Effect of serinol as a hydrophilic organic additive for improving interfacial property and redox kinetics in VRFB positive electrolyte

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Introduction

Vanadium redox flow batteries (VRFBs) are highly promising for large-scale energy storage due to their decoupled energy and power capacity. However, the sluggish kinetics and poor thermal stability of the positive VO^{2+}/VO_2^+ redox couple lead to significant voltage losses and capacity decay. To address these challenges, this study investigates the effectiveness of serinol (2-amino-1,3-propanediol) as a hydrophilic organic additive to enhance the interfacial properties and electrochemical performance of VRFBs. The superior capability of serinol is attributed to its hydrophilic functional groups (one primary amine and two hydroxyl groups), which significantly improve the wettability of the carbon felt electrode [1]. Furthermore, the lone pair electrons on its nitrogen and oxygen atoms serve as active sites that interact with vanadium ions, facilitating the charge transfer process by lowering the activation energy.

Results and Discussion

The electrochemical properties of the VO^{2+}/VO_2^+ couple were analyzed via CV and EIS (Fig. 1, Table 1). The 0.025 M serinol-added electrolyte significantly improved redox kinetics and reversibility, reducing the peak potential separation (ΔE) from 0.675 to 0.349 V and the peak current ratio (I_{PA}/I_{PC}) from 2.907 to 2.068. EIS analysis corroborated these results, showing that 0.025 M serinol yielded the lowest charge transfer resistance (R_{ct}) of 15.811 Ω (a 9.5% reduction vs. pristine, 17.465 Ω). This enhancement is attributed to serinol's hydrophilic amine and hydroxyl groups increasing electrode wettability and providing active sites for vanadium ions [2]. Higher concentration (0.050 M) showed less improvement (R_{ct} = 16.051 Ω), confirming 0.025 M as the optimal dosage.

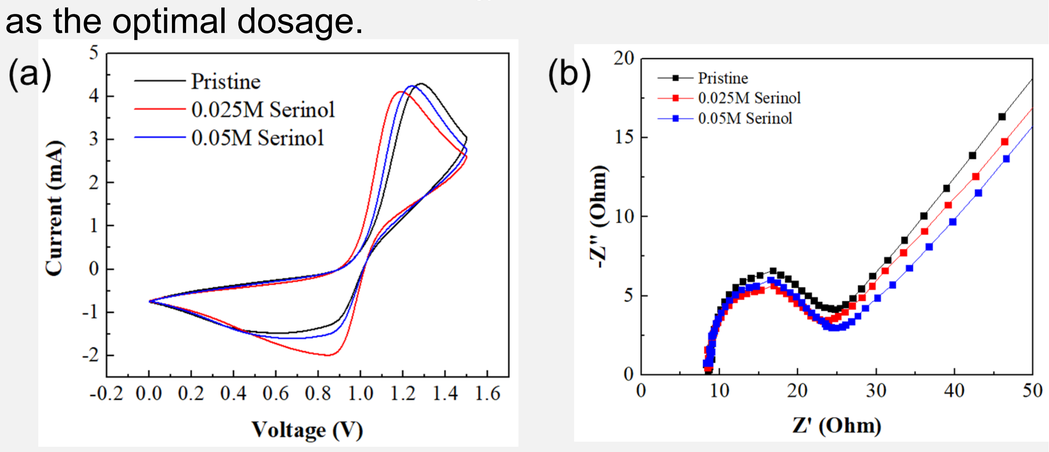

Figure 1. Electrochemical performance comparison of positive electrolyte solutions with various serinol concentrations (0.025 and 0.050 M): (a) CV curves and (b) Nyquist plots from EIS measurements.

Table 1. Numerical data of Fig. 1(a): the electrochemical performance of the $VO2^+$/ $VO2^+$ redox reaction.

Samples	I_{pa} (mA)	I_{pc} (mA)	I_{pa}/I_{pc}	E_{pa} (V)	E_{pc} (V)	ΔE (V)
Pristine	4.294	-1.477	2.907	1.286	0.611	0.675
0.025 M Serinol	4.113	-1.989	2.068	1.192	0.843	0.349
0.050 M Serinol	4.241	-1.605	2.642	1.241	0.671	0.57

Electrolyte chemical stability was evaluated via OCV measurements. Adding 0.025 M serinol extended the self-discharge time to a 0.8 V cutoff from 163 to 204 hours. This 24.5% increase confirms that serinol stabilizes positive VO_2^+ species and mitigates self-discharge. This is attributed to serinol's polar amine and hydroxyl groups forming a stable coordination environment with vanadium ions, which suppresses crossover and enhances thermal stability.

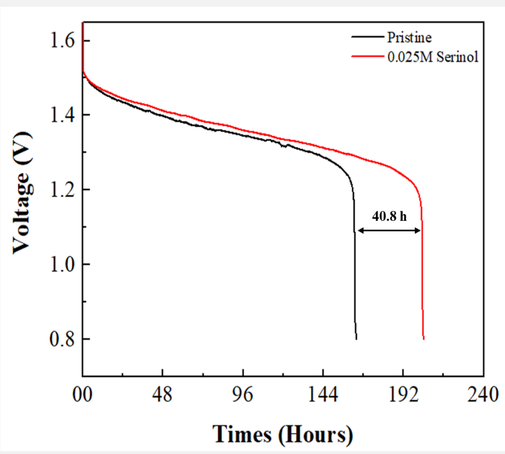

Figure 2. OCV curves for the pristine and 0.025 M serinol-supported electrolytes.

