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How do we thermal manage the Li-ion battery?
An inside out solution

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EV battery thermal management challenges

Electrification is inevitable, thermal management is critical for electric vehicle development, for better performance and safer operations. It is essential to:

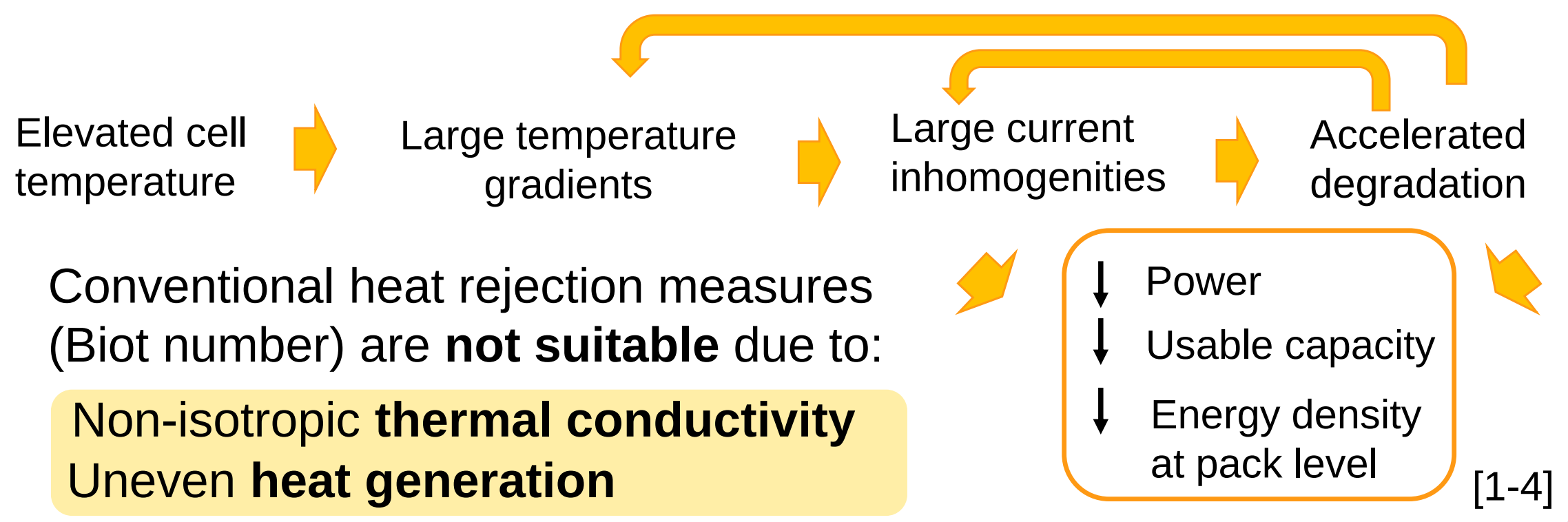
- ✓ Monitor cell heat generation & reduce thermal gradients
- ✓ Reduce the cost of thermal management
- ✓ Minimise risk of thermal runaway

↑Better **cooling method**
↑Longer usable **battery life**
↑Lower **operational costs**

Fig. 1: Li-ion battery pack (Nissan Leaf)

Lack of knowledge on cell heat rejection

Cell / pack **performance** is restricted by its **heat rejection capabilities**:



Elevated cell temperature → Large temperature gradients → Large current inhomogenities → Accelerated degradation

Conventional heat rejection measures (Biot number) are **not suitable** due to:

Non-isotropic **thermal conductivity**
Uneven **heat generation**

↓ Power
↓ Usable capacity
↓ Energy density at pack level

[1-4]

Safety: the problem with current cell designs

High temperatures are observed in batteries with poor heat rejection pathways

As a result, **thermal runaway is an increased risk**

Consequence is over-engineered thermal management solutions

e.g. Tesla Model 3 battery pack is only **57% mass efficient**

Thermal management system is **25% of the total battery pack cost**

Pack Designers choose the most energy dense cells

Cell manufacturers must optimise energy density

Cells are very energy dense, but unable to effectively reject heat

Is there another solution?

