Demonstration and Optimization of Prototype Zinc-Ion Battery Pouch Cell

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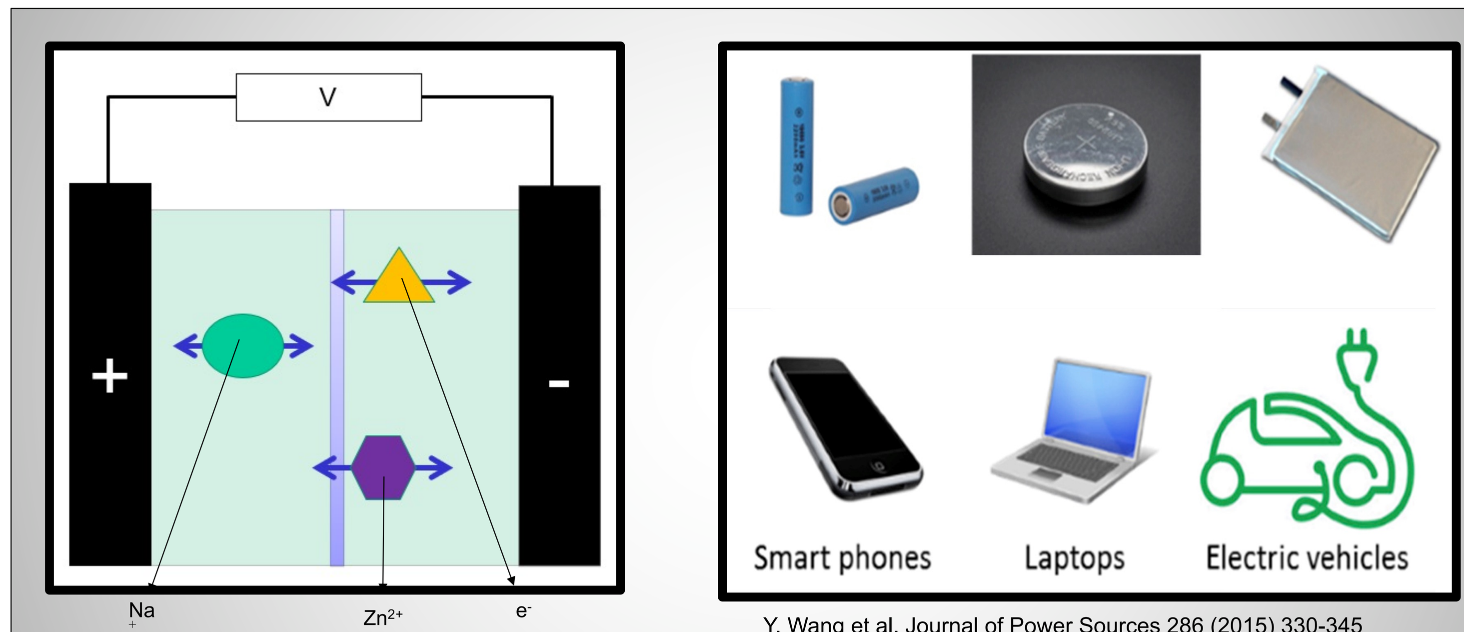
Abstract

The aqueous zinc-ion battery (AZIB) is an environment-friendly, safe, and cost-effective alternative to the lithium-ion batteries commonly used in wide range of applications. In search of an adequate cathode material for this system, sodium vanadate (NaV_3O_8) has been investigated as a candidate electrode material in Teng group in the Chemical Engineering Department at UNH. In this project, we used this material in a scaled-up production for use in prototype pouch cells (15 cm^2) with a loading of 5 mg cm^2. Slurries of NaV_3O_8 applied on a carbon paper substrate using a blade printing method. The printed NaV_3O_8 cathode and zinc anode were assembled into a stack of the zinc-ion battery pouch cell and tested at a current density of 0.01 A g-1. The chronopotentiometry measurements show the initial specific capacity of 323.54 mAh g^{-1} capacity and retention of 15% after 10 cycles. Future improvements in electrode and cell stack construction are suggested to improve the battery performance.

