Design and Implementation of a Test Stand for Temperature -Dependent Performance Analysis of Iron/Iron Redox Flow Batteries

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Motivation

Why IRFBs?
Cost-effective, safe, and environmentally sustainable energy storage [1].

Temperature Influence
Influences redox kinetics, efficiency, and hydrogen evolution.

Research Gap
Well-studied for vanadium/zinc-bromine RFBs [2], but limited for IRFBs.

Known & Unknown
Iron electrodes show up to 97.9% CE at 60 °C in electrochemical baths [3]. Very few practical, full-cell IRFB temperature studies.

Objective
Investigate IRFB temperature effects on redox kinetics, hydrogen recombination, and cycling efficiency using a custom test stand.

Experimental Procedure

Test Stand: Temperature-controlled setup with integrated recombination cell and independent heating for the flow cell and storage tanks (see Fig. 1).

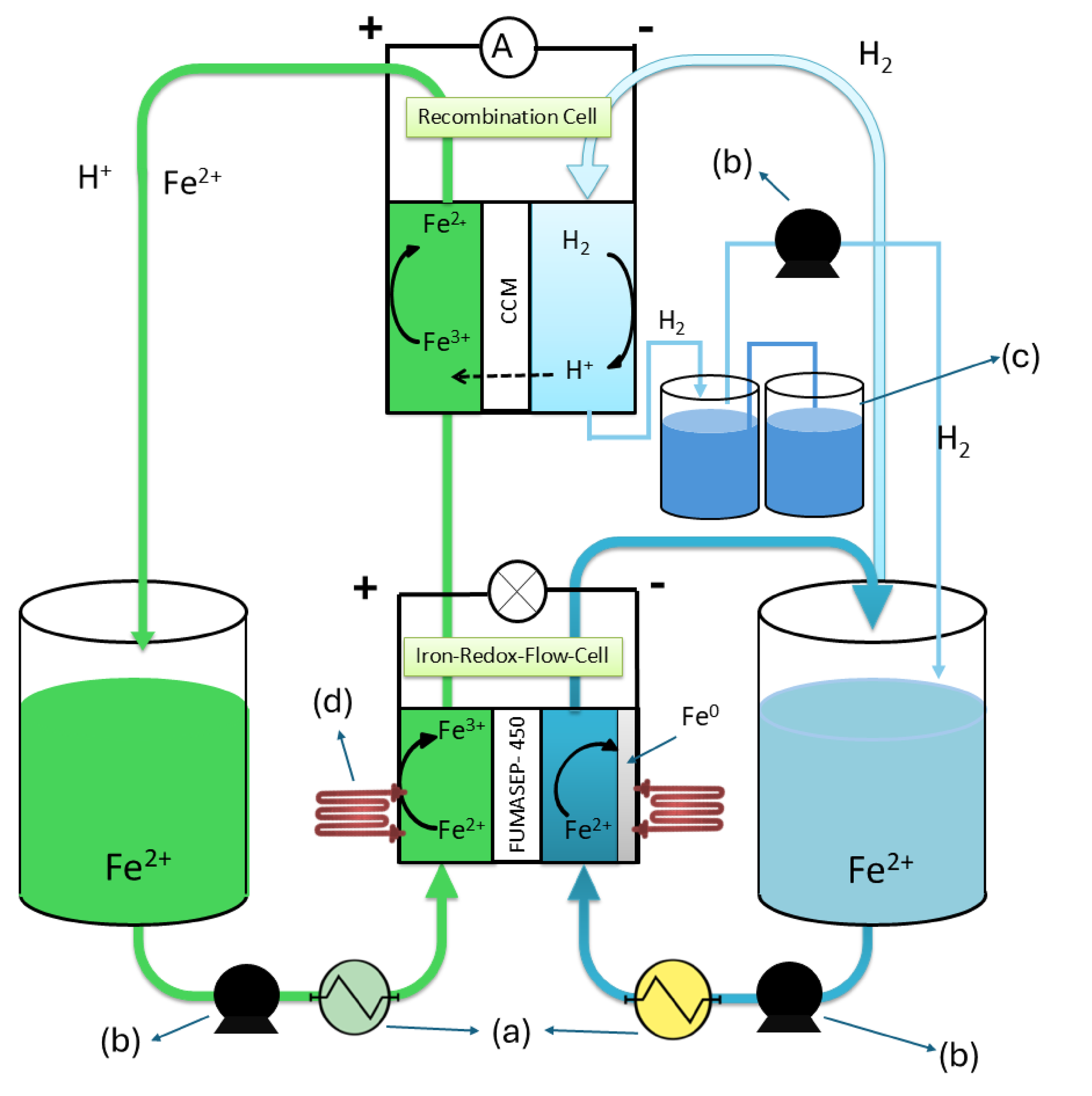
Electrolyte Composition: 1.5 M $FeCl_2$ + 2 M NH_4Cl + 0.2 M HCl used in both tanks (150 mL per side).

