Cell Cooling Coefficient, thermal gradients and their implications on degradation

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Introduction

Active cooling of Li-ion battery packs is a key feature of many current electric vehicles, due to the need to maintain safe and optimal temperatures to reduce cell/pack degradation. Choosing the right surface for cooling the cells is critical to optimising performance. Predicting the thermal operation of a cell under a specific cooling system will often require specific testing or extensive modelling and validation. The subsequent effect on degradation may only be determined through high complexity models or long term degradation studies.

In this work we combine experimental studies on degradation and thermal capability of different cooled surfaces, with discretised 3-D electro-thermal models to highlight the difference between external and internal cell thermal gradients and the subsequent effects on critical performance and degradation.

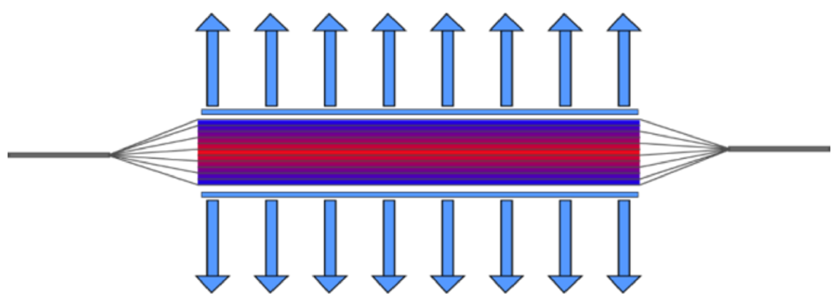
Pouch cell

Cell Cooling Coefficient (CCC)

The CCC is a thermal metric for Li-ion cells that defines their heat rejection capability through specific surfaces. It is calculated by dividing the heat rejected through the specified surfaces of the cell by the thermal difference developed across the body of the cell.

Cooling Methods

Surface Cooling



Tab Cooling

Measured CCC values

5Ah Kokam pouch cell:

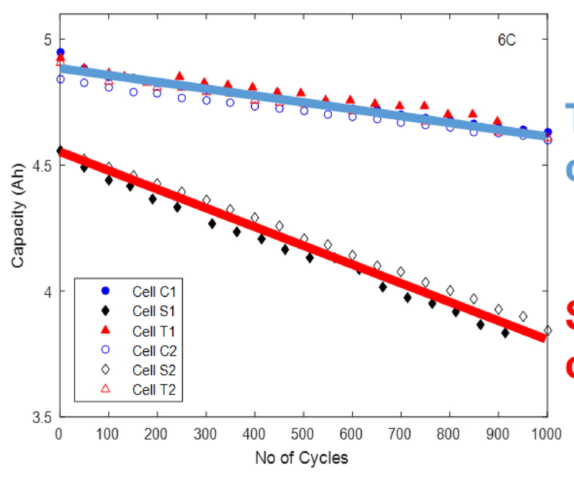
CCC_{tab} (W/K)	0.332
CCC_{surf} (W/K)	0.987

See reference [1]

Single sided surface cooling can reject 3 times more heat for a given thermal difference compared to tab cooling, indicating surface cooling is the preferred method. However…

Experimental Degradation Study

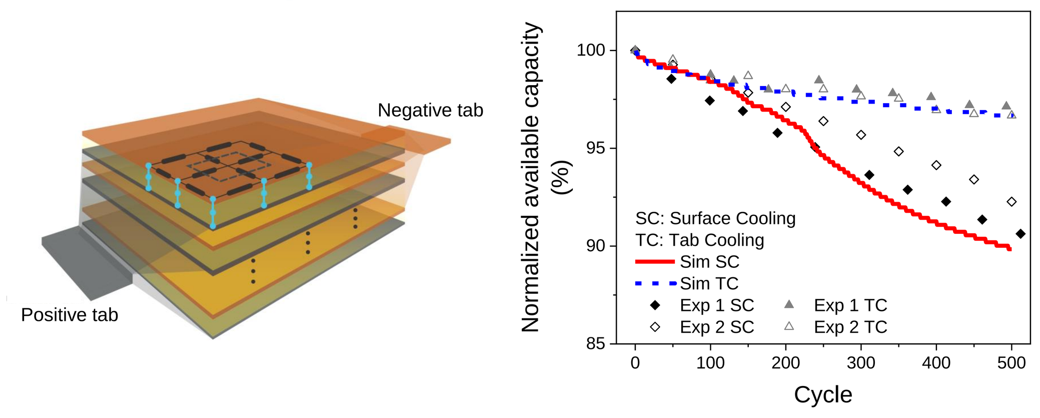
- Surface cooling results in significant loss to useable capacity & energy
- **Surface cooling results in a degradation rate 3 times higher than tab cooling**