Introduction/Background



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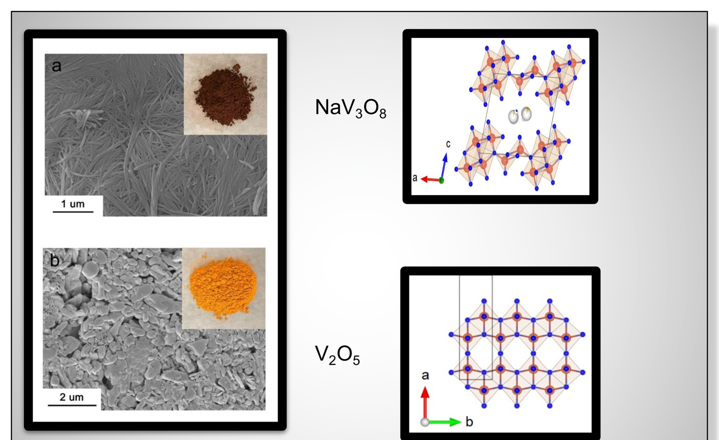
Microscopic schematic of the process occurring within the battery structure (left) to macroscopic principle and application of the purpose of the battery (right).

The aqueous zinc-ion battery (AZIB) is an environment-friendly, safe and cost-effective alternative to the lithium-ion batteries commonly used in wide range of applications. The research investigated here uses a scaled-up pouch cell battery to investigate sodium vanadate (NaV_3O_8) as a candidate for an electrode material.

Methods



SEM images of (a) NaV_3O_8 and (b) V_2O_5.

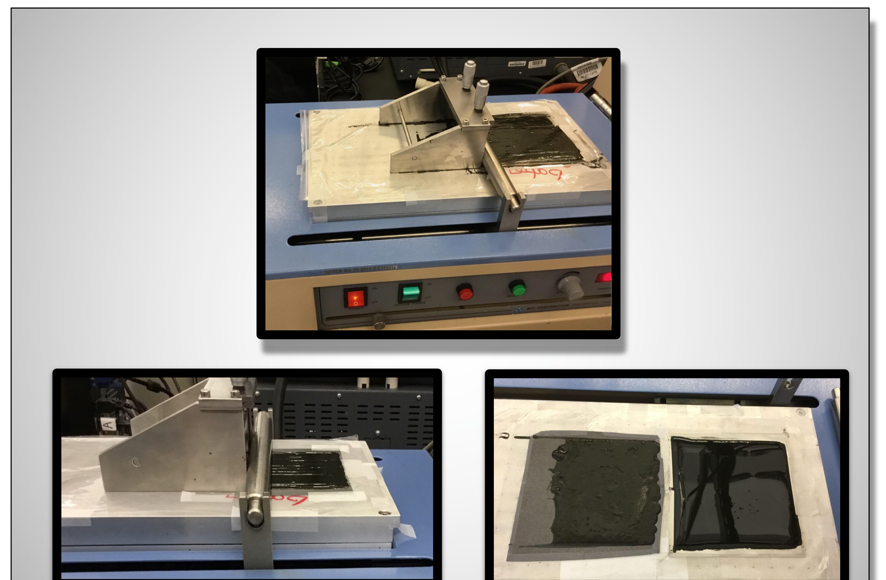
Schematic of atomic structures

Synthesized Material

Vanadium oxide (V_2O_5) was stirred with Sodium Sulfate (SO_4) for 72 hours to synthesize Sodium Vanadate (NaV_3O_8). The morphology of the NaV_3O_8 as seen in the left images (top), shows the ribbon-like structure and the receptive atomic structure that is crucial for intercalation and deintercalation of ions during the charging and discharging of the battery.