Cycling Conditions: Fe/Fe cell (40 cm²) cycled at ±25 mA·cm⁻² for 25 cycles with 1h charge/discharge and 5 min rest intervals; theoretical capacity: 6.10 Ah (20.25 Ah·L⁻¹).

Hydrogen Recycling: Excess hydrogen from the recombination cell was redirected to the negative tank to preserve acidic conditions.

Cyclic Voltammetry (CV): Graphite working electrode (Ø 3 mm, 0.07 cm²); scanned from −1.1 V to +0.75 V at 20 mV·s⁻¹ vs. Ag/AgCl (3 M NaCl, +0.195 V vs. RHE).

Morphological Analysis: Graphite rods held at −1.2 V in Fe^{2+} electrolyte revealed temperature-dependent iron plating behavior using a tape-masked design.



Positive Electrode:	$Fe^{2+}_{(aq)} \rightleftharpoons Fe^{3+}_{(aq)} + e^-$	$\phi^{0,+}$	= +0.77 V	(1)
Negative Electrode:	$Fe^{2+}_{(aq)} + 2e^- \rightleftharpoons Fe_{(s)}$	$\phi^{0,-}$	= - 0.44 V	(2)
Overall Reaction:	$3\,Fe^{2+}_{(aq)} \rightleftharpoons Fe_{(s)} + 2\,Fe^{3+}_{(aq)}$	ϕ_{cell}	= 1.21 V	(3)
Parasitic Hydrogen Evolution:	$2\,H^+_{(aq)} + 2\,e^- \rightarrow H_{2\,(g)}$	$\phi^{0,-}$	= 0 V	(4)

Figure 1. Schematic diagram of an Iron/Iron redox flow cell setup. a) Heating hoses, b) pumps, c) back pressure tanks, d) Cartridge heaters.

