KRAFTWERK Batterie BATTERIETAG NRW

BATTERY CONFERENCE 2015
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TUM CREATE

Influence of Cell Size on Performance of Lithium Ion Battery

Raghavendra Arunachala[1], Sabine Arnold[1], Lemuel Moraleja[1], Tim Pixis[2], Andreas Jossen[2], Juergen Garche[3]

[1]TUM CREATE Ltd, Singapore

[2]Institute for Electrical Energy Storage Technology, Technische Universität, München

[3]FCBAT Ulm, Germany

E-mail: raghavendra.arunachala@tum-create.edu.sg

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Overview

- Motivation
- Experimental
- Simulation Model
- Results and Discussion
- Conclusion and Outlook

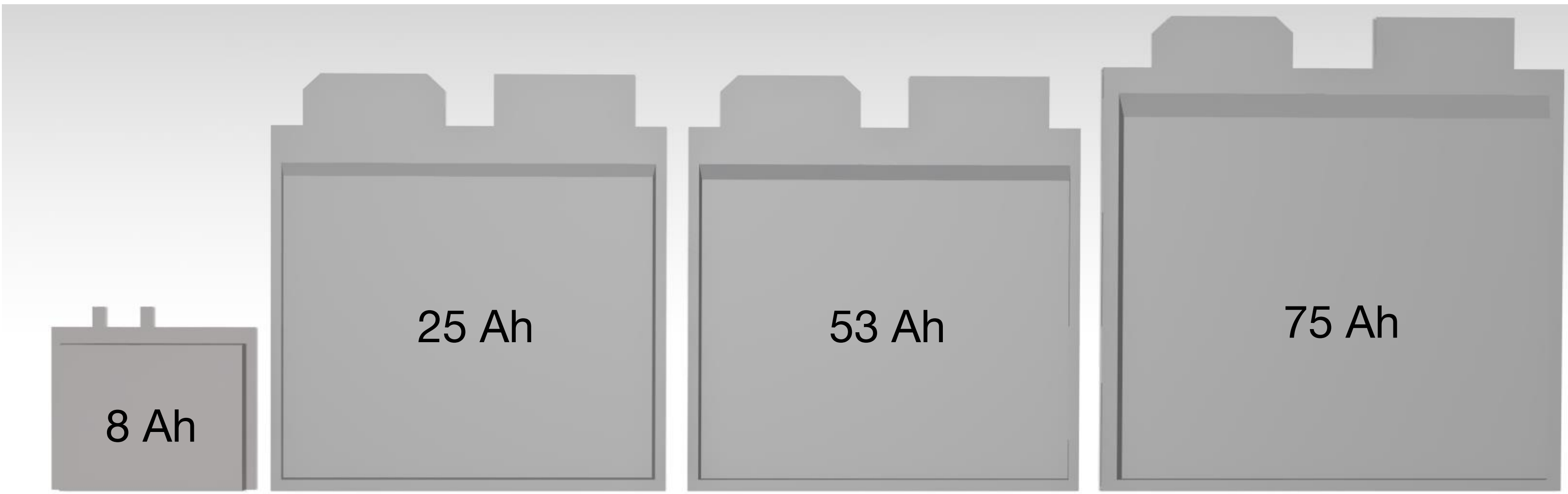
Motivation

- Large format cells are becoming population in EV Applications
- Lesser connections and fewer cells to monitor for BMS unit
- Different designs and approaches to produce large format cells

- Problems
  - Safety challenges due to high energy content
  - Temperature non-uniformities
  - Inhomogeneous current density and SOC distribution

- Consequence
  - Accelerated localized degradation of power performance
  - Lifetime reduction
  - Effects on battery safety
  - Different Concepts of thermal management

Experimental (1/4)



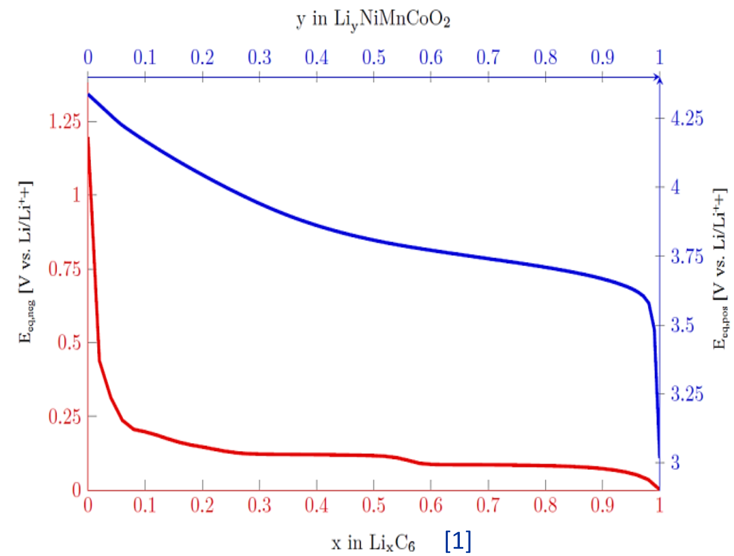
Nominal Capacity (Ah)	Size (mm) (WxHxT)	Weight (g)
8	105x100x7.05	157
25	225x224x6	570
53	225x224x12.3	1,200
75	263x266x11.2	1,500

