Avoiding cascading failure in battery packs through thermal analysis

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Background

If thermal runaway occurs for lithium-ion cells in a large battery pack, the hazard is dramatically increased if that failure propagates through the pack. This study defines the parameter space for avoiding such propagation.

The focus is on cell-to-cell propagation along a cell stack

Consider a cell that has undergone thermal runaway surrounded by cells that risk thermal runaway:

A parameter set for propagation mitigation - I

- Cells have a characteristic thermal runaway temperature. Runaway occurs if $T_c(t) > T_{TR}$.
- Some temperature reduction can be achieved by inert material between cells (ex: structure, casing).
- Ex: The heat capacity ratio of inert spacer material to cells is:

$$\phi_{capacity} = \frac{(\rho c_p \delta)_{spacer}}{(\rho c_p L)_{cell}}$$

Summary

Non-dimensional parameters can be used to describe heat flows.

- Thermal conduction: $\frac{1}{Bi} = \frac{R''_{contact}}{(L/\lambda)_{cell}}$.
- Heat capacity: $\phi_{struct} = \frac{(\rho c_p \delta)_{struct}}{(\rho c_p L)_{cell}}$.
- TR temp over heat release: $\theta_{TR} = \frac{\Delta T_{TR}}{T_{h,0} - T_{c,0}}$.
- Propagation criteria: $\theta_{max}(Bi, \phi_{struct}, T_{h,0} - T_{c,0}) < \theta_{TR}$.
- Heat must be removed before thermal runaway onset 150~200°C.
- Heat transfer parameters are critical for system design.

A parameter set for propagation mitigation - II

- For this analysis focus on heat transfer along stack and to surroundings (structural and/or cooling system).
- Between cells is a thermal resistance, $R''_{contact}$, from packaging and contact.

$$\frac{1}{Bi} = \frac{R''_{contact}}{(L/\lambda)_{cell}} = \frac{R''_{contact}}{R''_{cell}}$$

Max temp of next cell depends on

- Ratio of temperature rise to get thermal runaway, $\Delta T_{TR}$, to the temperature rise of initiating cell, $T_{h,0} - T_{c,0}$.

$$\theta_{TR} = \frac{\Delta T_{TR}}{T_{h,0} - T_{c,0}}$$

- Normalize max temperature of target cell similarly:

$$\theta_{max} = \frac{T_{c,max} - T_{c,0}}{T_{h,0} - T_{c,0}}$$

$$\theta_{max}$$ contours

No propagation if: $\theta_{max} < \theta_{TR}$