Thermal Analysis of Lithium-Ion Battery for Grid Energy Storage Applications

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Advantages and Challenges of Lithium-Ion Batteries

- High energy density, high power density, and potential low cost make it suitable for use in renewable energy and distributed energy systems.
- One of the challenges imposed by lithium-ion battery is the thermal management. The best operating temperature of lithium-ion battery is from -10°C to 50°C. An effective thermal management system is critical to maintain the health and life span of the battery

Lithium Battery Thermal Issues

- Li-ion battery are thermally sensitive. Excessive temperature rise could cause the battery to degrade or shorten life cycles.
- Li-ion batteries operating temperature are best to be maintained within 0 to 50^{o}C.
- Cooling of the battery pack is usually a challenge due to strict and limited packaging space
- Uneven cooling could cause different modules to perform differently

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Objectives

- This paper is aimed to design an effective thermal management system for the lithium-ion battery pack
- Estimating the thermal loss of the battery pack based on electric characteristics and experiments
- Predicting the temperature rise of the battery pack based on the test results of a single cell
- Modeling the temperature gradients of the battery pack under different operating conditions

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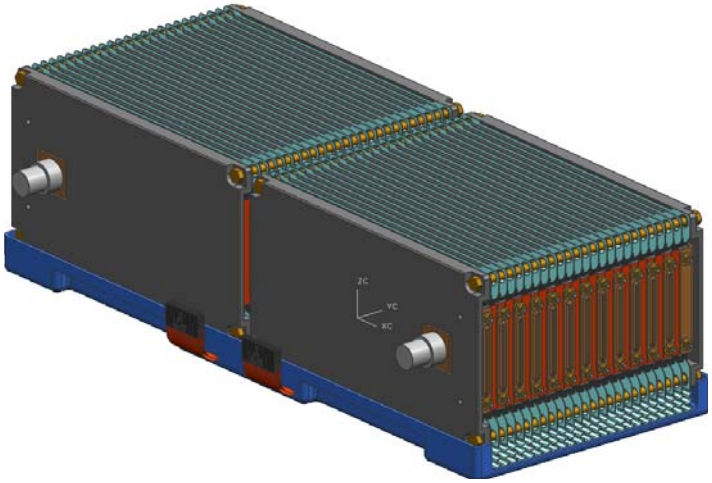
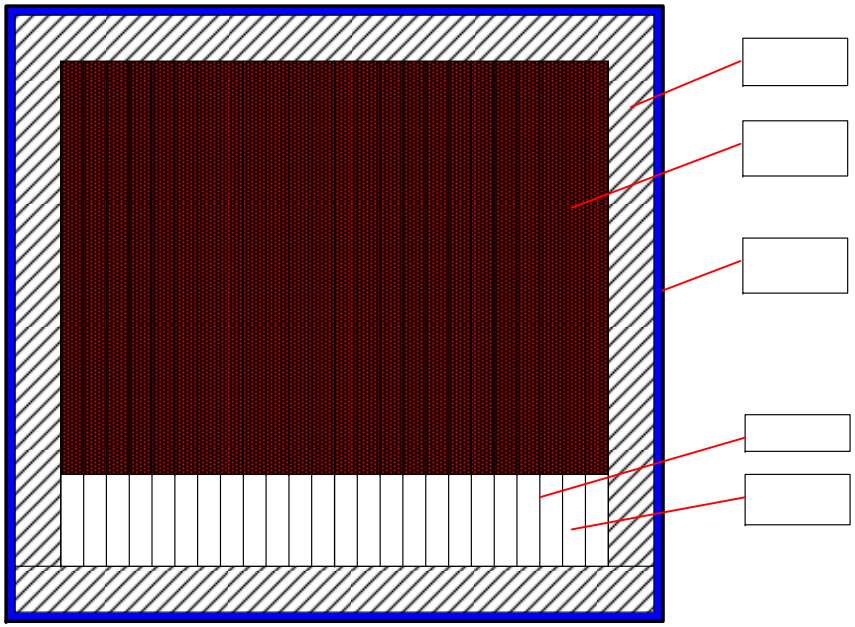
The Prismatic Cell Design and Packaging





- The pack consists of 48 lithium-ion battery cells.
- All the 48 cells are electrically connected in series to provide needed voltage.
- The pack is divided into two groups. Each group has 24 battery cells stacked together with aluminum cooling fins in between the cells.
- The battery pack is fitted into a metallic case, with thermal insulation inserted between the battery and the case.
- The cooling fins run through the battery and expends beyond the battery at the bottom to form a cooling channel to allow cooling to flow.
- There is no heat exchange between the ambient and the battery.
- Battery heat is carried out by the cooling fins. The cooling air takes away heat from the cooling fins.

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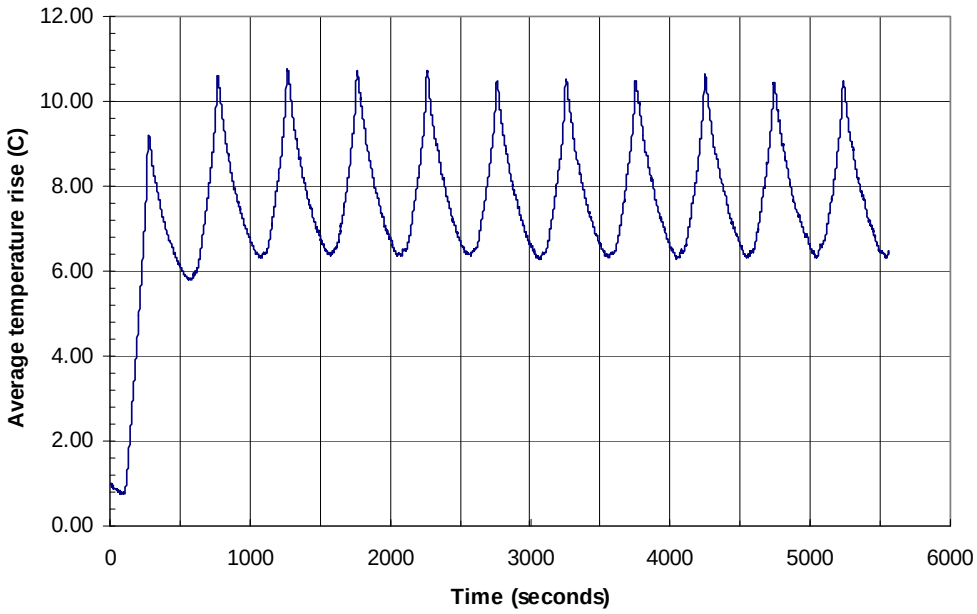
Battery Heat Generation

- In our study, we estimate the heat generation from two different method
  - Using measurement of a single cell testing
  - Using cell impedance measurement
- The cell testing shows temperature rise during cell charge and discharge.



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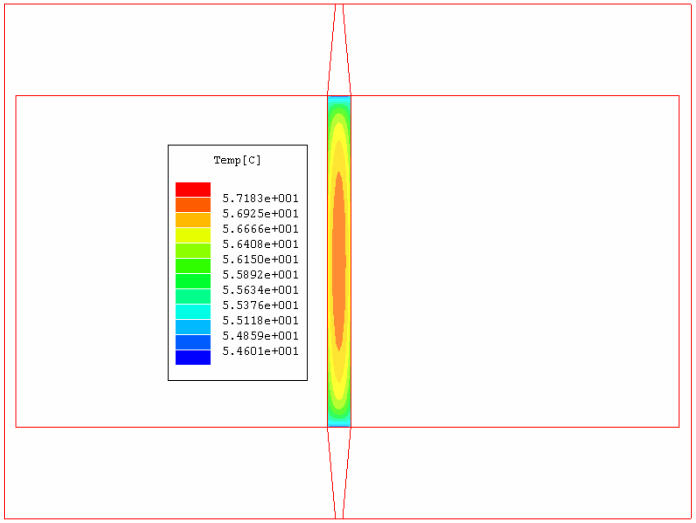
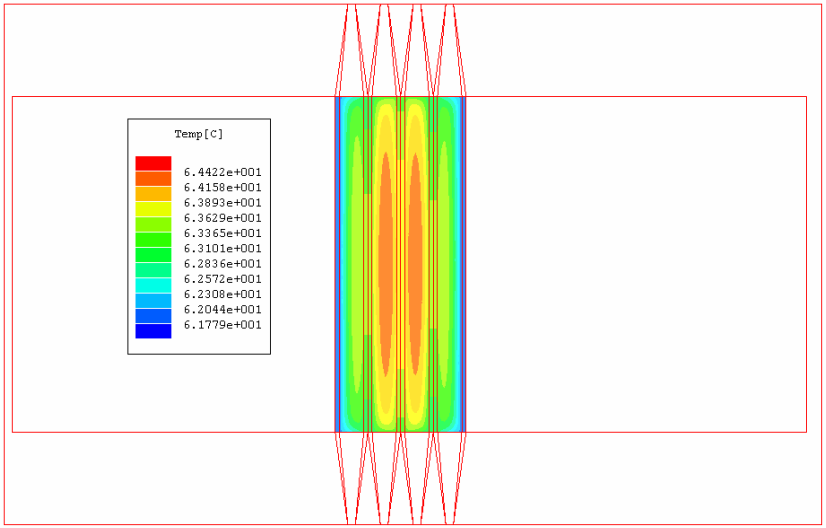
The Battery Cell Analysis

