PacifiCan-MMRI Accelerating Circular Economy (ACE) TechBrief Report

Project title: Electrolyte Design for Zinc-ion Capacitors as Low-cost and Durable Energy Storage Systems

Industry partner(s): Atlas Power Technologies

Researchers: Li Tao, Xuejun Lu, Keqi Qu, You Zeng, Mitchell B. Miller, and Jian Liu

Introduction & Background:

Aqueous zinc (Zn)-based electrochemical energy storage (AZEES) devices are emerging due to the high compatibility between Zn anode potential and aqueous electrolyte chemistry, satisfying the demands for low-cost, grid-level, and stationary applications. However, the consumption of high-cost electrolyte components (e.g., organic salts and solvents) and poor temperature adaptability remain challenging issues, which require low-cost, high-safety, and commercialized layouts for novel aqueous electrolytes. This work reported a nonflammable, anti-freezing, and low-concentration dual-anion urea-based (DAU) electrolyte induced by highly solubilized urea (up to 30 m) in dual-Zn salt solutions.

Relevance to Circular Economy:

This work represents an important step to develop low-cost and durable energy storage technologies from locally available resources (Zn, activated carbon) for stationary applications. The zinc-ion capacitor is environment-friendly, recyclable, and cost-effective and suitable for large-scale grid applications to promote renewable.

Methodology:

Single-anion urea-based (SAU) and DAU electrolyte systems were designed based on selected four Zn salts with different anion categories, including (SO_4^{2-}), chloride (Cl^-), acetate (OAc^-), and OTf^- in a binary mixture of water and urea. For the cathodes, ASAC-25 (purchased from Alberta, Canada), acetylene black, and PTFE binder were mixed in a homogeneous slurry by adding alcohol with a weight ratio of 8:1:1, and then the slurry was pressed on the Titanium (Ti) mesh with a disk size of 12 mm. The prepared electrodes were vacuumed and dried at 120 °C for 6 h. Cathodes (e.g., 3 × 3 and 12 × 12 cm^2) used for pouch cells were using Ti foils as current collectors. Besides, glass fiber (GF/F, Whatman) was used as separators. All electrochemical measurements including cyclic voltammetry (CV), and galvanostatic charge–discharge (GCD) were performed using a VSP-3e Potentiostat. GCD cycling ability was further tested in a NEWARE battery cycler (CT-4008T-5V50mA-164, Shenzhen, China).

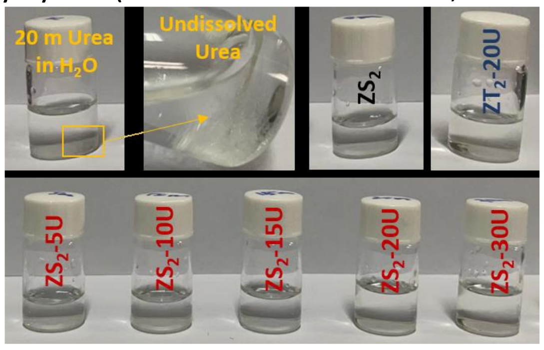

Figure 1: Images of a 20 m urea in H_2O and various SAU electrolytes.

Results & Discussion

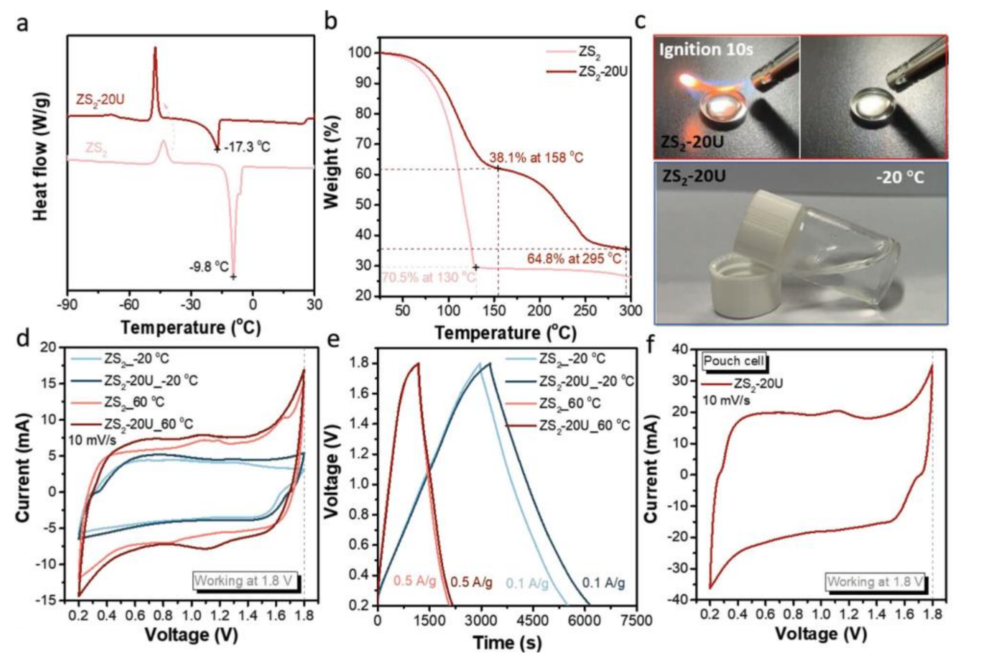

Figure 2: a) DSC scans and b) TGA curves of ZS_2 and ZS_2-20U electrolytes, respectively. c) Flammability (upper) and low-temperature storage (bottom) tests of ZS_2-20U. d) CV and e) GCD curves of ZS_2 and ZS_2-20U electrolytes operating at 60 and –20 °C, respectively. Plots of f) CV of pouch cell setups using the ZS_2-20U electrolyte.