Results

Cyclic Voltammetry (CV) & Morphology studies

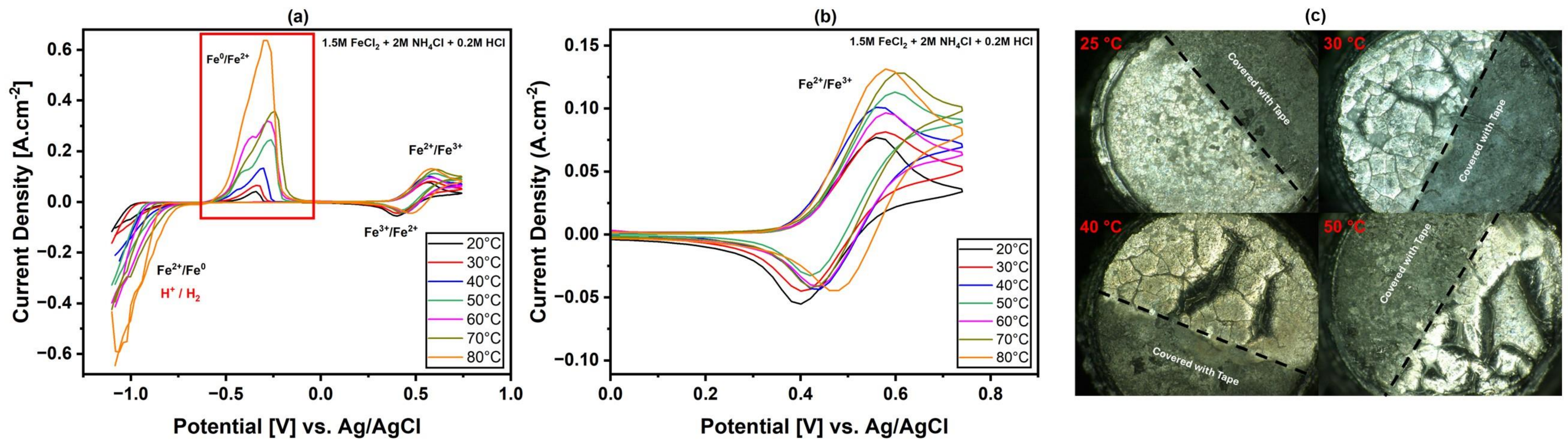


Figure 2. Cyclic voltammetry (CV) curves of the Fe/Fe electrolyte recorded using a graphite working electrode (area: 0.07 cm²), Pt counter electrode, and Ag/AgCl reference electrode. (a) Full potential range of CV curve. (b) Enlarged anodic region showing the effect of temperature on Fe^{2+} oxidation kinetics, (c) Optical microscopy images of graphite electrodes after potentiostatic holding at -1.2 V in the Fe^{2+} electrolyte at different temperatures.

Redox kinetics improve with temperature

- Higher CV peak currents and reduced overpotentials indicate improved Fe^{3+}/Fe^{2+} and Fe^{2+}/Fe^{0} reaction kinetics with temperature.

Morphology indicates stress and growth behavior

- At 40–50 °C, iron deposition showed cracking and faceted grain growth, suggesting plating stress and increased adatom diffusion.