Blade printing

Using the synthesized NaV_3O_8 for the active material along with Carbon Black, CMC, SBR, and deionized water, a slurry was created to be printed on the substrate using a blade printing method. Each iteration of slurry mixture was placed on both substrates to test for optimization. The thickness of the blade printing was important for ensuring that the electrode's active material was utilized effectively.



Results

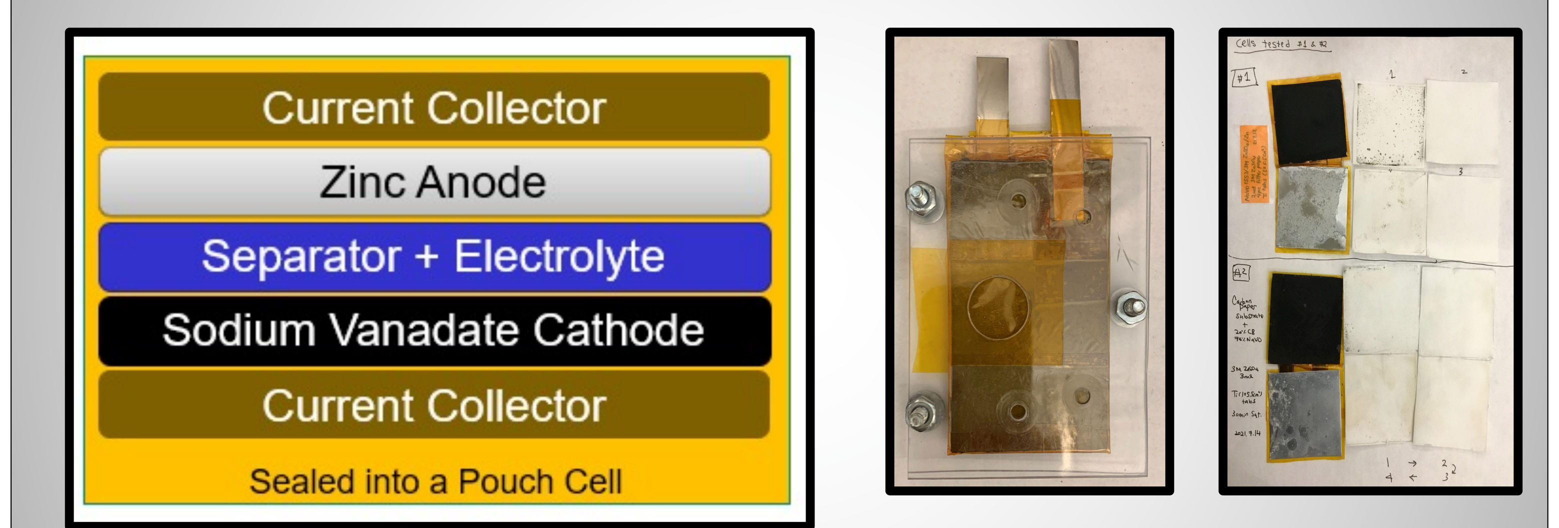
Printing

Examples of dried cathode material containing a slurry of 84 % NaV_3O_8 , 20 % Carbon Black, 4 % CMC, and 2 % SBR.

Improved cathode material containing 72 % NaV_3O_8, 20 % Carbon Black, 6 % CMC, and 2 % SBR.

The iterations of slurry recipes shown above show improved quality of the printing process when the CMC thickening agent is increased. Optimizing the content and the thickness of the blade printing is important to ensure conductivity and maximized utilization of all the active material on the cathode. The peeling from the substrate was removed by increasing the thickening agent per current research on optimization of electrodes. The 15 cm^2 pouch cell was loaded with 5 mg cm^2 of active material

