLogic
- Potentiostatic Electrochemical Impedance Spectroscopy (PEIS) with BioLogic

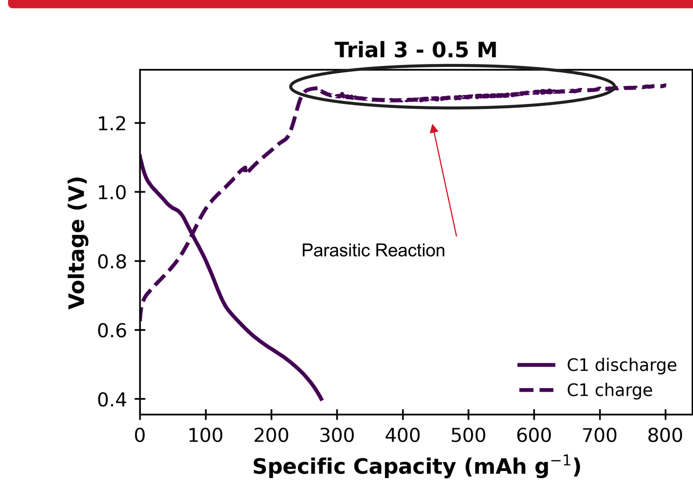
Auxiliary Materials:

FlackTek, Ball Mill, ARBIN, Python/Spyder, Vacuum Oven, Micropipettes, Balance, Heat Plate, Rolling Press, Electric Crimper