[1]

2 essential methods to cool lithium ion batteries

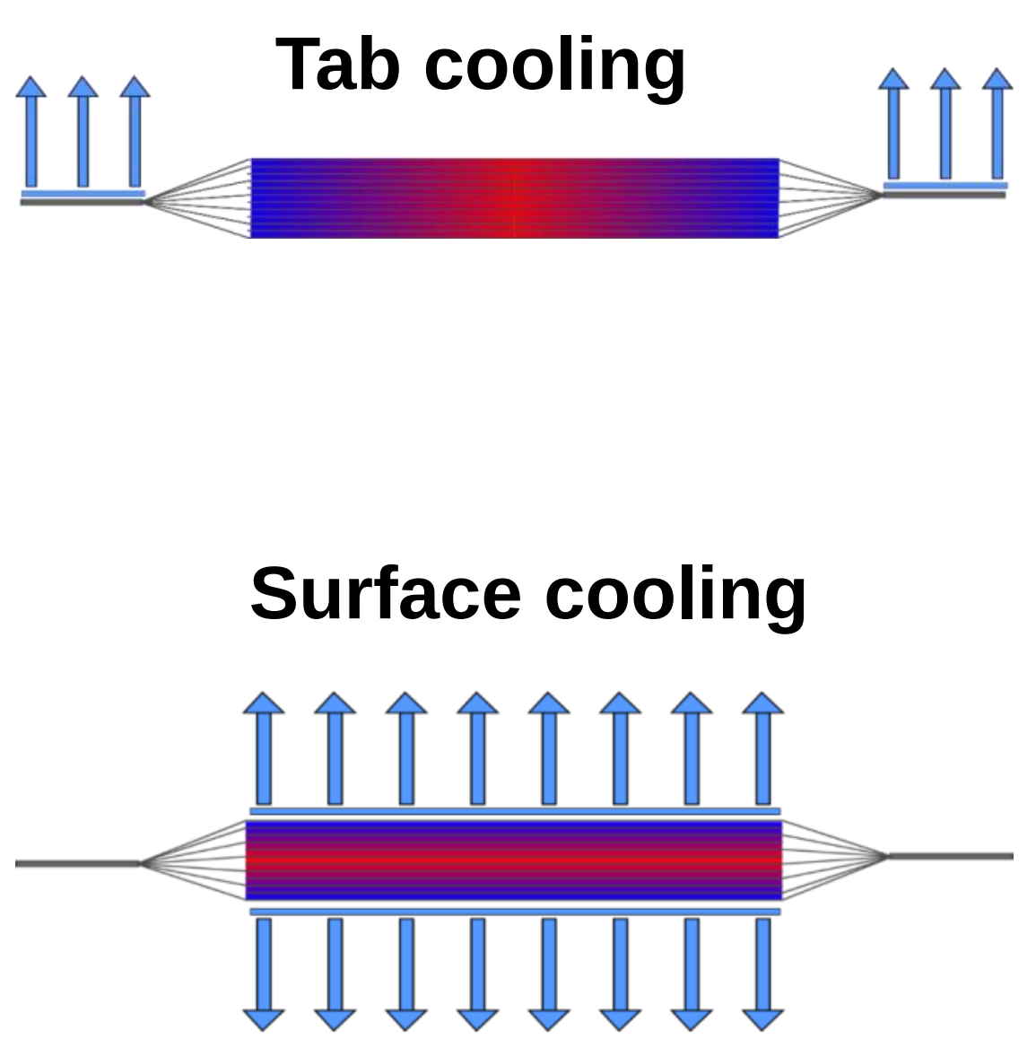


Fig. 2: Cooling strategies

Tab cooling

- Some thermal gradient within a layer
- Very low layer-to-layer thermal gradients
- **Very low layer-to-layer current inhomogeneities**
- **Each layer behaves the same**
- **Each layer is loaded evenly over a dynamic drive cycle**
- **Higher average temperatures (current cell designs)**

Surface cooling

- Low thermal gradients within a layer
- Significant layer-to-layer thermal gradients
- **High cooling rates possible, lower average temperatures**
- **Significant layer-to-layer current inhomogeneities**
- **Layers behave differently to one another**
- **Layers are loaded unevenly over a dynamic drive cycle**

[1-2]

Thermal Gradients study

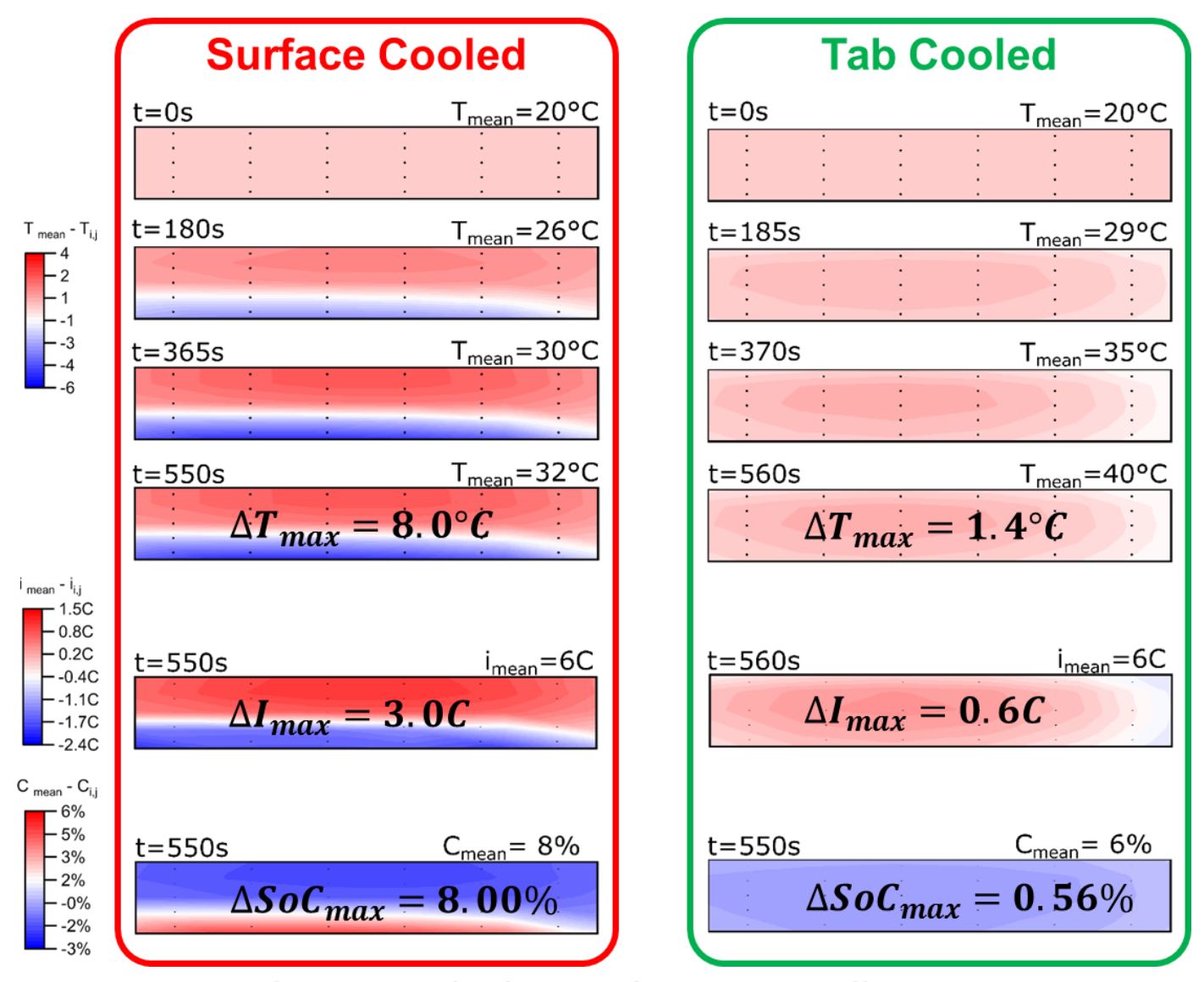


Fig. 3: Modelling of thermal gradient effect

Surface cooling
Large thermal gradient
Low average temperature

Tab cooling
Minimum thermal gradient
High average temperature
(bottleneck is the tab)

[3]

Increasing heat removal rate for tab cooling?

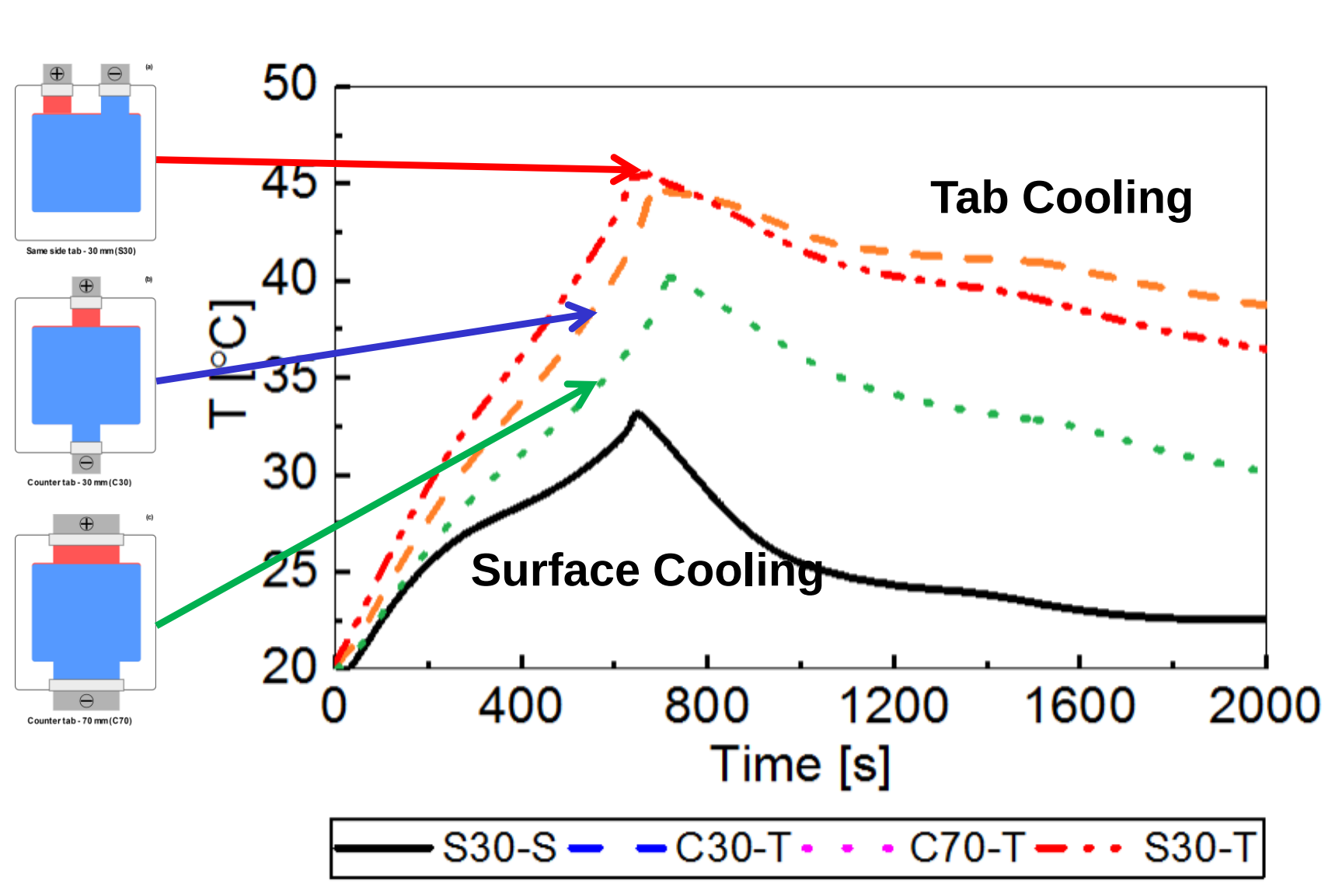


Fig. 4: Temperature rise of cells with various tabs configuration

Yes

•Counter-sided tabs are better

•Wider tabs are better

But not enough to equal surface cooling.

These cells were used to re-parameterise & validate the previous model*, and the model used to explore more design variables [3,6]

Optimising the cell design

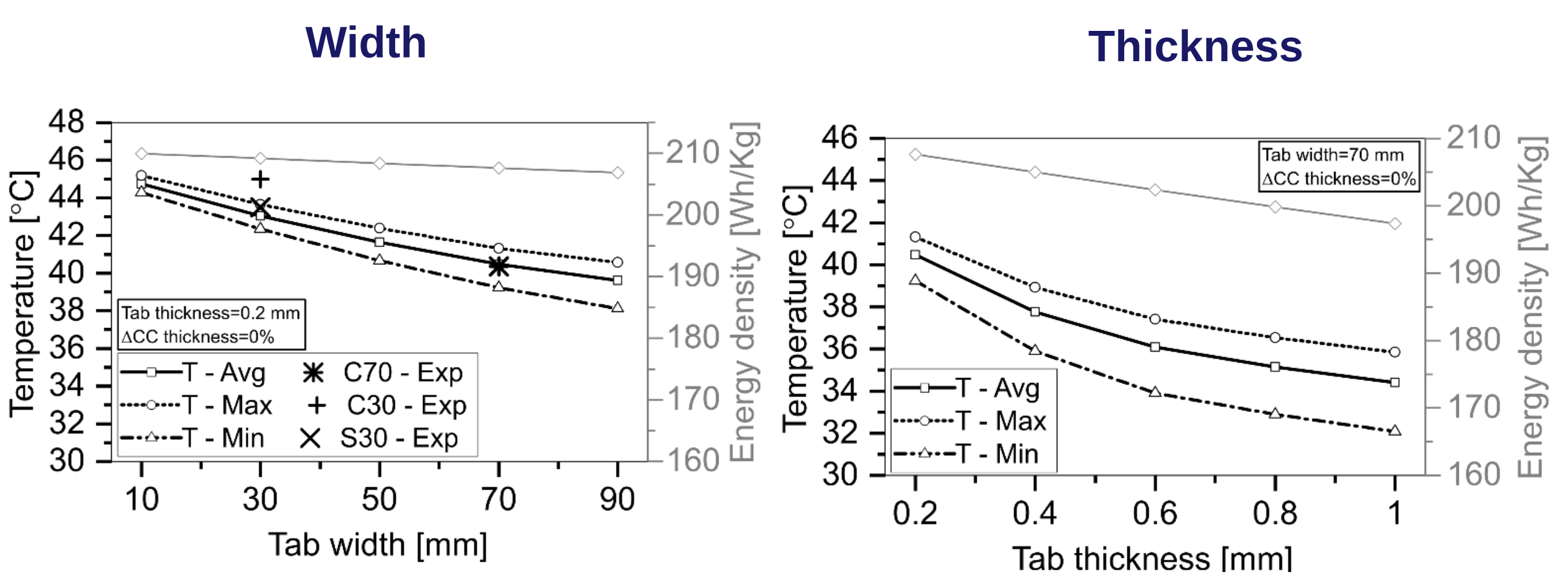


Fig. 5: Temperature rise of cells with various tabs configuration: Width and Thickness

Increasing tab thickness is extremely effective in reducing average temperature: Make tab cross-sectional area more comparable to total current collector cross-sectional area

The penalty on energy density is relatively small [6]

Does this work for large format cell ?