Cathode: Nickel Manganese Cobalt Oxide
Anode: Graphite
Nominal Voltage: 3.7 V
Electrolyte: $LiPF_6$ with EC:EMC

Experimental (2/4)

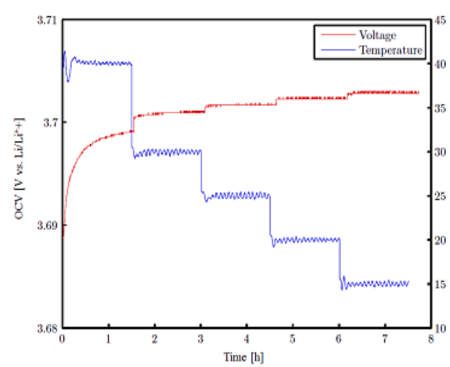
OCV measurement of NMC Half cells

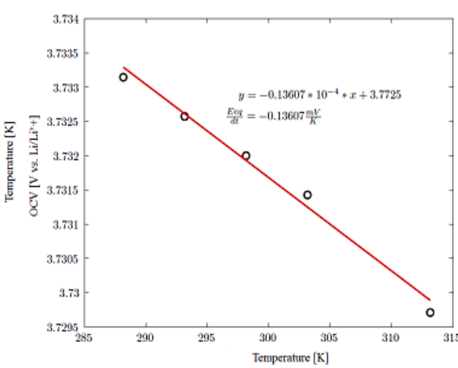
Command	Parameter	Limit
Charge	I = 0.02CA	U > 4.25 V
Discharge	I = 0.02CA	U < 2.7 V
Charge	I = 0.02CA	U > 4.25 V



Entropic Measurements

- 21 Measurements over SOC
- Temperature cycle at 15, 20, 25, 30 & 40°C
- OCV at the end of 90 min pause



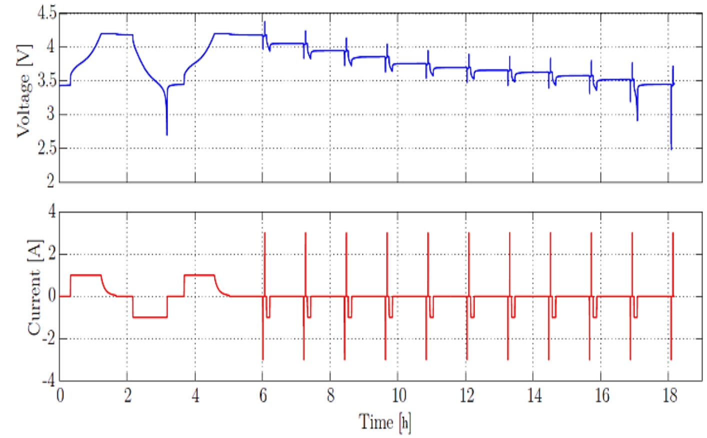


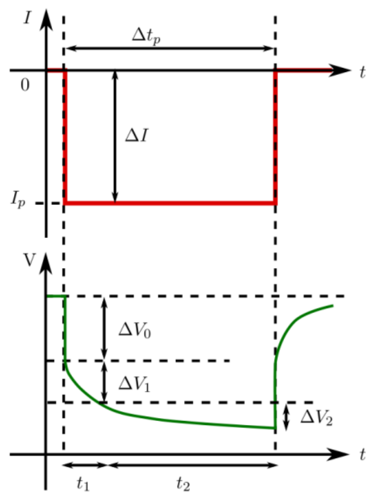
[1] K. Lee, "Voltage Relaxation of LiyFePO4 based Batteries," Master Thesis, Technical University Munich, Munich, 2014

Experimental (3/4)

- HPPC-Measurements:
  - 11 Measurements over SOC
  - 15°C, 25°C, 40°C
  - Short time transient resistance
  - Long time long time resistance
- EIS Measurement:
  - 14 Measurements over SOC
  - 15°C, 25°C, 40°C, 50°C
  - 6kHz – 10mHz
  - Internal resistance

