Ageing and Thermal Management

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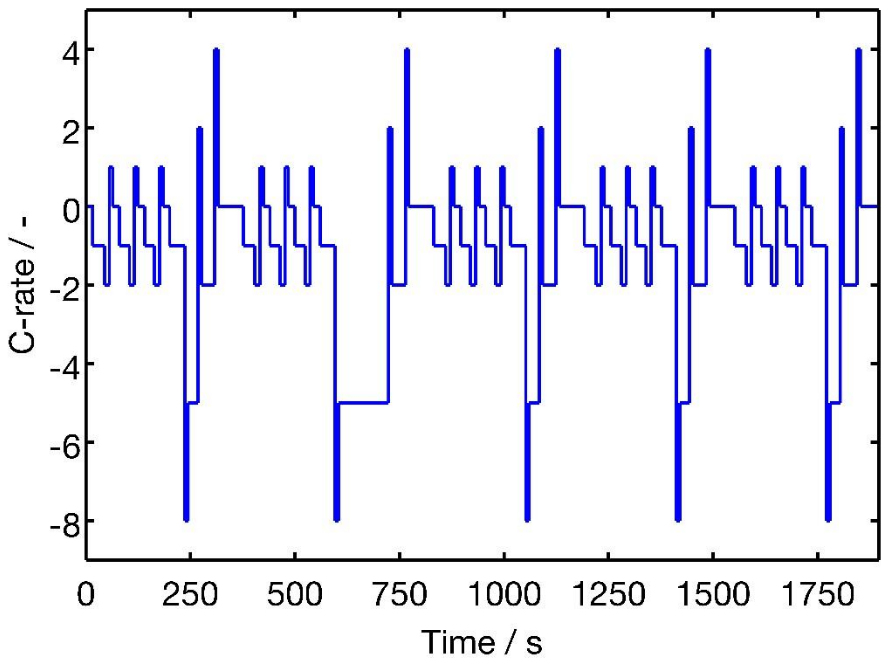
Nordbatt2, Trondheim, 2nd dec 2015

Thermal Battery Characterization

See also: Henrik Lundgren et al, Journal of The Electrochemical Society,163 (2) A1-A9 (2016)

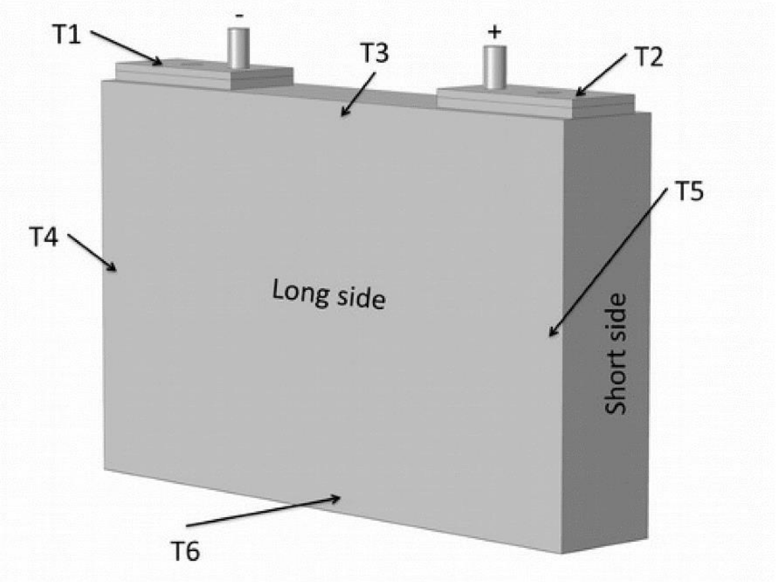
What is the Internal Battery Temperature?