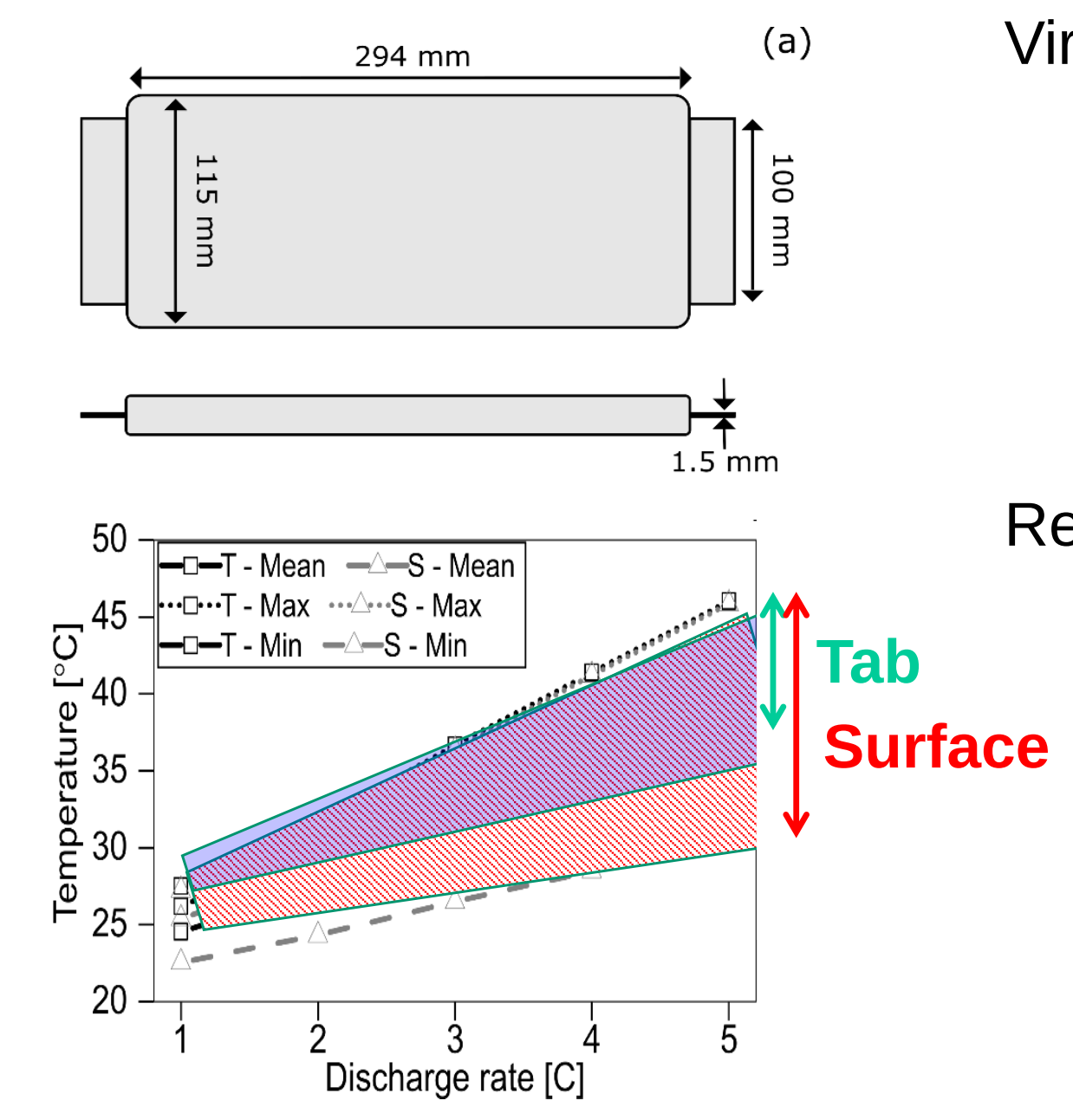


Fig. 6: Virtual cell simulation

Virtual cell

- Similar to LG Chem E63
- Capacity: 51.3 Ah
- Aspect ratio: 2.6
- Tab thickness:0.2 ->> 1.5mm
- Tab width: 100 mm

Results

- Same target T_{max}
- Comparable cooling rates
- Much smaller thermal gradient for tab cooling
- Expected, better performance, slower degradation

[1] [6]

CCC: Cell Cooling Coefficient

1. How to compare **thermal performance** from different cells?
2. How to evaluate cell **heat rejection** rate for a particular **thermal management strategy** (i.e. tab cooling)?

New metric needed to quantify cell heat rejection rate through a thermal pathway:

CCC ($W.K^{-1}$)

- Quantifies the cell's heat rejection capabilities
- Based only on a cell's physical design
- Independent of cell chemistry, format or geometry

[5]

How do we improve cell thermal management?

Relevant Datasheet Information: LIB A	
Capacity (Ah)	5
Energy Density (Wh/kg)	140
Rated Charge Rate (C-Rate)	2
Rated Continuous Discharge Rate (C-Rate)	30
Rated Pulse Discharge Rate (C-Rate)	50
Cell Cooling Coefficient (W/K)	**??**

Energy Performance

Power Performance

Thermal Performance

What temperature gradient do you need to remove 1W of heat from your cell?

1. To be able to **quantify a cell's heat rejection** capabilities
2. Then to **redesign cells** to optimise this to improve internal thermal pathways

The first part needs to be:

1. *A metric for cell designers to enhance*
2. *A standard against which all cells may be compared*
3. *A tool for battery pack design engineers to use in the initial design stages*

$$CCC_i = \dot{Q}_i / \Delta T_i$$

1. A **tool** to estimate the rate of heat rejection for a given thermal gradient
2. A **constant** for a particular cell and surface to be managed
3. A **metric** against which any two cells may be compared
4. A **standard** for competition and improvement

[5]

