Disclaimer

Approximating the heating of an entire battery pack from single cell data is unfortunately a very crude approximation without the use of propagation models or finite element methods (FEMs) like COMSOL, ANSYS, etc.

Assumptions

However, it's possible to get something ball-park by assuming that:

- **All cells in the battery pack are electrically and thermally identical**
- **Heating occurs homogeneously across the battery pack**
    - I.e. There are no local "hot spots" - everything is evenly distributed
    - This is *absolutely not true and a dangerous assumption to make from a safety perspective*, but again, we're just going for a ballpark number
- **Thermal/electrical parameters are constant**
    - In reality, resistances and cell performance will change with temperature
- **Ignoring the thermal mass of structural components in direct contact with the pack**
    - Decent assumption for non-conductive materials that house the batteries
    - Bad assumption when considering conductive materials like nickel tabbing, copper connectors, etc.
        - More conductive thermal mass means the pack will take longer to heat up and cool down (think of it like inertia, but for heat)

Basic Model Explanation

I'm also assuming very simple first-order forms of the basic methods of heat transfer:

(+) Heat is being **solely** added through dissipative losses in the cells via resistance. The rate that this heat results in temperature change corresponds to **conduction** to thermal masses.
(-) Heat is flowing out of the cells through basic black body **radiation**
(-) Heat is flowing out of the cells through still-air **convection** ('h' will change if there is airflow)

The basic approach in the linked simulation is to factor in these transfers of heat rate (i.e. power), propagate in time, and then integrate to get the net heat (i.e. energy) of the pack, then convert that net heat energy into temperature using an estimate of the specific heat of the pack.

Detailed Model Explanation

NOTE: You'll need to calculate the specific heat of the cell (C_cell) using your test data

Parameters

- **num_cells** Number of cells in the battery pack
- **I** Current in Amps
- **R_cell** Internal resistance of a single cell in Ohms
- **C_cell** Specific heat capacity of a single cell in J/(kg·°C)
- **m_cell** Mass of a single cell in kg
- **A_cell** Surface area of a single cell in m²
- **emissivity** Emissivity of the cell surface
- **sigma** Stefan-Boltzmann constant (5.67e-8 W/(m²·K⁴))
- **h_conv** Convection heat transfer coefficient in W/(m²·°C)
- **T_ambient** Ambient temperature in °C

Equations

Heat Generation (+)

The total heat generated by the battery pack is assumed to be entirely through resistive dissipation within the cell. Worth noting that Q is heat rate (J/s):

$$Q_{generated} = N * I^2 * R_{cell}$$

where

- N is the number of cells
- I is the current
- R_cell is the internal resistance of a single cell

Heat Dissipation (-)

Heat loss due to radiation:

$$Q_{radiation} = \epsilon * \sigma * A_{pack} * [(T_{pack} + 273.15)^4 - (T_{amb} + 273.15)^4]$$

- ϵ is the emissivity
- σ is the Stefan-Boltzmann constant
- A_pack is the total surface area of the battery pack
- T_pack is the temperature of the battery pack
- T_amb is the ambient temperature

Heat loss due to convection (i.e. heat transferred through contact with air as a medium)

$$Q_{convection} = h_{conv} * A_{pack} * (T_{pack} - T_{amb})$$

- h_conv is the convection heat transfer coefficient (super approximated here…)

Temperature Change

The temperature change of the battery pack is given by:

$$Q_{net} = Q_{generated} - (Q_{radiation} + Q_{convection})$$

$$\Delta T = (Q_{net} * \Delta t)/(m_{pack} * C_{cell})$$

- Δt is the discrete time-step used in the forward propagation simulation loop
- m_pack is the mass of the pack
- C_cell is the specific heat of the pack (again, we're assuming it's homogenous so it's just the specific heat of the cell)

Sample Output

In general, the output of a heating simulation with no active flow control should look like a standard 1st order response of a system to an input. The temperature will rise from the heat rate generated from resistive dissipation, which will also increase the rate of radiative and convective heat transfer away. Eventually, this leads to an equilibrium where the temperature will settle at as these forces match each other sustainably.

Here's an example: