Next Generation Redox Flow Battery Prototype Development


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Objective
Validate new mixed acid electrolyte chemistry in larger scale 1 kW /1 kWh stack to identify potential issues and challenges with scale-up.

Outline
- Shunt current model
- CFD and pressure drop
- 1 kW construction
- 1 kW stack demonstration

Catholyte: $\text{VO}_2^+ + \text{Cl}^- + \text{H}_2\text{O} - e^- \rightarrow \text{VO}_2\text{Cl} + 2\text{H}^+$

Anolyte: $\text{V}^{3+} + e^- \rightarrow \text{V}^{2+}$

Overall: $\text{VO}_2^+ + \text{Cl}^- + \text{H}_2\text{O} + \text{V}^{3+} \rightarrow \text{VO}_2\text{Cl} + 2\text{H}^+ + \text{V}^{2+}$

$E_{co}=1.0 \text{ V}$

$E_{ao}=-0.25 \text{ V}$

$E_o=1.25 \text{ V}$

Double Energy Density
Extend temperature window
Scale-up challenges for 1kW system

- Shunt current through fluid path due to ionically conductive electrolyte
  - *Want high electrolyte resistance along flow path to reduce shunt current*
- Minimize pressure drop to reduce pumping energy loss
  - *Uniform flow distribution in every cell and a single cell is required*
- **Trade-off design between flow and shunt current**
Shunt Current Model.

Schematic of (a) redox flow cell stack assembly, and (b) equivalent electric circuit model

1. Dimensionless channel resistance

\[ r = \sqrt{\frac{R_c}{4R_i + R_m}} \approx \frac{\sqrt{R_c}}{R_m} \]

2. Characteristic shunt current

\[ I_K = \frac{V_{oc} - I_L R_i}{4R_i + R_m} \approx \frac{V_{cell}}{R_m} \]

3. Number of cell: \( n \)

\[ \frac{r}{n} < \frac{1}{2e} \quad \text{High shunt loss} \]

Design Guidelines (< 1%)

\[ \frac{i_{avg}}{I_K} < 0.3 \quad \frac{r}{n} > 1 \]
Evolution of Stack Design

Gen 1.1

Shunt loss: ~ 3 %

\[ \frac{R_c}{R_m} = 86 \]

\[ \frac{r}{n} = 0.46 \]

Gen 1.4

Shunt loss: < 1 %

\[ \frac{R_c}{R_m} = 1200 \]

\[ \frac{r}{n} = 1.73 \]
Fluid Flow Model (CFD, Star CD)

Determined material properties for 1.7 M V + 5 M S electrolyte at 25°C

- density \( \rho = 1400 \text{ kg/m}^3 \),
- viscosity \( \mu = 6 \text{ cP} \)
- and determined permeability \( k=1.685 \times 10^{-10} \text{ m}^2 \) of electrode felt from

\[
-\frac{\mu}{k} v = \nabla p
\]

Stack CFD

Pressure field at 0.5 mL/min-cell-cm²

Combined CFD and shunt current analyses confirmed that Gen 1.4 design should enable 1 kW prototype stack with:

- < 1% shunt current loss
- < 1% deviation in flow across all cells
### Key parameters for 1 kW / 1 kWh prototype system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Current Density</td>
<td>80 mA/cm²</td>
</tr>
<tr>
<td>SOC Range</td>
<td>15-85</td>
</tr>
<tr>
<td>Electrolyte Concentration</td>
<td>2M V, 2M S, 5 M Cl</td>
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<tr>
<td>Electrolyte Volume (liters)</td>
<td>30/30</td>
</tr>
<tr>
<td>Stack Dimension (cm)</td>
<td>31 (W) × 44 (H) × 40 (L)</td>
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<tr>
<td>Active area (cm²)</td>
<td>780</td>
</tr>
<tr>
<td>Number of cells</td>
<td>15</td>
</tr>
<tr>
<td>Electrode</td>
<td>Graphite felt (SGL GFD4.6)</td>
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<tr>
<td></td>
<td>SIGRACET® expanded Graphite (TF6)</td>
</tr>
<tr>
<td>Flow frame</td>
<td>PVC (polyvinyl chloride)</td>
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<tr>
<td>Membrane</td>
<td>Nafion® 115</td>
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</tbody>
</table>
1 kW / 1 kWh mixed acid system
1 kW stack performance

Test Conditions
- Flow rates 2, 4, 6, and 7 slpm
- 15-85 SOC @ 80 mA/cm²

Temperature exceeds stability of conventional vanadium electrolyte
Comparison of Conventional and Mixed Acid Electrolyte under high temperature operation

- Increase in pressure resulting from precipitation of V$^{5+}$ with conventional electrolyte.
- No precipitation observed with mixed acid electrolyte with 50% increased concentration.
1 kW Stack cell-to-cell uniformity.

(a) Mixed acid (2 M V + 2 M S + 5 M Cl)
Nafion 115
GFD 4.6 mm Felt / 0.6 mm Grafoil
2 L/min (80 mA/cm²)
4 L/min (160 mA/cm²)

160 mA/cm²
80 mA/cm²

Capacity (Ah)

Current vs. capacity for all 15 cells in the stack

(b) 80 mA/cm², half charge
80 mA/cm², end of charge
160 mA/cm², half charge
160 mA/cm², end of charge

Cell voltage vs. cell number at 50% and 100% SOC

Pacific Northwest
NATIONAL LABORATORY
1 kw System Capacity Fade.

- 2M V, 2M S, 5M Cl mixed acid electrolyte
- 80 mA/cm²
- 15-85% SOC
- Nafion 115 membrane
- $T_{\text{tank}} \sim 38 ^\circ\text{C}$

- Current efforts are focused on mitigating capacity fade in single cell component tests which will be incorporated into the stack in FY13.
Summary

• Able to demonstrate mixed acid operating > 1.1 kW at 80 mA/cm² with a round trip energy efficiency of 82% for the stack and an energy content of 1.4 kWh.

Future Work

• Improve EE at higher current density.
• Incorporate lower cost membrane
• Improve capacity fade
• V/Fe chemistry demonstration with microporous separator

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