# Investigating the Electrochemical Behaviour of Iron/Hydrogen Recombination Cell in Iron/Iron Redox Flow Battery

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## Motivation

Iron/Iron Redox Flow Batteries (IRFBs) offer significant advantages, including low-cost active materials, abundant resource availability, and high theoretical energy density [1]. The Iron/Hydrogen recombination cell is pivotal in preventing capacity loss due to unintended hydrogen production. The reactions take place in recombination cell are written below [2].

$$Fe^{3+}_{(aq)} + e^{-} \rightarrow Fe^{2+}_{(aq)} \qquad \varphi^{0,+} = +\ 0.77\ V \qquad (1)$$

$$H_{2\,(g)} \rightarrow 2\,H^{+}_{(aq)} + 2\,e^{-} \qquad \varphi^{0,-} = 0\ V \qquad (2)$$

$$H_{2\,(g)} + 2\,Fe^{3+}_{(aq)} \rightarrow 2\,H^{+}_{(aq)} + 2\,Fe^{2+}_{(aq)} \qquad \varphi^{0}_{cell} = 0.77\ V \qquad (3)$$

Building on the work of Noack et al. (2020), this study investigates the electrochemical behaviour of the recombination cell under varying iron (III) concentrations and hydrogen flow rates. Identifying key parameters that influence hydrogen recombination is crucial for enhancing the electrolyte regeneration process, thereby improving the efficiency and reliability of IRFBs. The findings contribute to the development of sustainable and effective energy storage technologies.

## Experimental Procedure

- **Test Stand Setup:** An Iron/hydrogen cell setup with a 40 cm² cell was set up in Figure 1.
- **Electrolyte:** An Iron (III) solution (1.5 M $FeCl_2$ , 0.2 M HCl, 2 M $NH_4Cl$) allowed variation in $FeCl_2$ concentration to assess its impact.
- **Parameters:** Mass flow controller (20-120 mL/min) pivotal for curve generation, revealing operational insights.
- Iron (III) concentrations (0.3-1.5 M) at 80 mL/min provided performance insights, enhancing understanding**.**

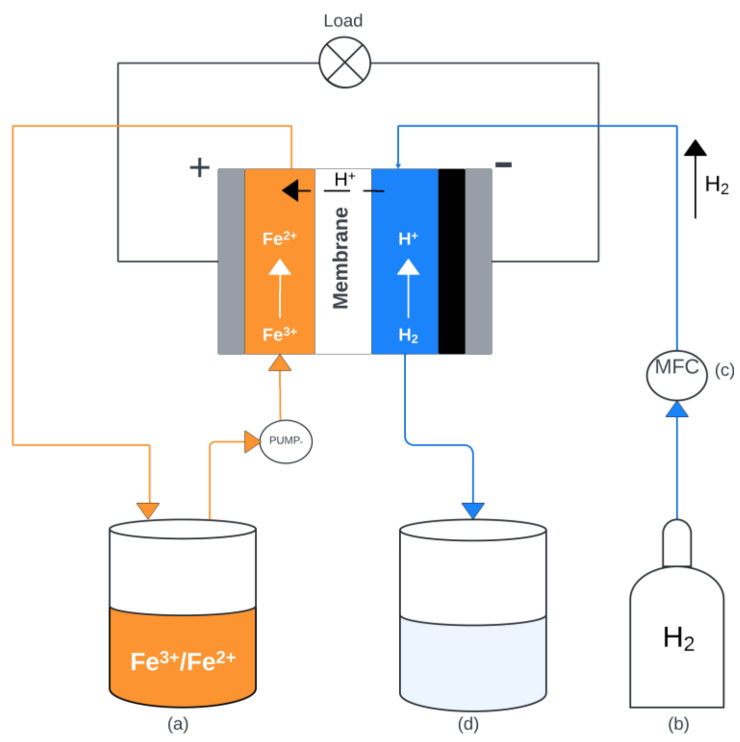


**Figure 1:** Schematic diagram of an Iron/hydrogen recombination cell setup. a) Fe3+ Electrolyte Tank, b) Hydrogen gas cylinder, c) Mass Flow Controller, d) Back pressure Tank.