Test profile for 25 Ah cell at 25°C





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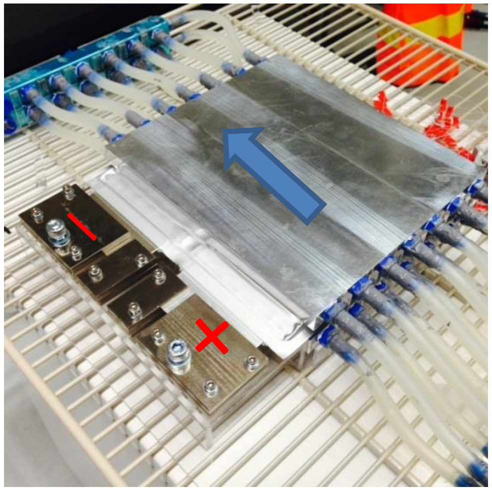
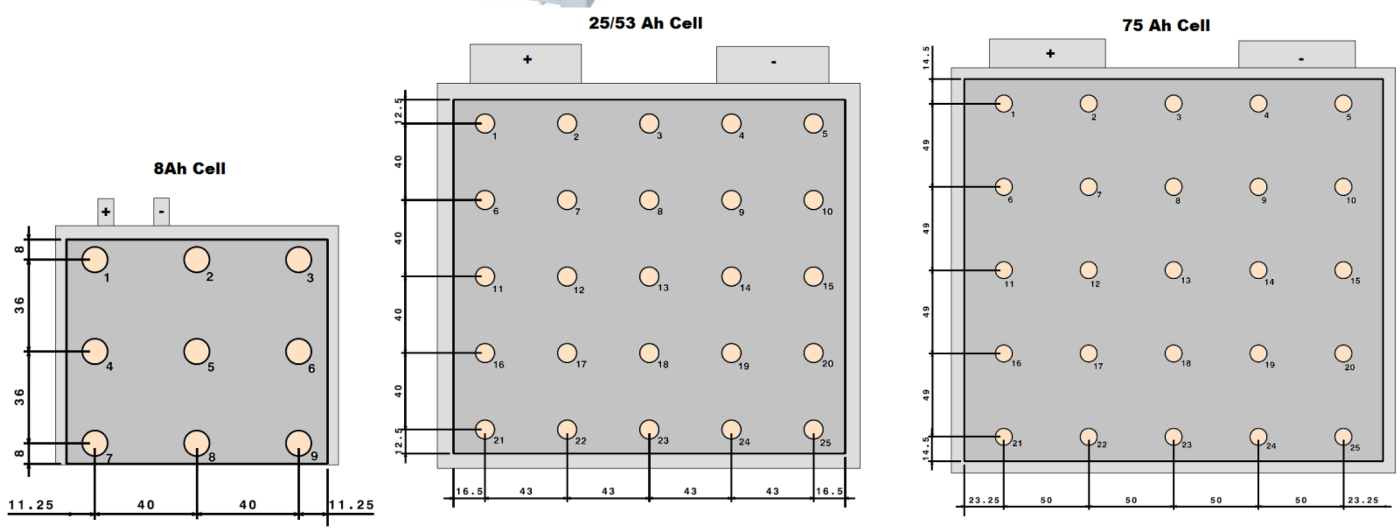
Experimental (4/4)



Command	Parameter	Limit
Charge	I = 1CA U = 4.2 V	I< 0.05 CA
Pause	3 h	
Discharge	I = 0.5, 1, 2, 3 C U= 2.7 V	I < 0.05 CA
Temperature	T = 15, 25 & 40°C	



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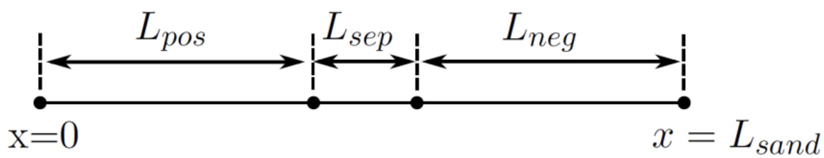
Simulation Model(1/5)

- Scale up approach
- Microscopic parameters are same
- Surface area, tab positions and size are different
- 3 scale modelling approach with coupling
- Simulation to study temperature and voltage