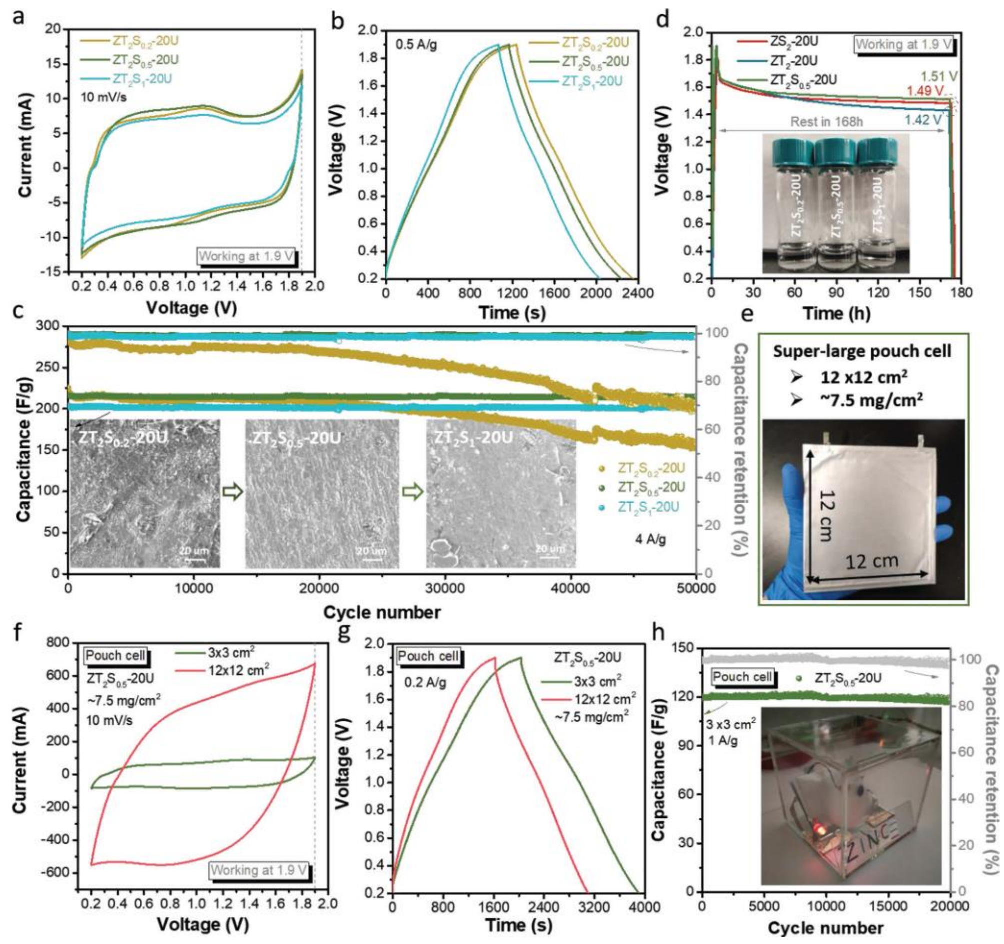

Figure 3: a) a) CV, b) GCD, and c) long-term cycling curves of various DAU electrolytes with different SO_4^{2-} anion additions. d) Self-discharge tests using ZS_2-20U, ZT_2-20U, and $ZT_2S_{0.5}$-20U electrolytes, respectively. e) Image of a super-large pouch cell setup with electrode area size of 12 × 12 cm^2. f) CV and g) GCD curves of the regular (3 × 3 cm^2) and super-large (12 × 12 cm^2) sized pouch cells using ZT2S0.5-20U electrolytes. h) Cycling performance of the regular (3 × 3 cm^2) sized pouch cell setups at a current density of 1 A g^{-1}.

$ZT_2S_{0.5}$-20U presented the super-high cycling ability over 20,000 times using the regular-sized pouch cell with ≈100% capacitance retention (Figure 3), which was capable of powering the LED light and rotating the mini-fan together. The results above have manifested the promising future of employing large-scale AZEES devices through the layout of low-cost and safe aqueous electrolytes with urea-solubilized Zn-ion storage technology and multiple anion criteria.

Conclusion & Next Steps

We proven a novel and low-concentrated urea-based electrolyte beyond single-anion selection criteria, then DAU electrolytes (e.g., $ZT_2S_{0.5}$-20U) deliver a combination of dual-salts (containing SO_4^{2-} and OTf– anions) dissolved in eutectic urea-H_2O solutions. The achieved electrolytes not only exhibit nonflammability and anti-freeze ability but also maintain excellent electrochemical performance at a low salt concentration (≈2.5 m). The regular pouch cell setups (e.g., high cathode loading mass of ≈7.5 mg cm^{-2} and area size of 3 × 3 cm^2) using $ZT_2S_{0.5}$-20U show a high capacitance of 232.4 F g^{-1} at the current density of 0.2 A g^{-1} in a range of 0.2–1.9 V, accompanying with a superior cycling stability of ≈100% capacitance retention over 20,000 cycles.

Further reading: L. Tao, X. Lu, K. Qu, Y. Zeng, M.B. Miller, J. Liu. Small, 2024, 2311205. https://doi.org/10.1002/smll.202311205