Hybrid Cycle used at Scania CV

Experimental Setup

- Large format 25 Ah NMC/graphite cell (DIN SPEC 91252:2011-01)
- Temperature Probes
- Heat sink at 25 °C, placed at bottom
- Hybrid load cycle up to 8C

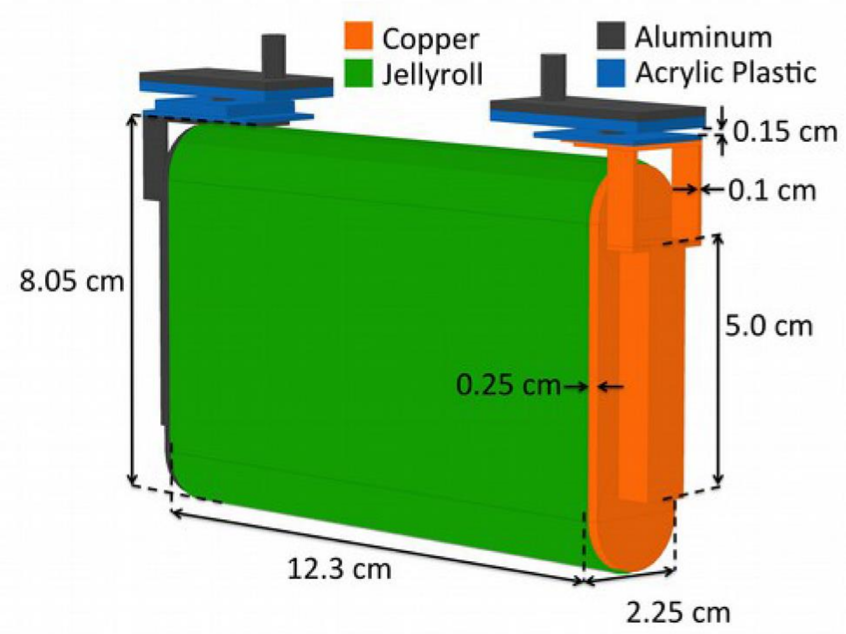


Temperature probe positions

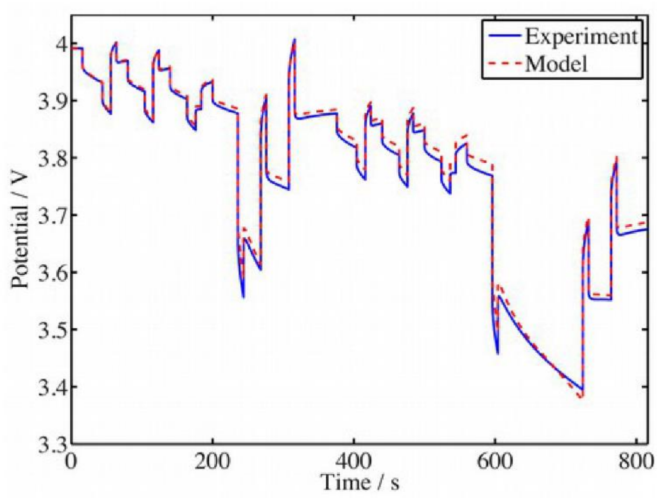
Model Setup

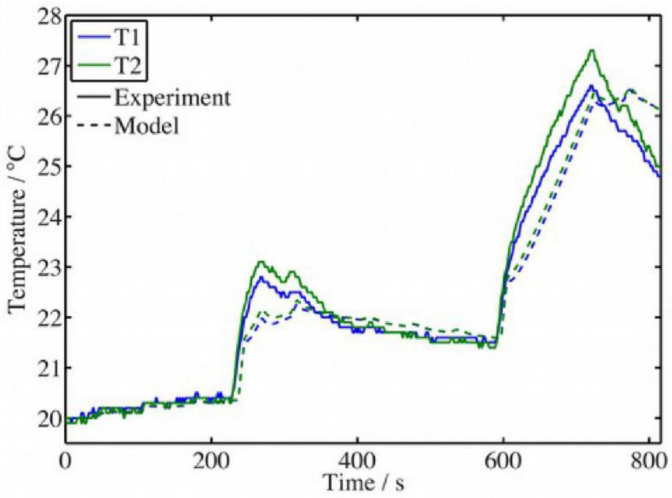
- Heat transfer model
  - Full 3D geometry
  - Joule heating in current collectors
  - Electrochemistry heat sources from electrochemical model in jelly roll