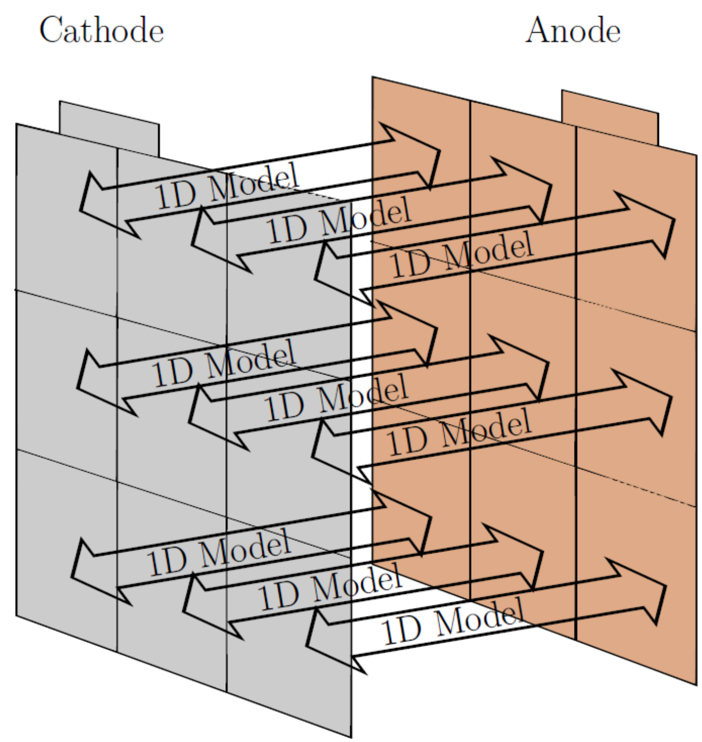
Simulation Model(2/5)

Electrochemical Model



Basics :

- Porous Electrode Theory
- Concentrated Solution Theory
- Ohm's Law
- Fick's Law
- Butler-Volmer Equation

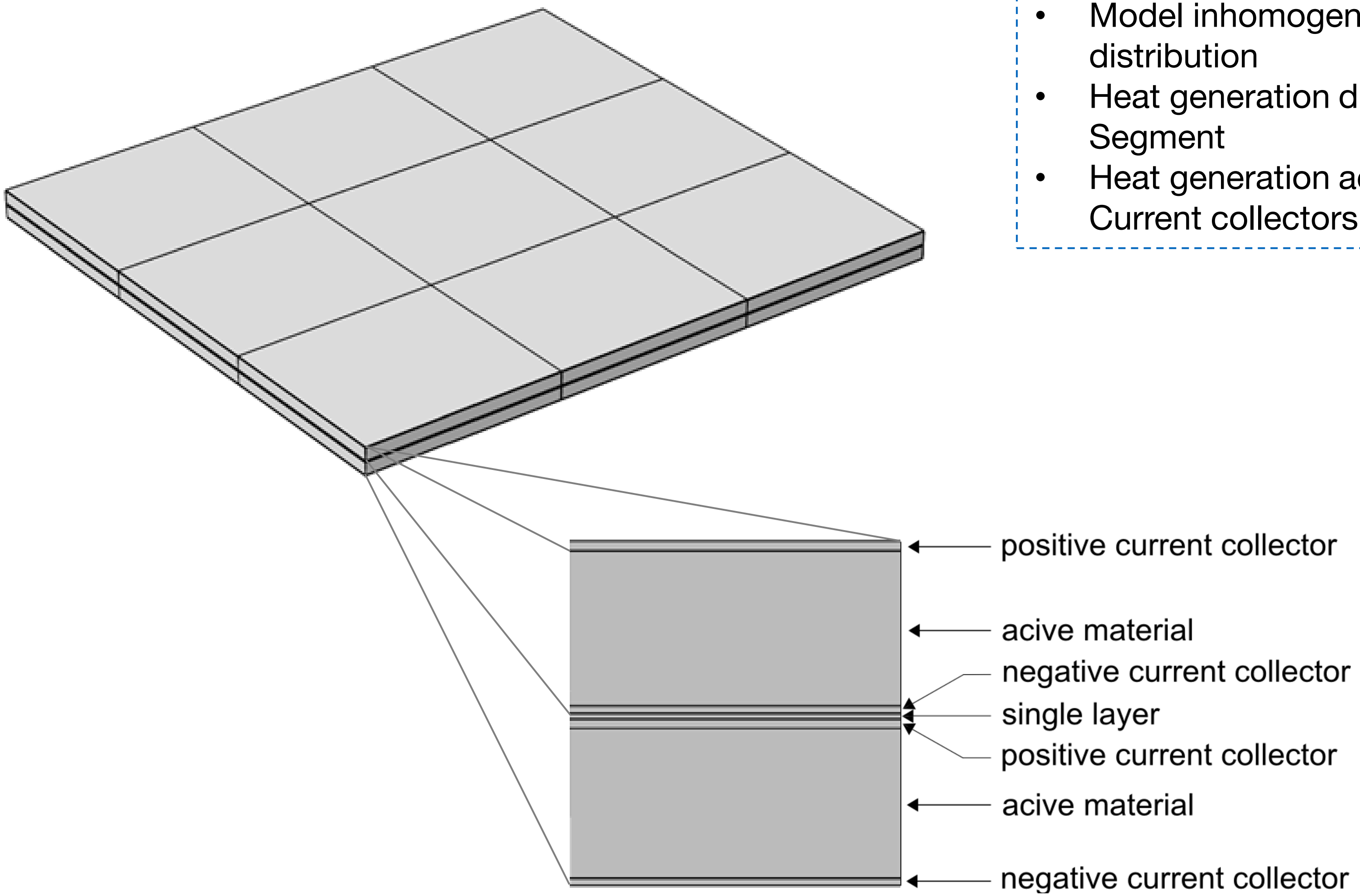


- 9 electrochemical sub-models
- Current collector segmented into 9 pieces
- Model non-uniform electrochemical performance

