Introduction to the Materials Science of

Rechargeable Batteries

Week 2: Thermodynamics of Battery Materials
Bonus Lecture 2.6: The NaNiCl System

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Materials Development for Sodium Metal Halide Batteries

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Thanks to the GE Battery team!

GE Hybrid Locomotive

Benefits

• 10% fuel savings (32,000 gal/loco/yr)
• 10% emissions reduction
• 1750 HP boost
• 20-year life
• ecomagination

Na-NiCl₂ cell

10% fuel savings (32,000 gal/loco/yr)
Battery Basics – Power & Energy Metrics

Power - needed to drive at high speeds…to accelerate and climb grades

Energy - needed to provide range - distance
## Batteries by Vehicle Application

<table>
<thead>
<tr>
<th>HEV’s</th>
<th>Plug-in HEV’s</th>
<th>EV’s</th>
<th>Hybrid Loco</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

**Increase in size of battery (kWh), reducing Power to Energy (P/E) ratio**

<table>
<thead>
<tr>
<th>Peak Power [kW]</th>
<th>30</th>
<th>50</th>
<th>60</th>
<th>100</th>
<th>90</th>
<th>30</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Storage [kWh]</td>
<td>1.3</td>
<td>2.1</td>
<td>5</td>
<td>14</td>
<td>35</td>
<td>19</td>
<td>750</td>
</tr>
<tr>
<td>Pow/Eng [k/hours]</td>
<td><strong>23</strong></td>
<td><strong>23</strong></td>
<td><strong>12</strong></td>
<td><strong>7</strong></td>
<td><strong>2.6</strong></td>
<td><strong>1.6</strong></td>
<td><strong>1.3</strong></td>
</tr>
</tbody>
</table>

**Applicable Battery Technology**

- **Power**
- **Dual**
- **Energy**

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*imagination at work*

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The NaNiCl\textsubscript{2} System

- Steel case
- Molten Na anode
- Na-conducting ceramic membrane $\beta''$ alumina
- Beta Alumina Solid Electrolyte
- Ni current collector
- Cathode $\text{Ni | NiCl}_2 | \text{NaCl | NaAlCl}_4$
**Na-NiCl₂ cell basic chemistry**

**Current collector (Ni)**
- Anode (liquid Na)
- Cathode (Ni+NaCl+Additives)
- Liquid electrolyte (NaAlCl₄)
- Beta” Alumina Solid Electrolyte (BASE)
- Case (mild steel)

**Cell operating conditions**
- Temperature ~ 270C-350C
- Voltage ~ 1.8-3.4V (OCV: 2.58V)
- Current ~ 20-100A
- Cell power ~ 100-200W
- Resistance (initial) ~ 7-10mΩ
- Pressure 1-2 bar

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**Charge**

\[ \text{Ni} + 2\text{NaCl} \rightarrow \text{NiCl}_2 + 2\text{Na}^+ + 2e^- \]

**Discharge**

\[ \text{Ni} + 2\text{NaCl} \rightleftharpoons \text{NiCl}_2 + 2\text{Na}^+ + 2e^- \]
**Na-NiCl₂** cell basic structure

* After Sudworth et al. 2001

* J. L. Sudworth, J. Power Sources, 100, 149 (2001)
Granulated Ni + NaCl

Steel case

Steel anode current collectors (4)

Nickel cathode current collector and carbon wick

β'' alumina ceramic membrane

NaAlCl₄ electrolyte (mp 185°C)
The NaNiCl System

\[ 2Na + NiCl_2 \rightleftharpoons 2NaCl + Ni \]

\[ \Delta G_f^\circ = -360 \text{kJ/mole} \]

\[ \Delta \phi = 2.59 \text{V} \quad I = 45 \text{Amps} \]