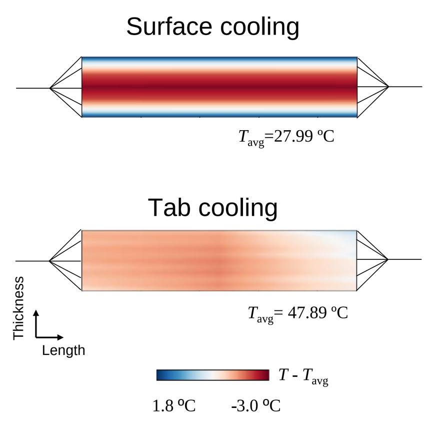


See reference [2]

High-rate degradation study (2C charge, 6C discharge) under tab cooled versus under dual sided surface cooling on 5Ah Kokam pouch cell, with cooled surfaces held at 20°C using water cooled Peltier elements.

Experimentally validated degradation model





- Accelerated degradation reproduced in a distributed thermally-coupled ECN model reflecting the real inner structure of the cell
- The model gives access to otherwise unmeasurable internal states in the cell: local T, SOC and SOH
- **Surface cooling: higher internal thermal gradient, lower average T**
- **Tab cooling: lower internal thermal gradient, higher average T**

Effect of thermal gradients on degradation

- CCC correctly predicted that tab cooling would lead to a hotter cell than surface cooling
  - **CCC gives the gradient from cooling to maximum external cell temperature**
- Model results predict that internal thermal gradients within the electrode stack are higher in surface cooling
  - **Electrode stack thermal gradient is the most critical for degradation**
- **Cell-level inhomogeneities (I, T, SOC, etc.) are critical to correctly modelling degradation**

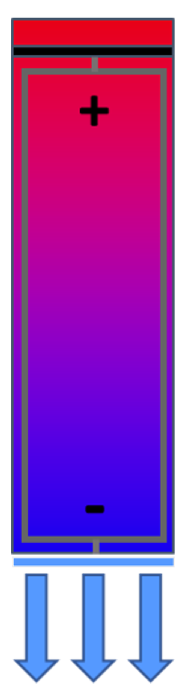
Cylindrical cell

CCC for cylindrical cells – how to do it?

The highly compact nature of cylindrical cells makes it more difficult to make CCC measurements

Base Cooling

- Base cooling is a highly popular and simple cooling strategy for cylindrical cells
- The negative electrical connection needs to be made at the positive end of the cell, at the shoulder
- Compact size makes it more susceptible to influence from external boundary conditions



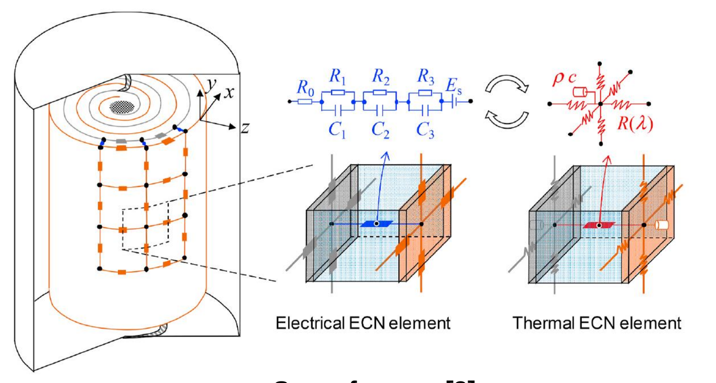
Measured CCC values

5Ah LG M50 21700 cell:

CCC_{base} (W/K)	0.139

- CCC for this base cooled 21700 cylindrical cell is approx. 60% lower than the tab cooled pouch cell
- **Will this result in large internal gradients and high degradation rates?**