Prototype Assembly



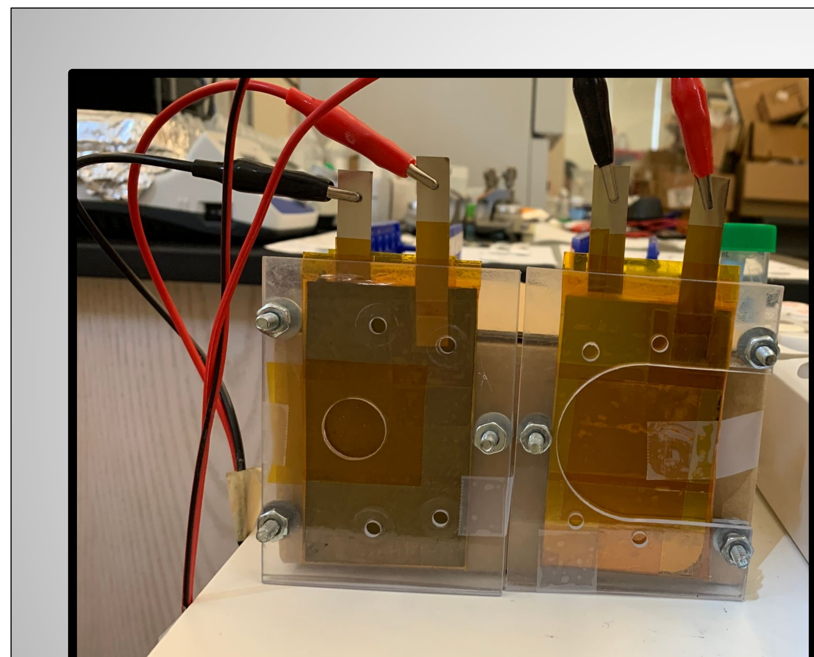
Schematic figure of pouch cell configuration

Constructed pouch cell

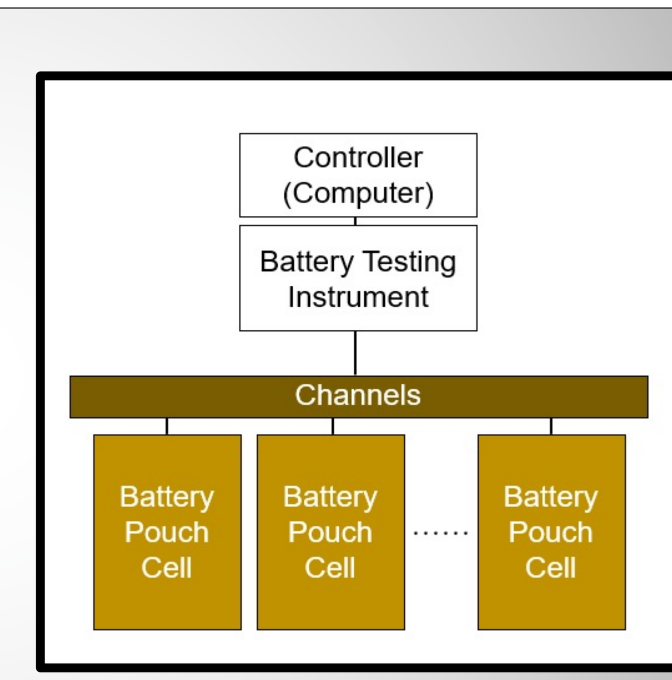
Dismantled used pouch cell

The assembly of the pouch cell is the final process in creating the prototype. This prototype is stacked starting with the printed cathode with the current collector attached. This is seen in the middle image as the tabs that are above the pouch. The separators (4) are placed on top of the cathode and the electrolyte is applied. The last thing to be placed is the zinc anode with a current collector attached. All The stacks are methodically sealed using Kapton tape to create a pouch. The pouch is then placed in an acrylic holder as seen in the middle image above. After the testing process is completed, the pouch is dismantled to for observation.