Simulation Model (3/5)

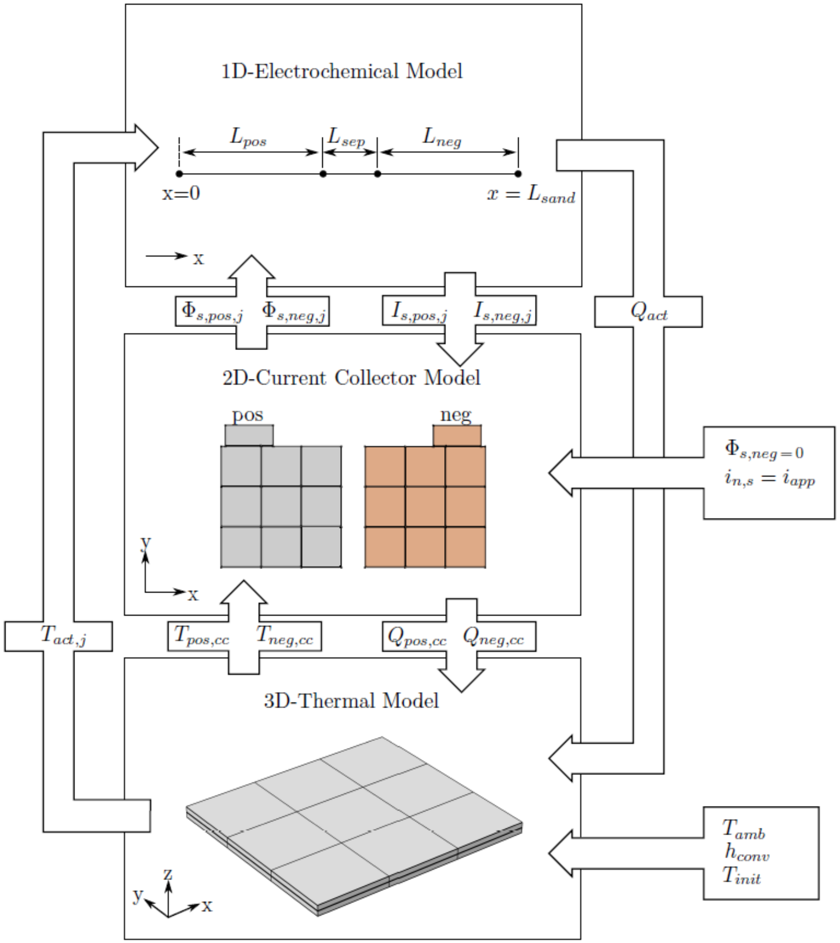
Thermal Model

- Model inhomogeneous temperature distribution
- Heat generation different in every Segment
- Heat generation active material and Current collectors



Simulation Model (4/5)