CCC: Tabs

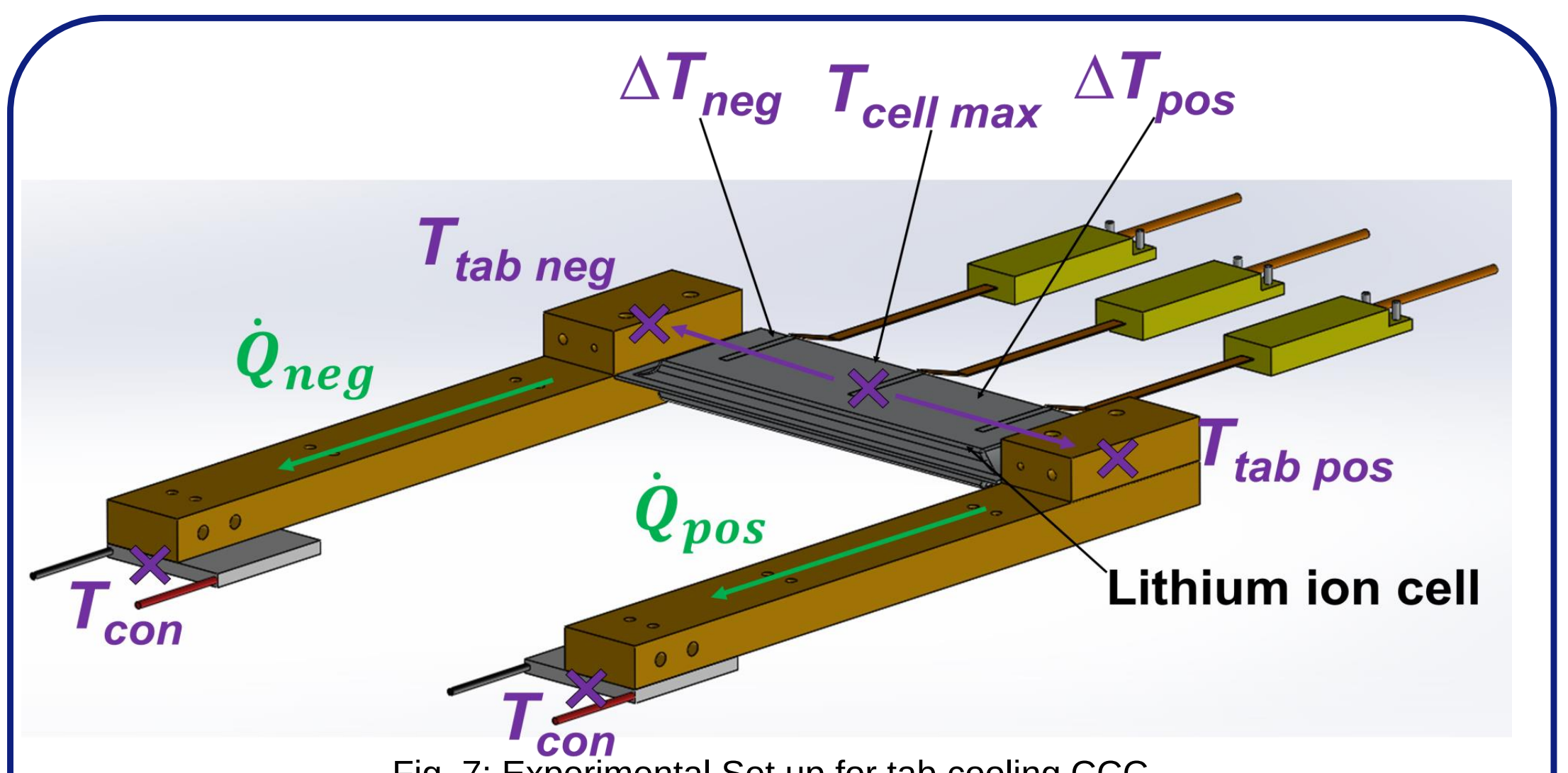


Fig. 7: Experimental Set up for tab cooling CCC

$$CCC_{tab} = (\dot{Q}_{neg} + \dot{Q}_{pos}) / 0.5(\Delta T_{neg} + \Delta T_{pos})$$

[5]

$$CCC_{neg} = \dot{Q}_{neg} / \Delta T_{neg}$$

$$CCC_{pos} = \dot{Q}_{pos} / \Delta T_{pos}$$

How to use CCC – Evaluate Cells (CCC ratio)