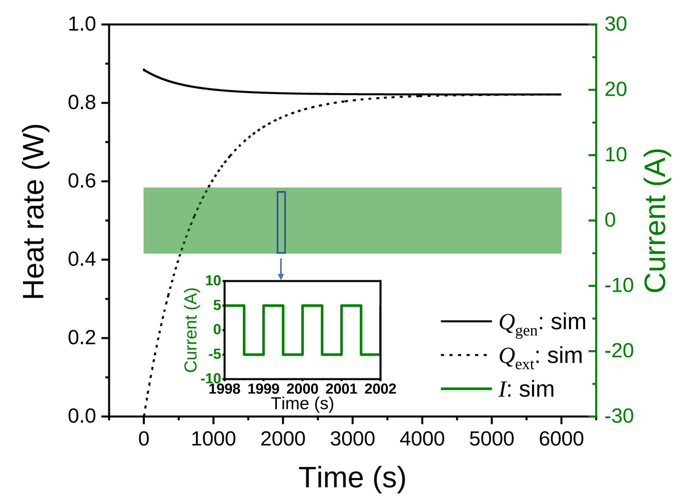
Model and CCC simulation

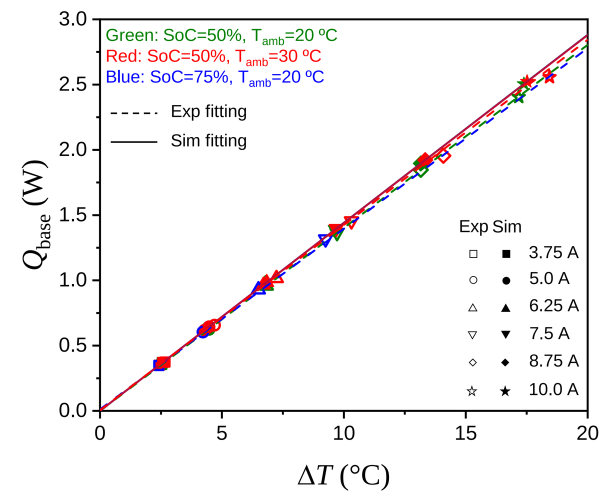


See reference [3]

As for pouch cell, model built:
- Equivalent circuit network (ECN) model
- Electro-thermal coupled
- 3D distributed
- Detailed internal structures

Experimental set-up for CCC simulated in the model identically:
- Pulsing current
- Steady state simulation
- Extreme semi-adiabatic boundary conditions
- Decent computational speed, as ECN model is efficient

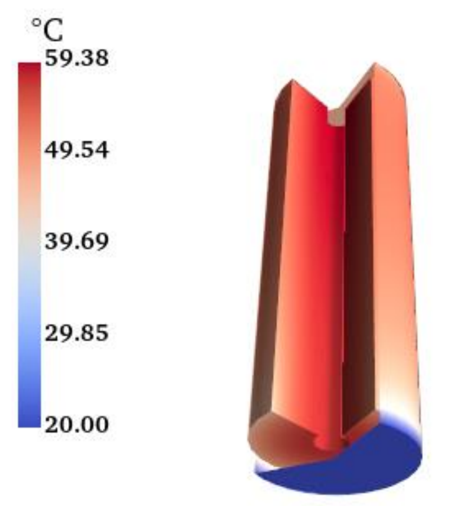




Model predictions for CCC value for cylindrical cell
- Good fit to experiments
- Validated for different currents, SoCs, and Ts
- All cell temperatures modelled with good agreement to experiment

Thermal gradient predictions for cylindrical cell

Prediction of fast discharge (2C) under base cooling for LG M50



ΔT_{Can} = 26.11 °C

$\Delta T_{Jellyroll}$ = 1.91 °C

- As the CCC predicts, base cooling leads to large external cell gradient
- The model predicts the internal jellyroll thermal gradient is significantly smaller due to the relatively high thermal resistance between the jellyroll and can
- **Degradation rate may be significantly lower than the external gradient would suggest**

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Reference

[1] Hales et al., *Journal of the Electrochemical Society*, 2019, DOI: 10.1149/2.0191912jes
[2] Hunt et al., *Journal of the Electrochemical Society*, 2016, DOI: 10.1149/2.0361609jes
[3] Li et al., *Journal of Power Sources*, 2021, DOI: 10.1016/j.jpowsour.2021.229594.