- Prismatic cells will have the highest temperature in the center of the cell
- The gradients of cell temperature will increase significantly as the number of cell increases.





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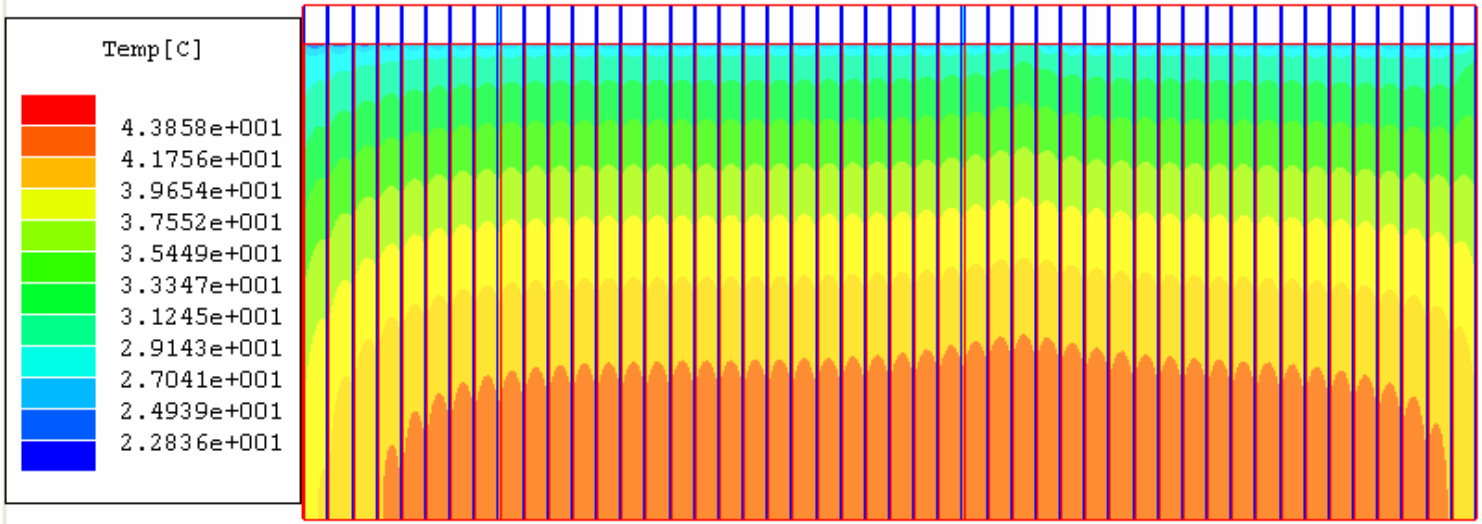
Temperature Estimation

- The battery pack temperature-rise were calculated using both analytical and numerical method
- When the cells are sealed in a potting material, the center bottom of the pack will have the highest temperature rise.