Large form factor 20Ah A123

	A123
CCC_{tab} (W/K)	0.243
CCC_{surf} (W/K)	4.081
CCC_{tab}/CCC_{surf}	0.060

Bad

2C cycling at 20°C cooling surface temperature

Short life = tab cooling, long life = surface cooling

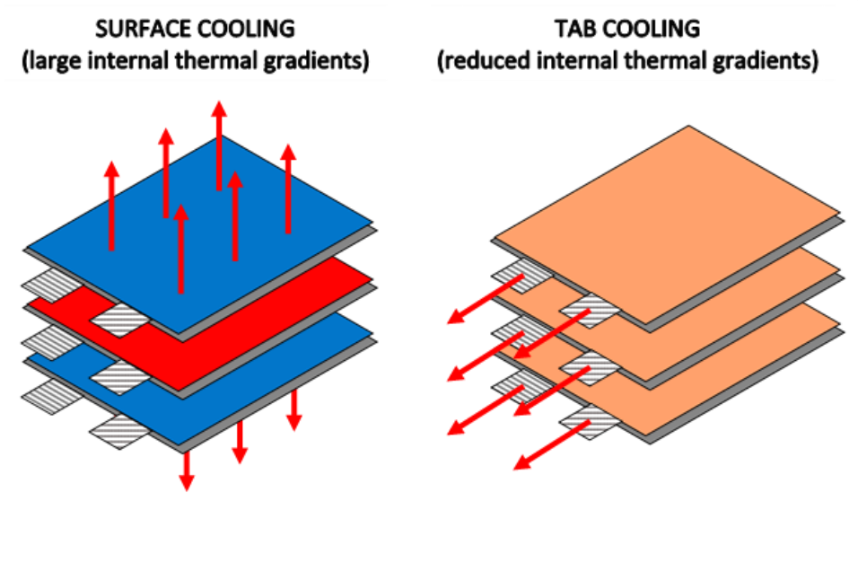
High power 5Ah Kokam

	5Ah Kokam
CCC_{tab} (W/K)	0.332
CCC_{surf} (W/K)	0.980
CCC_{tab}/CCC_{surf}	0.339

Better

6C cycling at 20°C cooling surface temperature

Short life = tab cooling, long life = tab cooling



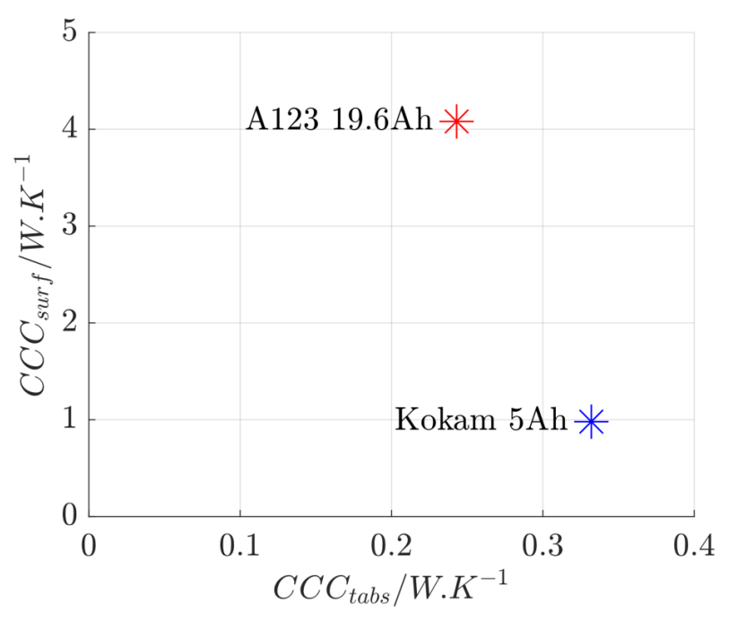


Fig. 8: CCC for different cells [5]

Summary

1. Lithium ion battery industry has fallen into the trap of 'sub-system optimisation' and optimised cells for energy density
    a. As a consequence many cells are designed poorly for thermal management
    b. It is often so bad it actually reduces useable energy and lifetime
2. Introduction of Cell Cooling Coefficient, as a standard metric to compare how easy or hard it is to cool a cell
    a. Immediately useful for cell evaluation and system design
    b. Potential to revolutionise battery industry if it triggers competition to design better cells
3. A virtual cell has been redesigned showing how straightforward it is to open up the thermal bottleneck and improve performance
    ❖ Cell suppliers and users should work together to optimise the whole system

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