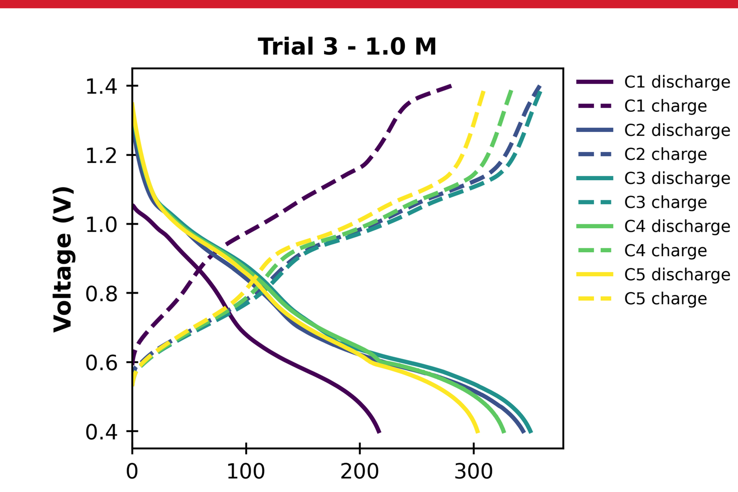
Electrolytes: 0.5 M and 1.0 M

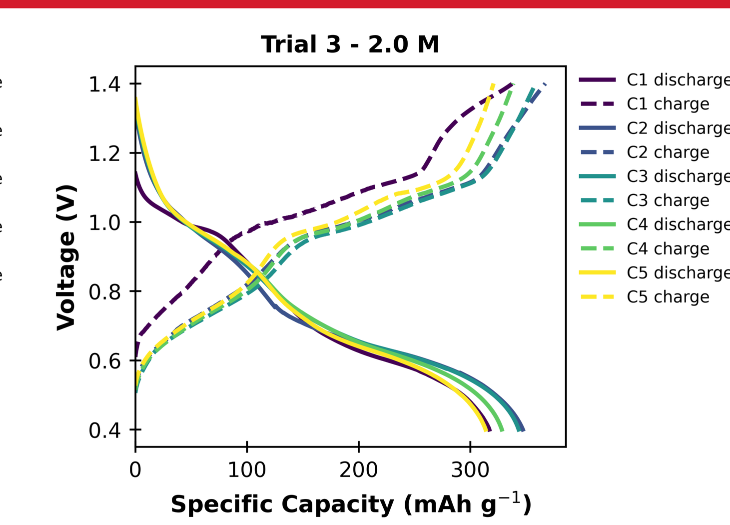


Results

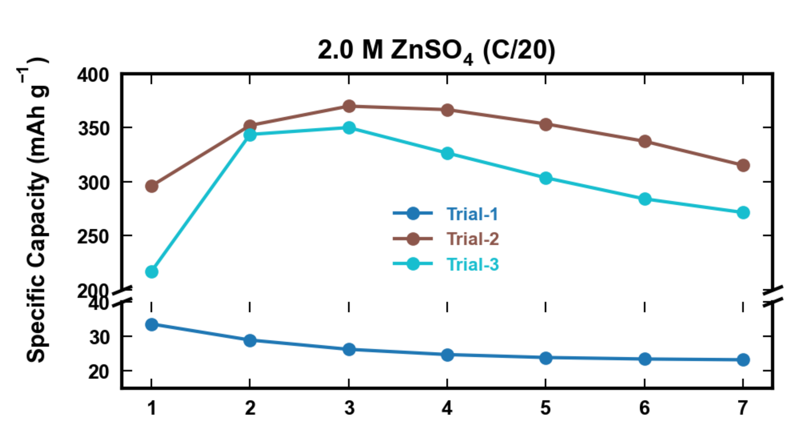


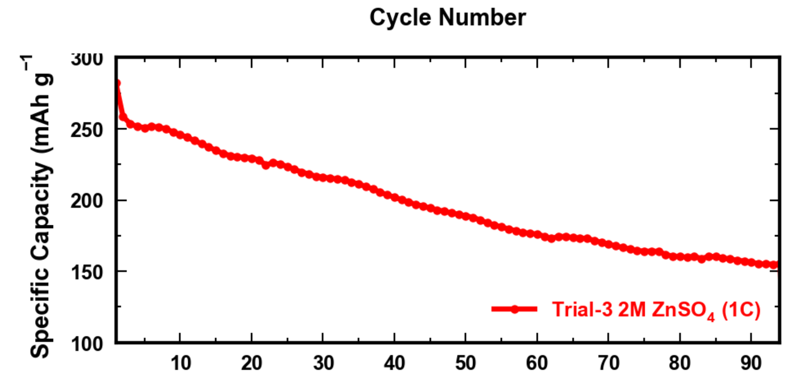
0.5 M allows for Parasitic Reactions, which inhibit Zn intercalation



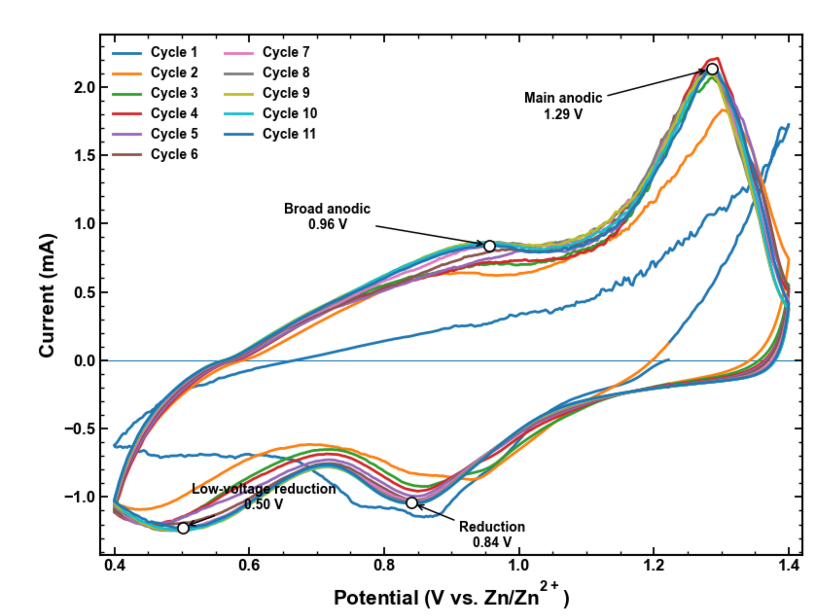


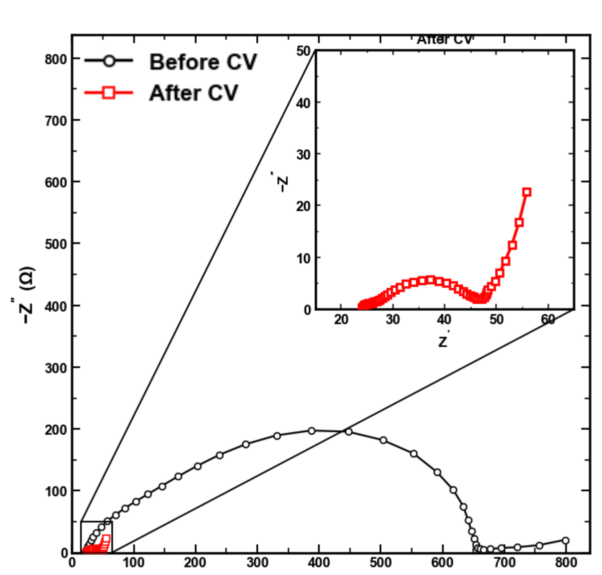
Trial 3 1.0 M and 2.0 M showed similar specific capacities, but 2.0 M exhibited a slight greater specific capacity after 5 cycles





Specific capacity decaying quickly as expected at 1C





Electrochemical performance was improved based on observed peaks. After CV, impedance was significantly less than prior.

Conclusion and Future Steps

- Improve cathode capacity by increasing $ZnSO_4$ electrolyte concentration and improving cathode uniformity
- Increasing electrolyte concentration and cathode uniformity led to higher specific capacities and consistent battery performance
- Supports our hypothesis that both electrolyte chemistry and electrode fabrication influence battery performance
- Research contributes to the development of more sustainable energy storage technologies that support greater integration of renewable energy into the grid
- Future work will focus on:
  - Testing more cells
  - Measuring longer-term cycling performance
  - Optimizing cathode preparation
  - Utilizing a 3.0 M concentration electrolyte

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