Schematic of coupling of sub models

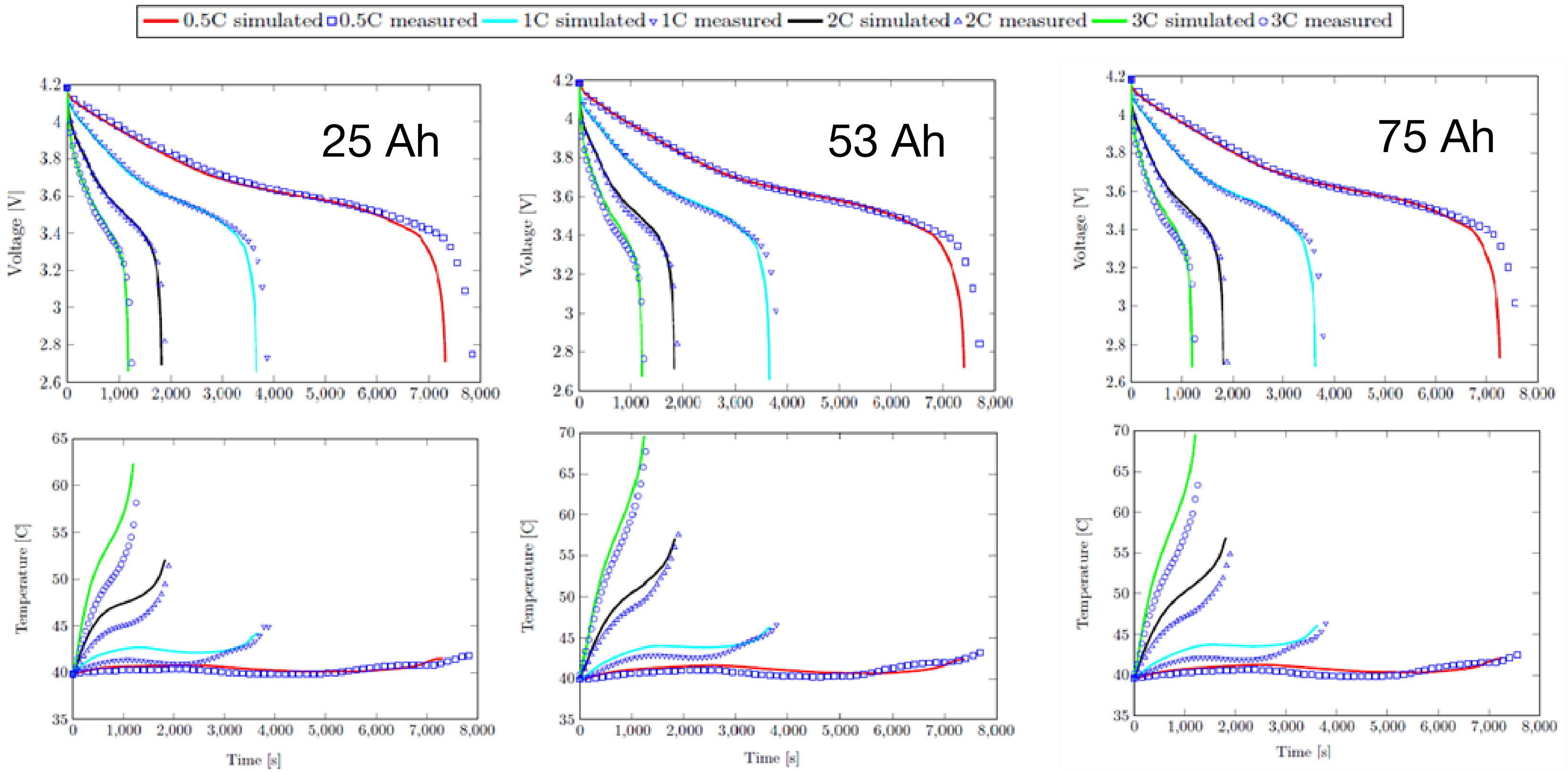


Simulation Model (5/5)

Term	Equations
Transport in solid phase	$\frac{\partial c_s}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}(D_s r^2 \frac{\partial c_s}{\partial r})$
Transport in electrolyte	$\varepsilon \frac{\partial c_l}{\partial t} = \nabla \cdot \varepsilon D \nabla c_l - \frac{i_l \cdot \nabla t_+^0}{F} + a j_n (1 - t_+^0)$
Potential in Solid Phase	$i_s = -\sigma_{eff} \nabla \varphi_s$
Potential in Electrolyte Phase	$\nabla \Phi_l = -\frac{i_l}{\kappa} + \frac{2RT}{F}(1 - t_+^0)\left(1 + \frac{d \ln f_\pm}{d \ln c_l}\right) \nabla \ln c_l$
Electrochemical Kinetics	$j_n = i_0[\exp\left(\frac{\alpha_a F}{RT}\eta\right) - \exp\left(\frac{\alpha_c F}{RT}\eta\right)]$ $\eta = \Phi_s - \Phi_l - U - F \cdot j_n \cdot R_{film}$ $i_0 = F(k_a)^{\alpha_c}(k_c)^{\alpha_a}\left(c_{s,max} - c_s\right)^{\alpha_c}(c_s)^{\alpha_a}(c)^{\alpha_a}$
Equilibrium Potential	$E_{eq} = E_{eq,ref} + \left(T - T_{ref}\right) * \frac{dU}{dT}$
Temperature distribution	$\rho C_p \frac{dT}{dt} = \nabla(k \nabla T) + Q_{irr} + Q_{conv} + Q_{rev}$ $Q_{irr} = Q_{ohm} + Q_{pol}$ $Q_{ohm} = \sigma_{eff} \nabla \varphi_s \nabla \varphi_l + \sigma_{eff} \nabla \varphi_l \nabla \varphi_l + \kappa_{eff} \nabla \ln c_l \, \nabla \Phi_l$ $Q_{conv} = h_{conv}(T - T_{ref})$ $Q_{rev} = I * T * \frac{\partial E_{eq}}{\partial T}$

Results & Discussion (1/10)