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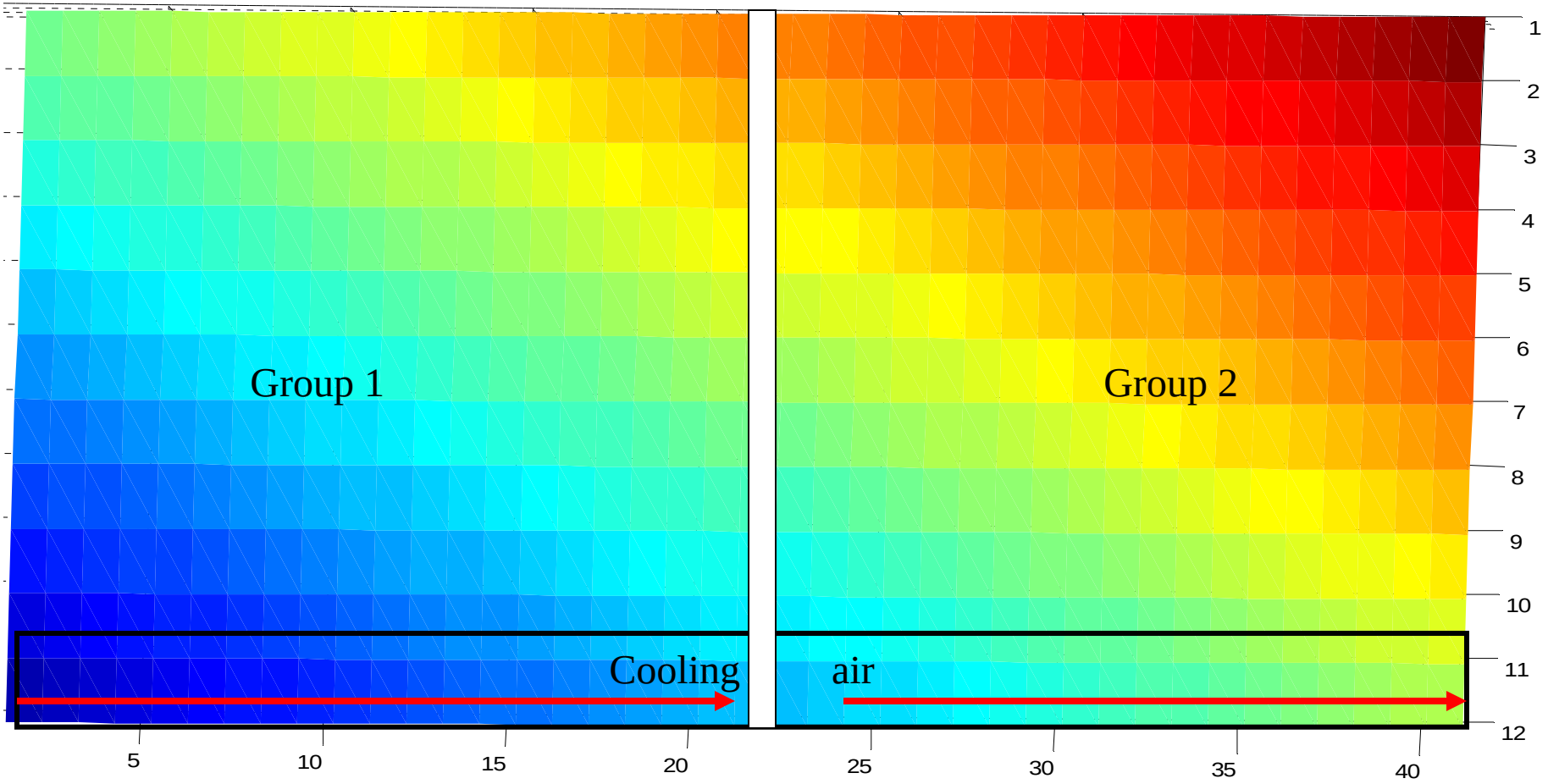
Pack Temperature Distribution



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Comparison of Temperature Rise Calculated Using Analytical and Numerical Methods