- Electrochemical battery model
  - Doyle/Newman model with reduced dimension to 1D(+1D) using average jelly roll temperature

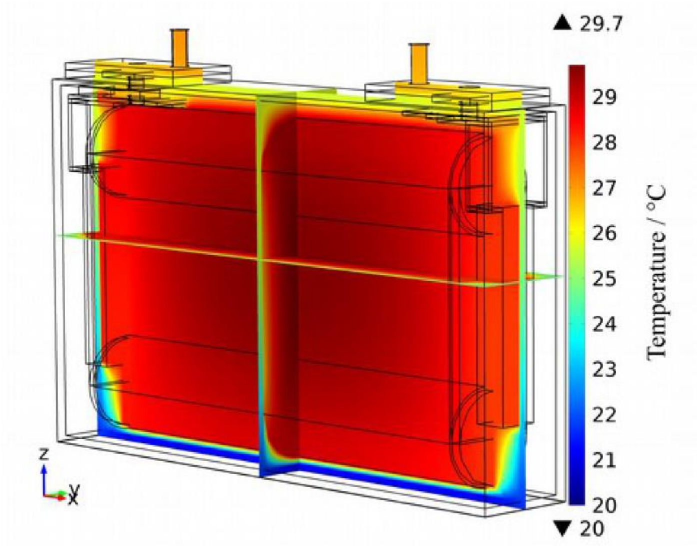


Model Validation

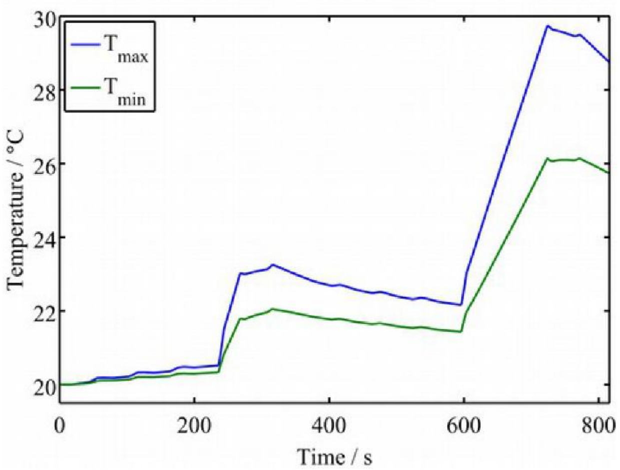




Internal Temperatures



Internal Temperatures at 724 s



Max/Min Jelly Roll Temperatures

Conclusions from Thermal Characterization

- Orientation matters - long side cooling will cause higher internal gradients

- Main path for heat flux is between jelly roll and can – not through current collectors

- Largest internal temperature differences < 5 °C
  - Temperature-induced local differences in current density and state-of-charge are expected to be small
  - Temperature-induced non-uniform ageing effects would be expected, but small

Battery Ageing Modelling

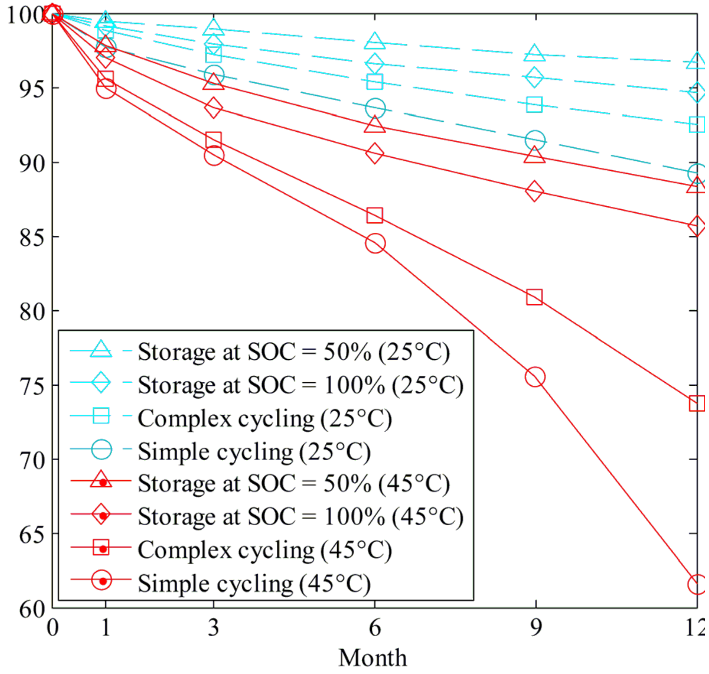
See also: Henrik Ekström and Göran Lindbergh, Journal of The Electrochemical Society, 162 (6) A1003-A1007 (2015)

