Membraneless Soluble Lead Redox Flow Batteries at Low to High External Flow Rates

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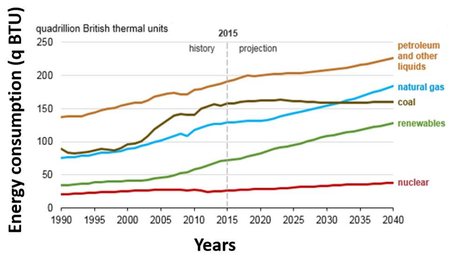
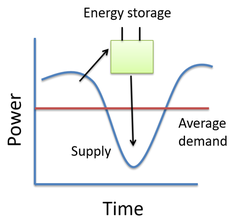
Abstract: Soluble lead redox flow battery (SLRFB) is among the least expensive in its class, because of the raw material used and the single electrolyte flow loop which eliminates the expensive proton exchange membrane. Challenges such as limited cycle life and low energy efficiency need to be overcome, however, to take it to the next label. In our research group, we have established through CFD-electrochemical reaction modeling, measurements, and flow visualization the dominant role of natural convection in SLRFB. In this work, we present our efforts to harness natural convection for efficient battery designs that need minimal external pumping during battery operations.

Introduction

World energy consumption

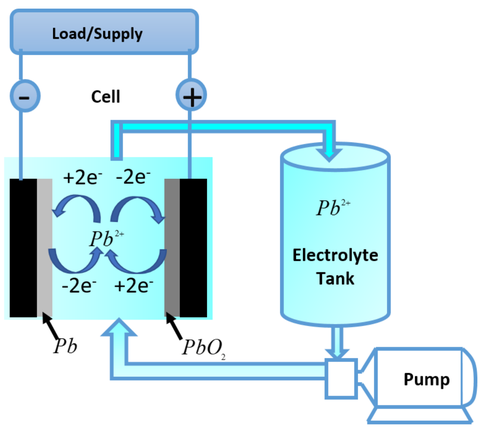


Energy storage



VRFB plant, Japan

Schematic of SLRFB



Electrochemical reaction

Negative electrode reaction:

$$Pb^{2+} + 2e^- \underset{discharge}{\overset{charge}{\rightleftharpoons}} Pb \qquad (E^0 = -0.13V/SHE)$$

Positive electrode reaction:

$$Pb^{2+} + 2H_2O \underset{discharge}{\overset{charge}{\rightleftharpoons}} PbO_2 + 4H^+ + 2e^- \qquad (E^0 = 1.56V/SHE)$$

Full-cell reaction

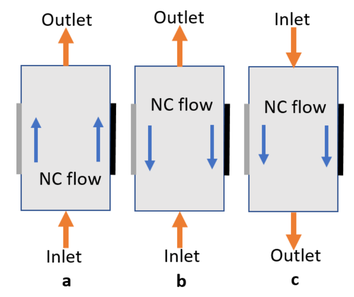
$$2Pb^{2+} + 2H_2O \underset{discharge}{\overset{charge}{\rightleftharpoons}} Pb + PbO_2 + 4H^+ \qquad (E^0_{cell} = 1.69V/SHE)$$

Side reaction

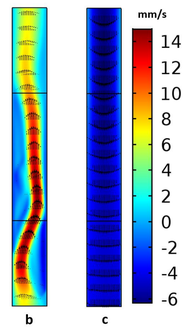
$$PbO + H_2O \underset{discharge}{\overset{charge}{\rightleftharpoons}} PbO_2 + 2H^+ + 2e^-$$