Battery performance at varied temperatures

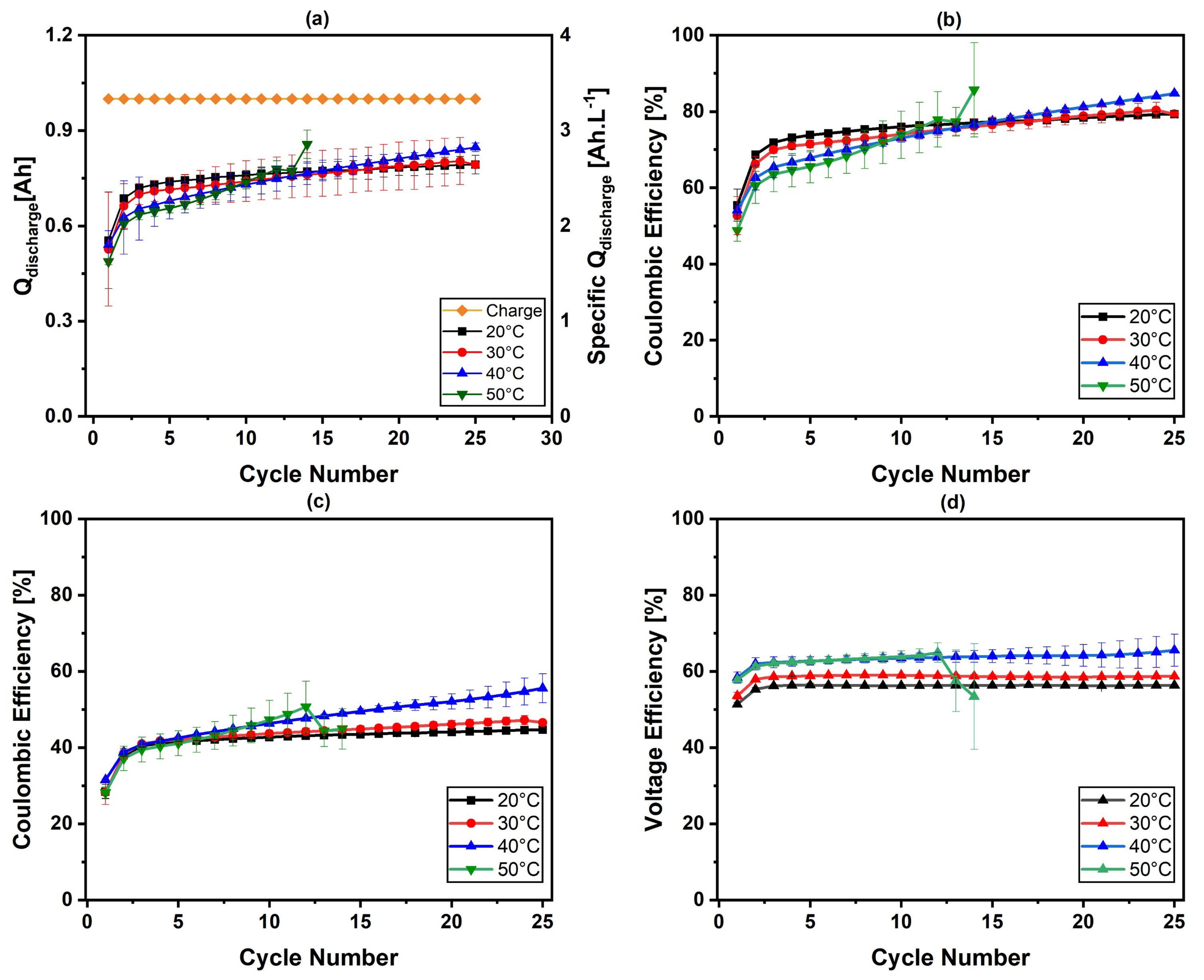


Figure 3: (a) discharge capacity/ specific discharge capacity vs cycles, (b) coulombic efficiency vs cycles, (c) energy efficiency vs cycles, (d) voltage efficiency vs cycles. All experiments are the mean of two experiments with standard deviations at room temperature.

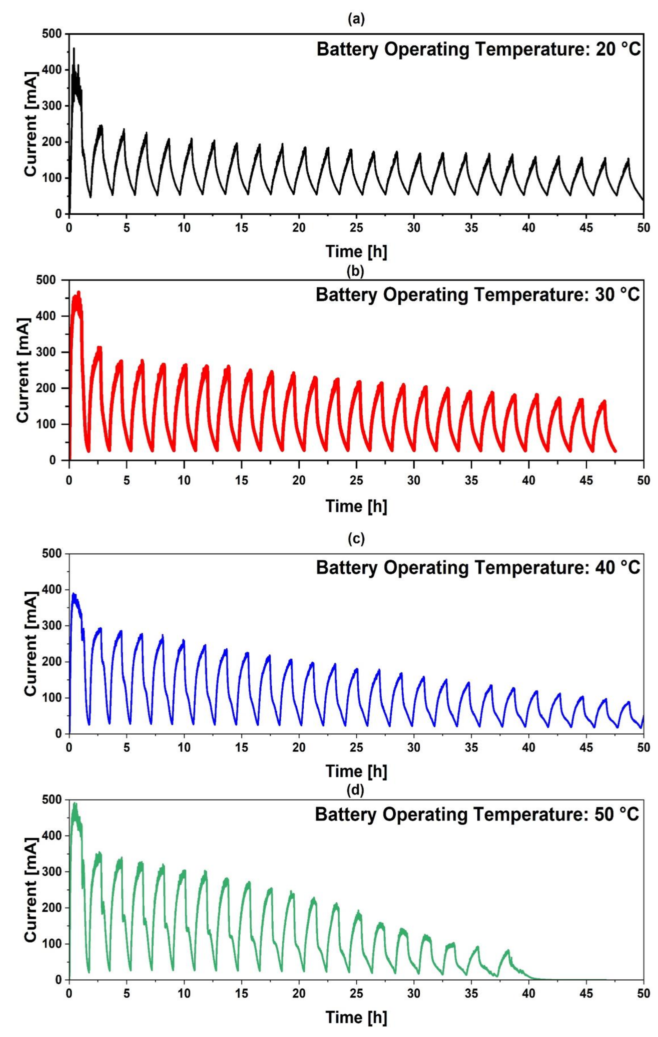


Figure 4: Recombination cell current profiles during 25 charge/discharge cycles at battery operating temperatures of (a) 20 °C, (b) 30 °C, (c) 40 °C, and (d) 50 °C.

Discharge performance trends - 25 °C showed better early-cycle CE and capacity; 40 °C shown better results in long-term stability due to kinetic advantages.

Hydrogen management is critical - 50 °C cycling led to efficiency loss after cycle 18 due to hydrogen evolution, accumulation, and Fe precipitation.

Recombination cell activity correlates with HER - Rising recombination current at higher temperatures reflects increased hydrogen evolution and recombination demand.

Optimal range observed at 40 °C - Balanced performance: enhanced redox kinetics and stable CE/VE with fewer hydrogen-related losses.

Conclusion

This study demonstrated that elevated temperatures improve IRFB kinetics but also intensify hydrogen evolution and gas management challenges. Cycling efficiency stabilized at moderate temperatures. Future research should focus on extending 50 °C temperature studies beyond 15 cycles to assess long-term performance and develop strategies for managing hydrogen evolution and precipitation at higher operating temperatures.

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