Battery Thermal Characterization

PI: Matthew Keyser • Team: Aron Saxon, Mitchell Powell, and Ying Shi
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SUMMARY
- NREL collaborated with U.S. DRIVE and USABC battery developers to obtain thermal properties of their batteries.
- Measured heat capacity and heat generation of cells under various power profiles.
- Obtained thermal images of the cells under various drive cycles.
- Data measured results to validate thermal models.
- Data have been shared with battery developers.

Thermal properties are used for the thermal analysis and design of improved battery thermal management systems to support life and performance targets.

OVERVIEW

Timeline
- Project Start Date: October 2004
- Project End Date: September 2018

Barriers
- Decreased battery life at high temperatures
- High cost due to an advanced thermal management system
- Cost, state, complexity, and energy consumption of thermal management system
- Decreased performance at low temperatures
- Insufficient cycle life stability to achieve the 3,000 to 5,000 “charge-depleting” deep discharge cycles

RELEVANCE

Life, cost, performance, and safety of energy storage systems is strongly impacted by temperature

Objectives
- Thermally characterize cell and battery hardware and provide technical assistance and modeling support to DOE/S. DRIVE, USABC, and battery developers for improved designs
- Enhance and validate physics-based models to support the thermal design of long-life, low-cost energy storage systems
- Quantify the impact of temperature and duty cycle on energy storage system life and cost

APPROACH

Cells, Modules, and Packs
- Tasks: Calibration of calorimeters, thermal data acquisition, and data analysis.
- Test Profiles: Normal operation, aggressive operation, drive cycles, battery packs.

TECHNICAL ACCOMPLISHMENTS

Efficiency of Cells Tested in FY15 and FY16

<table>
<thead>
<tr>
<th>Cycle Type</th>
<th>Current (A)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY15</td>
<td>100% Power</td>
<td>90.0</td>
</tr>
<tr>
<td></td>
<td>50% Power</td>
<td>96.0</td>
</tr>
<tr>
<td>FY16</td>
<td>100% Power</td>
<td>88.0</td>
</tr>
<tr>
<td></td>
<td>50% Power</td>
<td>92.0</td>
</tr>
</tbody>
</table>

| Lithium Cell Efficiency at 30°C, 0°C, and -15°C Under Full Discharge from 100% to 0% SOC
<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°C</td>
<td>90.0</td>
</tr>
<tr>
<td>0°C</td>
<td>85.0</td>
</tr>
<tr>
<td>-15°C</td>
<td>80.0</td>
</tr>
</tbody>
</table>

Heat Rate Comparison of Cells Tested in FY15 and FY16

<table>
<thead>
<tr>
<th>Cycle Type</th>
<th>Current (A)</th>
<th>Heat Rate (watts/cell)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY15</td>
<td>100% Power</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>50% Power</td>
<td>9.0</td>
</tr>
<tr>
<td>FY16</td>
<td>100% Power</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>50% Power</td>
<td>10.0</td>
</tr>
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Cell-Level Testing

Thermal Imaging
- Temperature variation across cell
- Spatial distribution of temperature
- Unique testing method reducing environmental impacts

Thermal Management Performance
- Temperature variation across cell
- Assuring proper thermal performance
- Avoiding over- or under-heating
- Avoiding coolant distribution imbalance temperature

Heat Generation and Efficiency

Measure battery and module thermal properties using state-of-the-art calorimeters.

Lithium Cell Efficiency at 30°C, 0°C, and -15°C Under Full Discharge from 100% to 0% SOC

Low-CURRENT HEATING

Heat in a cell is produced by:
- Resistance of cell components (cathode, anode, etc.)
- Chemical reactions within the cell due to the transfer of ionic and electron species

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TITANATE ANODES LIMIT PHASE TRANSITION

Calorimetry Testing Can Identify Entropic Heating/Cooling

Thermal Management System Performance - PHEV CDCS Drive Cycle

Efficiency Comparison of Cells Tested in FY16 and FY16

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HEV/CDCS Drive Cycle

Pack Thermal Temperature Studies

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Limiting Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
<td>Full charge/discharge</td>
</tr>
<tr>
<td>-15°C</td>
<td>Full charge/discharge</td>
</tr>
</tbody>
</table>

Technologies Office - Energy Storage Program

Funding provided by the US Department of Energy’s Vehicle Technologies Office - Energy Storage Program

FUTURE WORK

- Continue thermal characterization for DOE, USABC, and partners
- Cell, module, and pack calorimeters are available for industry validation of their energy storage systems
- Develop battery usage models with calorimeter heat generation data that will predict thermal performance of energy storage systems under various drive cycles and environmental conditions—models to be utilized by GM, Ford, Fiat-Chrysler (FCA), and battery developers
- Use data to enhance physics-based battery models in conjunction with DOE's Computer-Aided Engineering for Automotive Batteries (CARB) program
- Continue to develop and evaluate liquid, air, and vapor compression thermal management systems to extend energy storage cycle life
- Work with OEMs and battery manufacturers to:
  - Identify best solutions to reduce cell-to-cell temperature variations within a pack or in order to extend life
  - Minimize parasitic power draws due to the thermal management system
- Investigate new solutions for the thermal management of batteries such as phase change material, new refrigerants, etc.

COLLABORATION AND ACKNOWLEDGMENTS

Key USABC collaborators include:
- Partners: Fiat-Chrysler (FCA), Ford, and GM
- Contractors: LLNL, LUP, Maxwell, Sakti, SiC Innovation, Saso

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