Chronopotentiometry Testing



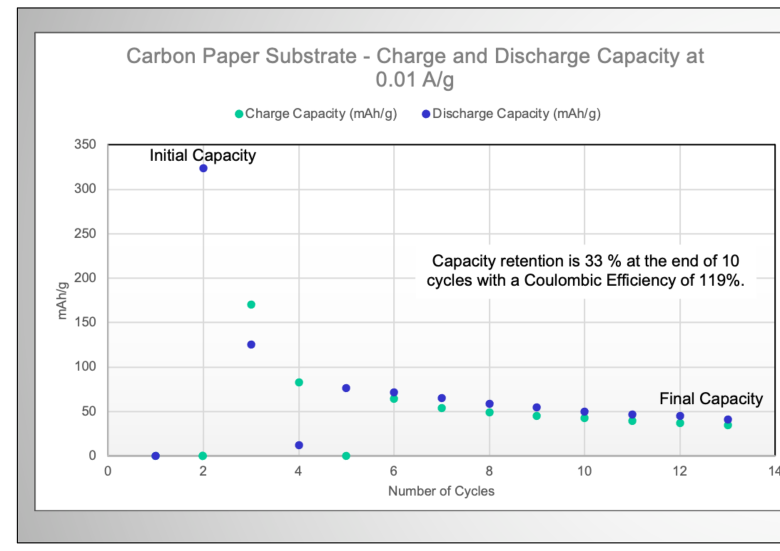
Pouch cells being testing the lab for capacity and retention.

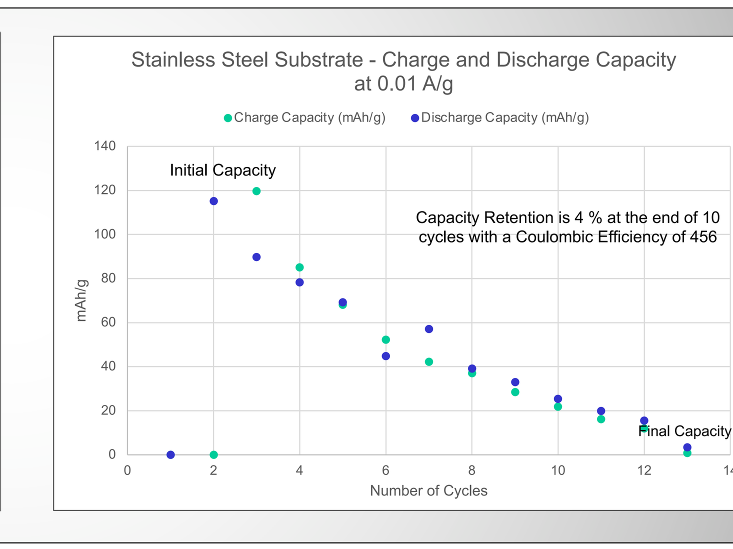


Schematic drawing of the testing of the capacity and retention of the pouch cell.

The prototype using different substrate materials were programmed with various current densities to test for capacity, retention, and Coulombic Efficiency. Depending on the battery and the current densities used, the time of this process varied. The current density was applied through the electrodes attached to the prototype and the data was collected via an excel spreadsheet.

Discussion





When the prototypes where applied a current density of 0.01 A g-1, the carbon paper substrate shows more capacity retention than its stainless-steel counterpart. The stainless-steel capacity tends to degrade quicker. The Carbon paper shows more promise with its higher initial capacity and capacity retention that has a gradual decreasing effect. Both substrates show inequalities with the Coulombic Efficiencies being higher than 100%. The discharge capacity represents the intercalation ability of the material on the cathode. Using chronopotentiometry to apply a constant current shows the batteries capacity. If the testing runs for a longer time, more energy is applied to the battery can handle more capacity per cycle.

Conclusion/Summary

Further improvement is necessary to increase the Coulombic Efficiency to have an enhanced cycle life of the battery. In order to better the Coulombic Efficiency three things must be investigated: conductivity of the cathode material, continued optimization of the slurry contents, and increased physical conductivity in the layers of the battery stack. Achieving at least a 70% retention of capacity for at least 100 cycles with a Coulombic Efficiency at or near 100% will be achieved only when all conditions are optimized.

Recent studies have been done on free standing electrodes with a combination of slurries, but without a substrate. Possible studies in the future might involve using a conductive film without the substrate to optimize battery performance.

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