Experimental Data: LFP/Graphite 18650 cell

Ageing rate depends on:

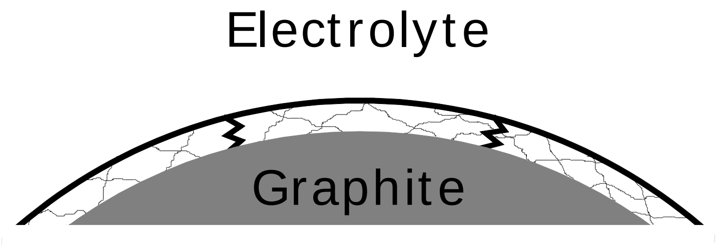
- State-of-charge
- Current
- Temperature
- History

Data: Safari and Delacourt, JES 158 A1123 (2011)



SEI Layer Growth Model

- SEI growth due to reduction of an electrolyte species
- Transport occurs through covering and cracked regions of the layer
- SEI forming electrode kinetics depends both on potentials and layer transport limitations
- Cracked area is proportional to graphite expansion rate

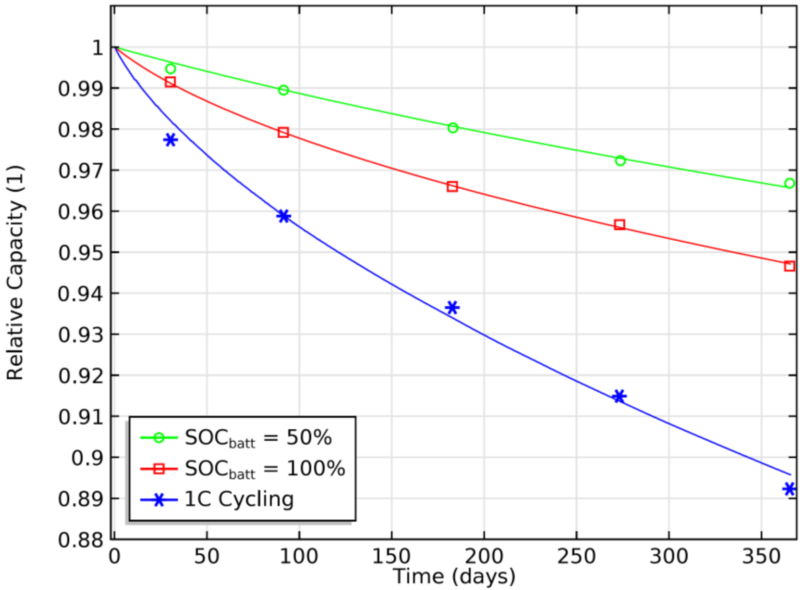


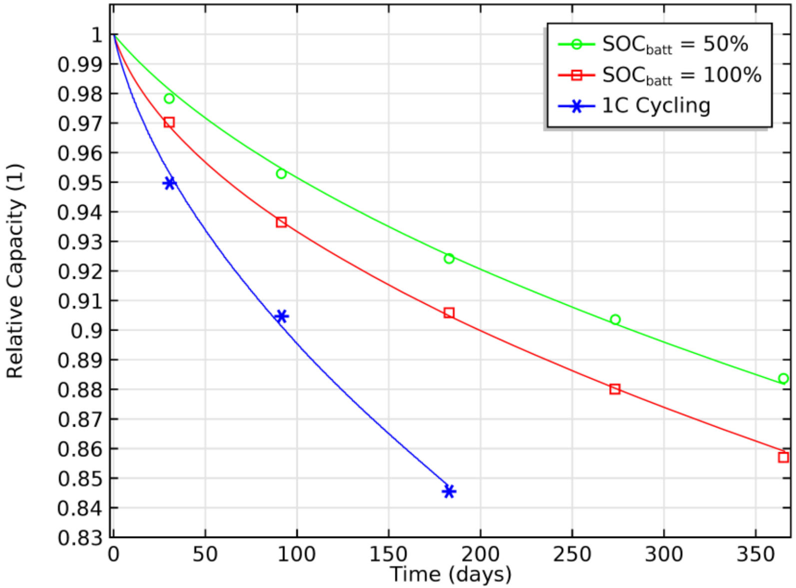
SEI Equation and Model Parameters

$$I_{\mathrm{SEI}} = -(1 + HK_{\mathrm{crd}})\frac{JI_{\mathrm{1C}}}{\exp(\frac{\alpha\eta_{\mathrm{SEI}}F}{RT}) + \frac{Q_{\mathrm{SEI}}fJ}{I_{\mathrm{1C}}}}$$

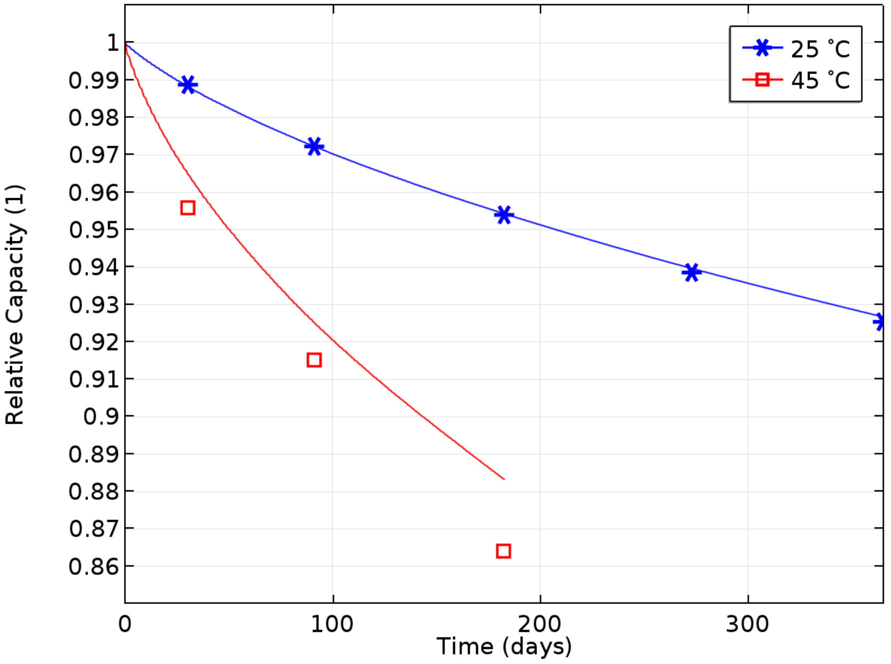
- α – elektrokinetic transfer coefficient
- *J* – lumped kinetic parameter
- *f* – lumped SEI layer diffusion limitation parameter
- *H* – lumped crack area
- One set of four parameters needed for each temperature

Model Fitting Results at 25°C and 45°C





Model Prediction Tests



Future and Ongoing Work

- Temperature Characterization
  - Temperature probes inside cells
  - Temperature controlled current cables

- Ageing
  - Single electrode experiments
  - Graphite electrode ageing models at higher currents
    - …what would be the effect of the high current pulse?
  - Positive electrode materials
    - … what is the effect of the NMC positive electrode?

Finally, some homework for you…

…we need better temperature dependent data on

- capacity and power fade
- heat conductivities
- heat capacities
- electrode kinetic parameters
- equilibrium (open-circuit) potentials
- lithium diffusion in the active materials