## Results:

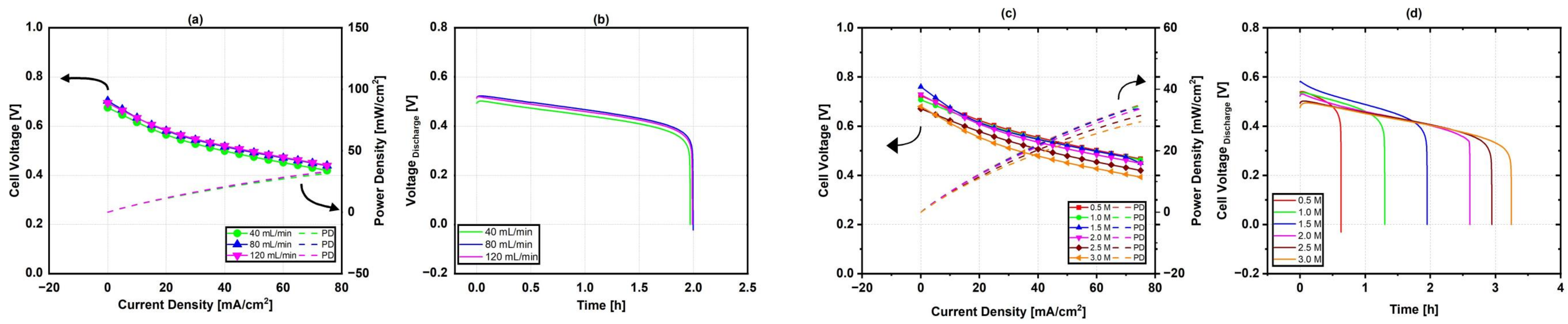


**Figure 2:** a) Current density, power density vs cell Voltage, b) Time vs Discharge Cell Voltage , c) Current Density, Power Density vs Cell Voltage, d) Time vs Discharge Cell Voltage under conditions of varied hydrogen flow rates and varied Iron (III) concentrations with [$V_{electrolyte}$ = 100 mL, theoretical capacity = 4.01 Ah, and current density = 50 mA/cm²].

- Fig 2 (a) shows stable polarization curves with no mass transport limitations.
- In Table 1, Lowest lambda value recorded at 3 A, indicating effective hydrogen purging and optimal operational conditions.
- In Fig 2(c), Ohmic losses and high activation potentials influence slow reaction kinetics with varied Iron(III) concentrations.
- In Fig 2(d), Discharge capacity does not meet theoretical capacity, indicating ohmic and kinetic losses limit performance.

| Current Density (mA/cm²) | Theoretical $H_2$ Flow Rate (mL/min) | Actual $H_2$ Flow Rate (mL/min) | Lambda (λ) |
|---|---|---|---|
| 45 | 12.6 | 40 | 3.17 |
| 52.5 | 14.7 | 40 | 2.72 |
| 60 | 16.8 | 40 | 2.38 |
| 67.5 | 18.9 | 40 | 2.12 |
| 75 | 21 | 40 | 1.9 |

**Table 1:** Theoretical hydrogen flow rates and lambda (λ) values at varying currents for an Iron/$H_2$ recombination cell with an actual hydrogen flow rate of 40 mL/min.

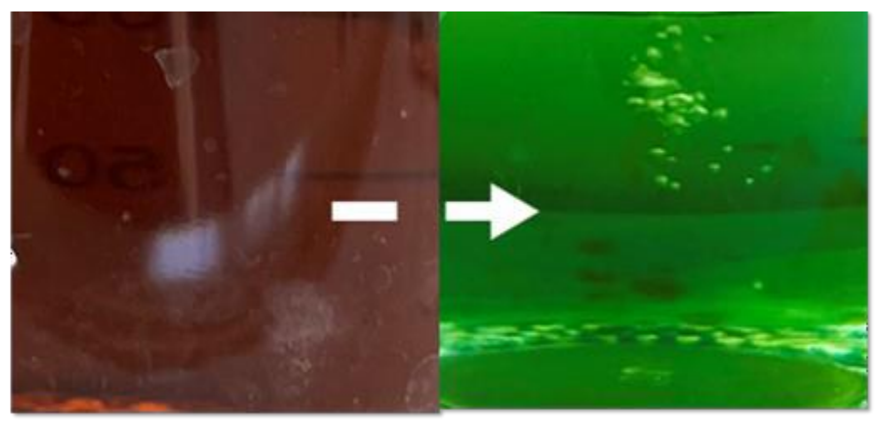

**Figure 3:** The image showcases the observable transformation in electrolyte coloration, indicative of the conversion from Fe3+ to Fe2+.

## Conclusion:

In conclusion, the research indicated that ohmic and kinetic losses significantly impacted the performance of Iron/Hydrogen recombination cells. Increased Iron (III) concentrations were found to extend discharge time, yet these enhancements did not translate to achieving theoretical capacity due to the aforementioned losses. The lambda values, particularly the lowest recorded at 1.9 for a hydrogen flow rate of 40 mL/min at 3 A, indicate effective hydrogen purging and optimal operational conditions within the Iron/Hydrogen recombination cell. Future research will aim to lower lambda values to optimize cell efficiency and deepen our understanding of its electrochemical behavior.

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