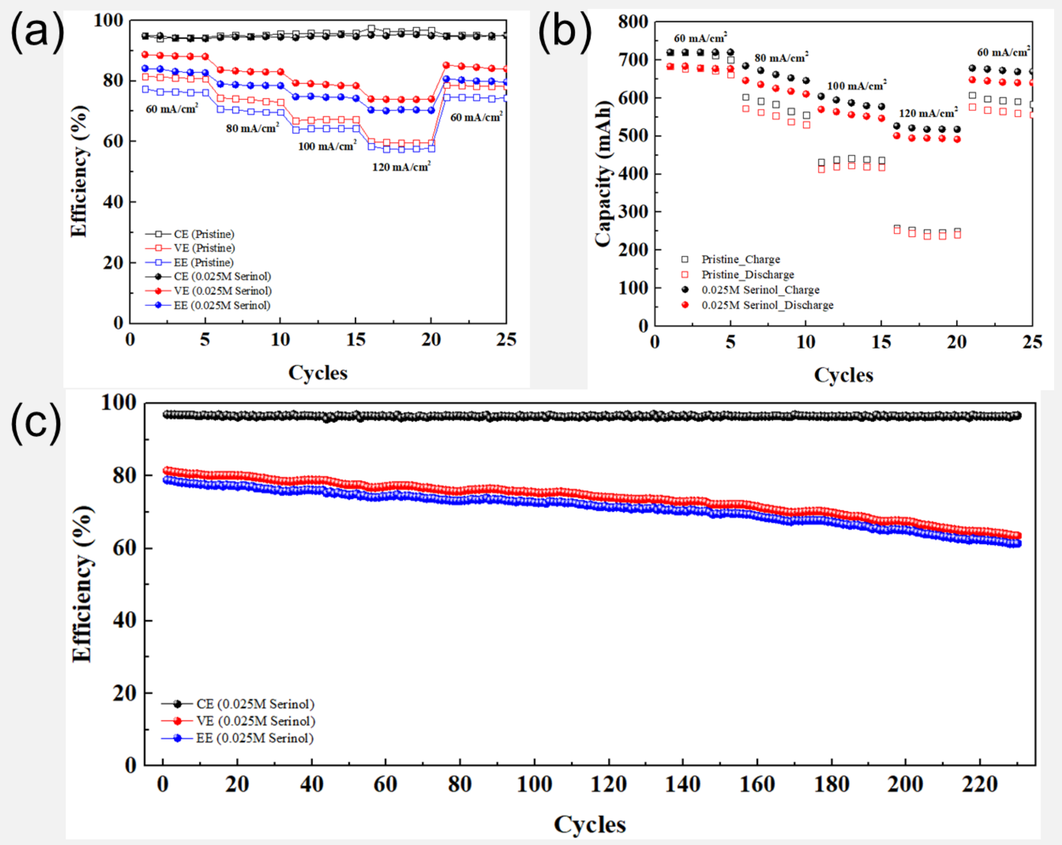

Figure 3. Performance comparison of the pristine and 0.025 M serinol-supported electrolytes under various cell operation tests: (a) cycle performance and (b) capacity of rate capability tests and (c) long cycle performance.

Full-cell tests evaluated the practical stability and rate capability of the serinol additive from 60 to 120 mA/cm² (Fig. 3(a), (b)). At a high current density of 120 mA/cm², the 0.025 M serinol-supported electrolyte achieved an energy efficiency (EE) of 70.39% and a voltage efficiency (VE) of 73.96%, significantly outperforming the pristine cell (EE: 57.77%, VE: 59.73%). Moreover, its discharge capacity at 120 mA/cm² was more than double that of the pristine one (495.11 vs. 242.40 mAh), confirming reduced overpotential and accelerated redox kinetics during high-rate operation. Long-term cycling over 220 cycles (Fig. 3(c)) demonstrated remarkable stability, maintaining high average efficiencies (CE: 96.45%, VE: 74.24%, EE: 71.6%) and mitigating capacity decay over extended operation.

Conclusion

Serinol was successfully implemented as a hydrophilic additive to enhance VRFB performance and stability. The introduction of 0.025 M serinol significantly improved VO^{2+}/VO_2^+ redox kinetics, reducing peak potential separation (ΔE) by 48% and charge transfer resistance (R_{ct}) by 9.5%. OCV tests confirmed mitigated self-discharge, extending voltage retention by approximately 40 hours. Furthermore, full-cell evaluations demonstrated superior rate capability at high current densities and maintained a high average energy efficiency of 71.6% over 220 cycles. These findings suggest serinol as a promising additive to overcome kinetic and stability limitations in VRFBs for efficient large-scale energy storage.

Acknowledgements

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