Terminal Voltage and Temperature Validation at 40°C

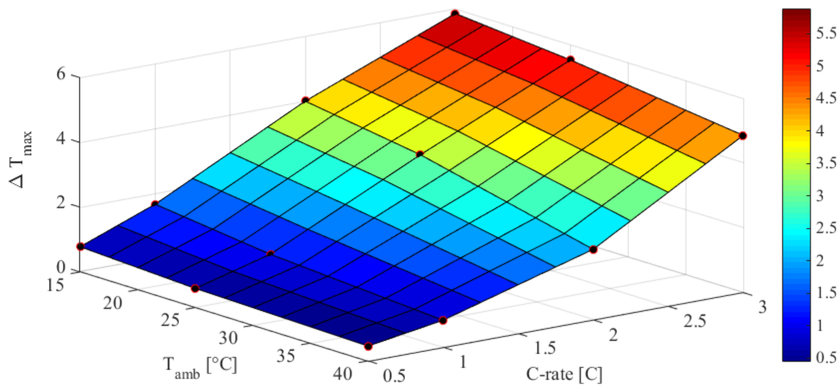


Results & Discussion (2/10)

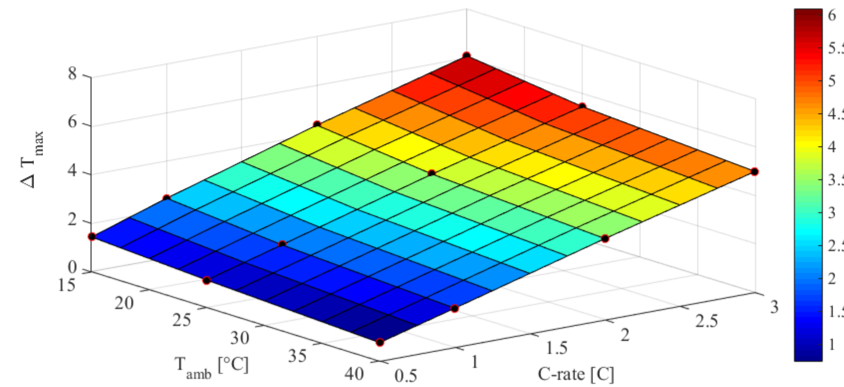
- Simulated Voltage is in good agreement with measured data
- At low discharge rate simulated voltage under estimates the discharge capacity
- Temperature rise at the beginning of discharge is high during simulation

Results & Discussion (3/10)

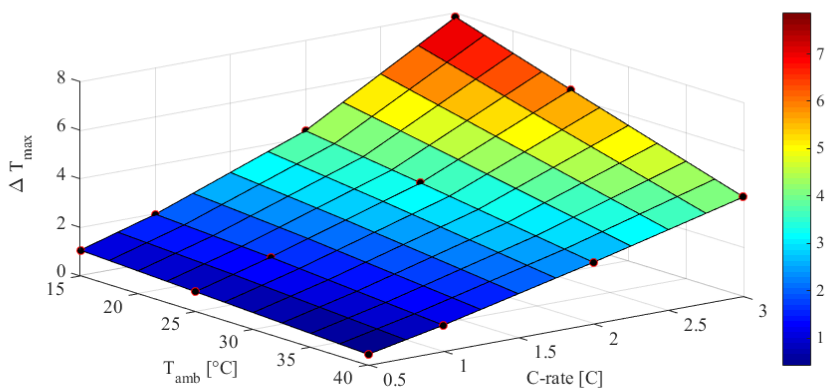
Max. Temperature Gradient (ΔT_{MAX}) with forced air circulation