Effect of Flow Reversal

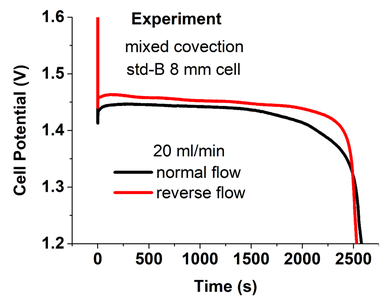
Flow directions



Velocity field

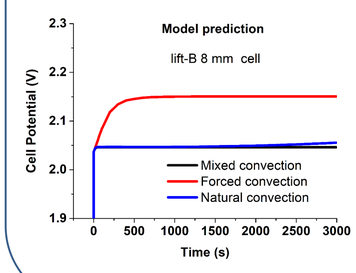


Discharge Potential: Exp

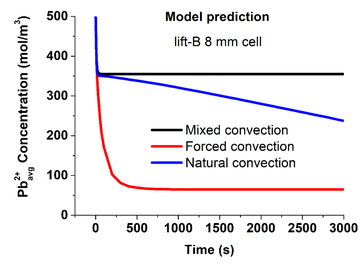


Natural vs Mixed Convection

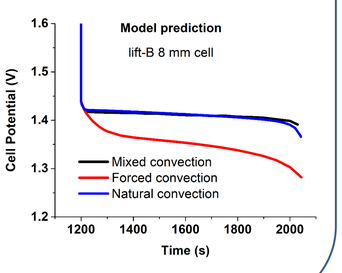
Charge potential



Pb^{2+} concentration

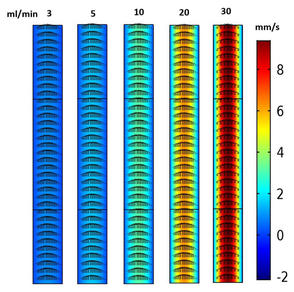


Disch potential

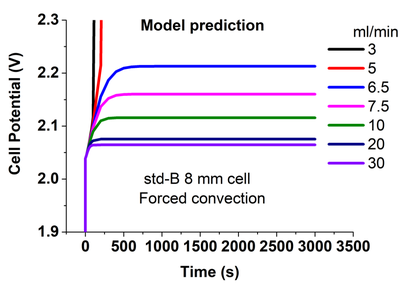


Effect of Flow Rates: No Natural Convection

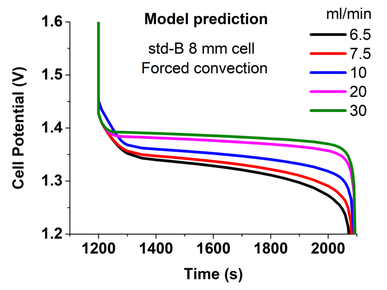
Velocity field: Steady



Charge potential: model

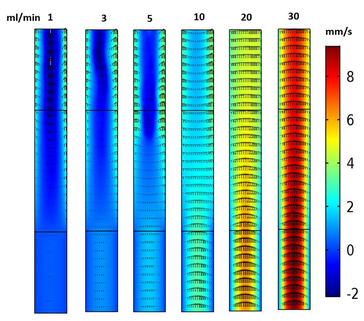


Discharge potential: model

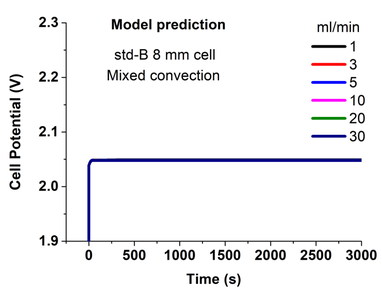


Effect of Flow Rates: With Natural Convection

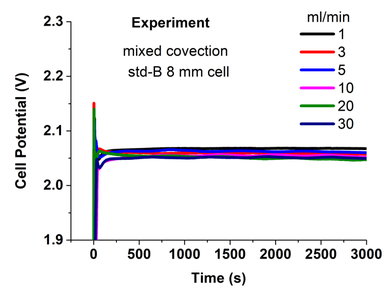
Velocity field: Charge



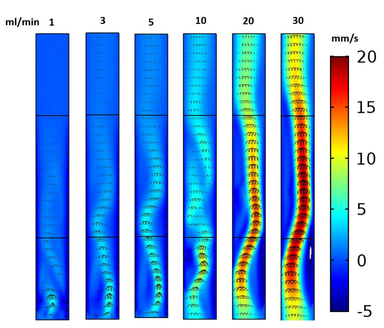
Charge potential: model



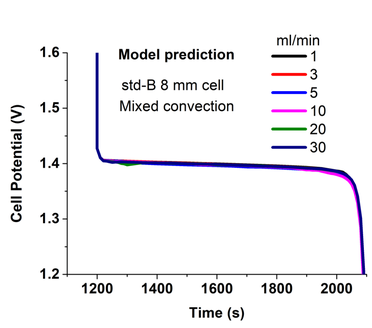
Charge potential: Exp



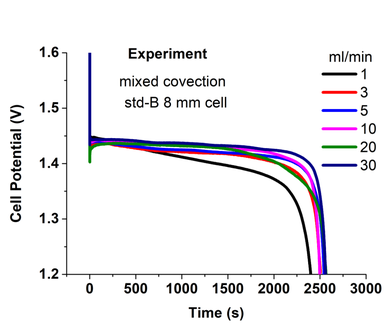
Velocity field: Discharge



Discharge potential: model



Discharge potential: Exp



Conclusions

- ✓ Natural convection affects the cell performance even in the presence of external flow.
- ✓ Constant chare-discharge potential is obtained even at low flow rate in the presence of natural convection.
- ✓ Measurements support this very well.
- ✓ High overpotential is obtained at low flow rate in the absence of natural convection.
- ✓ Wavy velocity profile is found during discharge due to opposite nature of natural convection and external flow.
- ✓ Flow reversal improves discharge performance.
- ✓ Natural convection works quite similar to mixed convection unless it depleted.

References

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