Dissecting the quinone bromide flow battery

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Dissecting the Quinone Bromide Flow Battery

Qing Chen, Michael R. Gerhardt, Louise Eisenach, Michael P Marshak, Roy G Gordon, Michael J Aziz.

5-26-2015
Quinone-bromide flow battery

References:
QBFB reaches 1.0 W/cm²

Black: base case

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Membrane</th>
<th>Flow rate</th>
<th>Temperature</th>
<th>Posolyte</th>
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</thead>
<tbody>
<tr>
<td>Baked SGL 10AA</td>
<td>Pretreated 212</td>
<td>200 mL/min</td>
<td>20 °C</td>
<td>3 M HBr, 0.5 M Br₂</td>
</tr>
<tr>
<td>SGL 10AA</td>
<td>212</td>
<td>100 mL/min</td>
<td>30 °C</td>
<td>3.5 M HBr, 0.5 M Br₂</td>
</tr>
<tr>
<td>Etched Toray 060</td>
<td>115</td>
<td>50 mL/min</td>
<td>40 °C</td>
<td>2.5 M HBr, 0.5 M Br₂</td>
</tr>
</tbody>
</table>

Red: high power build

- Baked SGL 10AA
- Pretreated 212
- 400 mL/min
- 45 °C
- 3 M HBr, 2 M Br₂

When kinetics and mass transport limits are insignificant, polarization curves are linear.
Ohmic resistors in the cell

Cell Discharge

H₂AQDS

AQDS

H⁺

Br₂

Br⁻

Flow Plate

Flow Plate

Electrolyte +

Electrolyte –

Membrane

Faradaic resistance

Ionic resistance

Electronic resistance

We may use linearized Butler-Volmer
Separating voltage losses

Flow Plate

H$_2$AQDS

Nafion

212

Br$_2$

H$^+$

AQDS

Flow Plate

e$^-$

e$^-$

Full Cell

50% SOC

Discharge

Base case

325 mΩ cm$^2$

50% SOC

EIS

50% SOC

0 A DC current

0.01 A AC current

104 mΩ cm$^2$

Membrane ionic + electronic (+ & -)

104 mΩ cm$^2$

Membrane ionic: 60 mΩ cm$^2$

Electronic: 22 mΩ cm$^2$ (each)
Separating voltage losses

- **Pd-H RE** (~50 mV vs. RHE)
- **H₂AQDS** → **H⁺** → **Neg. side**
- **AQDS** → **e⁻** → **Flow Plate**

**Full Cell**
- **Membrane ionic + Electronic (+ & -)**: 104 mΩ cm²
- **Electrolyte ionic (+) + Faradaic (+)**: 94 mΩ cm²
- **Electrolyte ionic (-) + Faradaic (-)**: 127 mΩ cm²
- **Membrane ionic + Electronic (+ & -)**: < 10 mΩ cm²

**Base case**
- 50% SOC
- **H₂AQDS oxidation**
- **Voltage vs. Pd-H (V)**
- **Current density (A/cm²)**

**Voltage vs. Pd-H (V)**
- 0.0 0.2 0.4 0.6 0.8 1.0
- 0.15 0.20 0.25 0.30 0.35 0.40

**Current density (A/cm²)**
- 0.0 0.2 0.4 0.6 0.8 1.0
Two phase conducting and Current distribution

1D homogeneous porous electrode model neglecting mass transport

Faradaic current, \( i_f \)

Ionic current, \( i_i \)

Electronic current, \( i_s \)

\[ \rho_f \]

\[ \rho_l \]

\[ \phi_1 \]

\[ \phi_2 \]

\[ L \]

\[ x \]

\[ 0 \]

1. Electronic current, \( i_s \): solid electrode phase;
2. Liquid current, \( i_l \): liquid electrolyte phase;
3. Faradaic current, \( i_f \):

\[ \eta_{nego} = \phi_1 - \phi_2 \approx \int_0^L i_l(x) \rho_l \, dx \]

\[ r_{nego} = \frac{\eta_{nego}}{i_{tot}} = \rho_l \int_0^L \frac{i_l(x)}{i_{tot}} \, dx \]

**Overvoltage**

**Resistance**

**Reference**

Potential probes for current distribution

$\frac{i_s}{i_{tot}} = V_{1,2,3} / r_{1,2,3}$

Measured by EIS

All $\frac{i_s}{i_{tot}}$ appear independent of $i_{tot}$
Overvoltage from the negative side

\[ r_{\text{nego}} = \frac{\eta_{\text{nego}}}{i_{\text{tot}}} = \rho_l \int_0^L \frac{i_l(x)}{i_{\text{tot}}} \, dx \]

Neg. \( \rho_l \sim 2.2 \, \Omega \, \text{cm} \)

(~ 5.4 \, \Omega \, \text{cm after Bruggerman correction using 55% porosity})

Line & scatters: experimental values
Dashed lines: 1D porous electrode model

161 mΩ cm²
Electronic + Electrolyte Ionic + Faradaic

All \( i_s/i_{\text{tot}} \) appear independent of \( i_{\text{tot}} \)

0.3 A/cm²
H₂AQDS oxidation
base case

Flow Plate

50% SOC
Discharge
Base case

Cell Voltage (V)
Current density (A/cm²)

0.325 Ω cm²
Electrolyte Ionic + Faradaic

127 mΩ cm²

Electrolyte Ionic + Faradaic

22 mΩ cm²
Electronic (-)
Conclusions

- Highest QBFB peak power density to date: 1.0 W/cm$^2$
- Linear polarization for QBFB
- Contributions to overvoltage have been quantified
- Negative Faradaic reaction occurs primarily in the first 300 µm of the electrode
- Enables future engineering improvements

Acknowledgements

We thank the Alán Aspuru-Guzik research group for molecule property theoretical calculation, Sustainable Innovations, LLC. for Product-to-Market insights and ARPA-E for funding the research.

Thank you!
Capacity-loss $\eta_i$-loss
- Quinone decomposition
- Negolyte leakage

Non-Capacity-loss $\eta_i$-loss
- Br$_2$ crossover
- H$_2$ evolution
- O$_2$ permeation

Latent-$\eta_i$-loss
- Cell resistance change
- Water transport

Minority side leakage & active species decomposition

Majority side leakage, decomposition & side-reactions

Minority side side-reactions

Posolyte leakage
- Posolyte decomposition
- Posolyte crossover
- CO$_2$ & O$_2$ evolution
EIS
50% SOC
0 A DC current
0.01 A AC current

$Z_{\text{img}}$ (Ω cm$^2$)

$Z_{\text{real}}$ (Ω cm$^2$)
Fig. 5. The potential profile and current distribution for symmetric electrodes geometry under secondary current distribution (Wa (anode) = 0.1, Wa (cathode) = 100).