	Numerical	Analytical	Difference
Lowest Temperature rise (°C)	11.0	10.8	1.8%
Maximum Temperature rise (°C)	16.4	17.3	9.5%
Temperature gradient (°C)	5.4	6.5	1.1°C
Inlet/outlet air temperature difference (°C)	16.3	15.8	3.2%
Lowest pack temperature (°C)*	9.0	9.0	-
Highest pack temperature (°C)*	40.7	39.6	2.8%

*Note: Inlet temperature is 9°C

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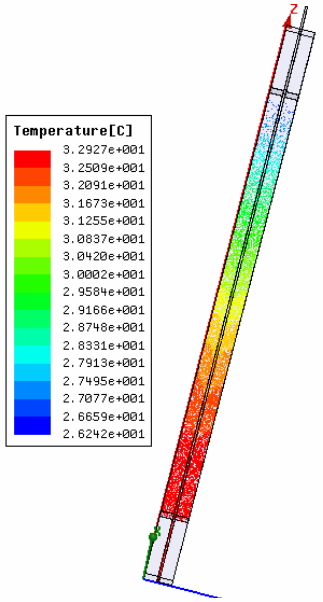
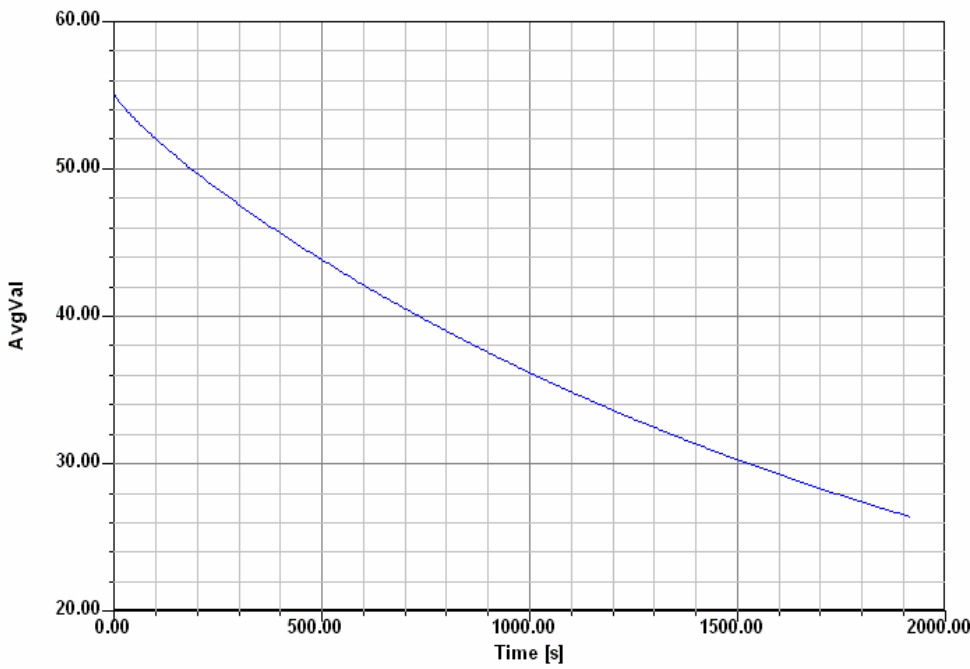
Transient Analysis

- When pack temperature reaches 55^{o}C
- This analysis (graph on the right) shows the time for the battery to cool down to certain operating temperature.





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Conclusions

- In order to effectively cool the Li-ion battery pack, and maintain the battery temperature within acceptable temperature, with air cooling, a significant size of cooling fins are needed.
- The inlet air temperature needs to be about 10^{o}C, with air flow rate of 35 ft3/min, in order to effectively cool the battery.
- The study shows that air cooling is a viable option for the Li-ion battery pack in plug-in HEV applications.
- An even temperature (or large gradient) distribution could cause some battery cells premature failure.

Future Studies

- Investigate liquid cooling and advanced cooling feasibilities for Li-ion batteries
- Develop Li-on battery health monitoring system based on impedance measurement and data analysis
- System approach to plug-in hybrid vehicle thermal management that will include power electronics, electric motors, and batteries

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