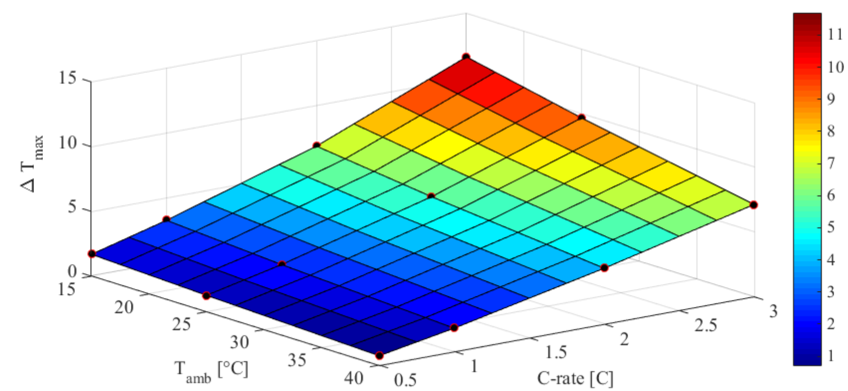
(a) 8 Ah



(b) 53 Ah



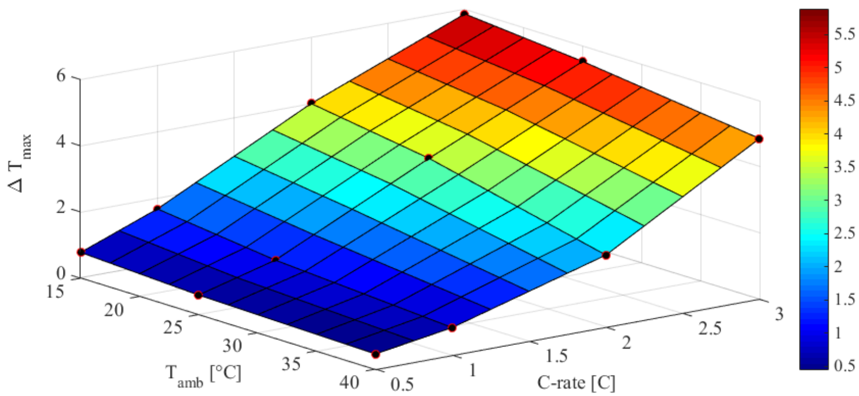
(c) 53 Ah



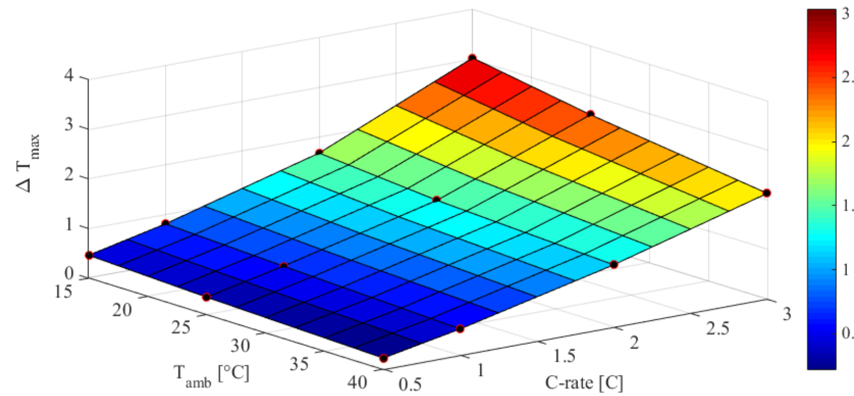
(d) 75 Ah

Results & Discussion (4/10)

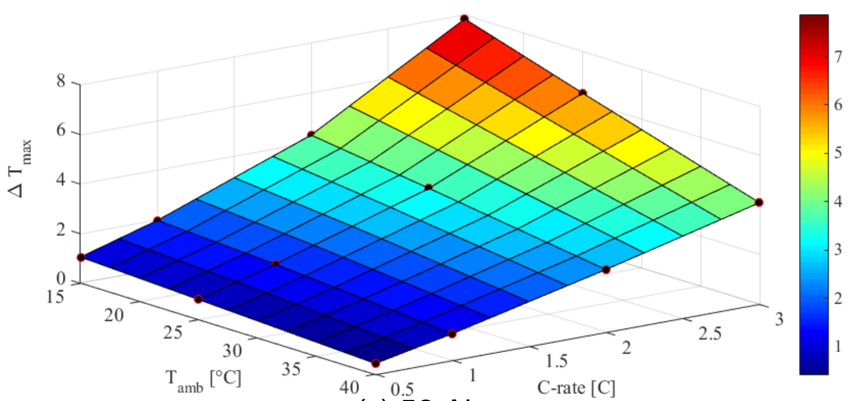
Max. Temperature Gradient (ΔT_{MAX}) with Al. Cooling plates



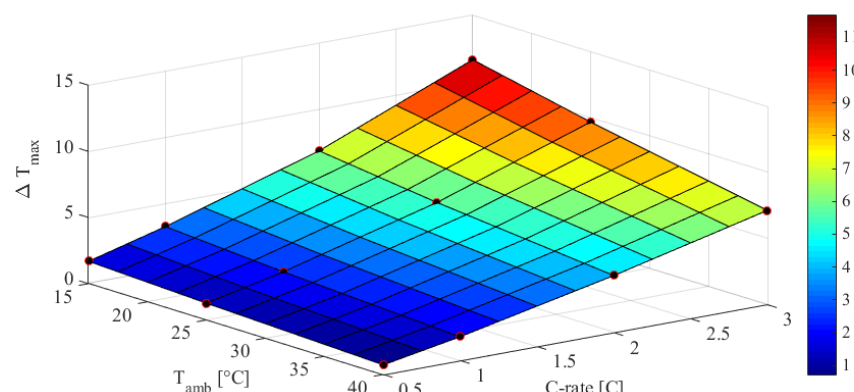
(a) 8 Ah



(b) 53 Ah



(c) 53 Ah



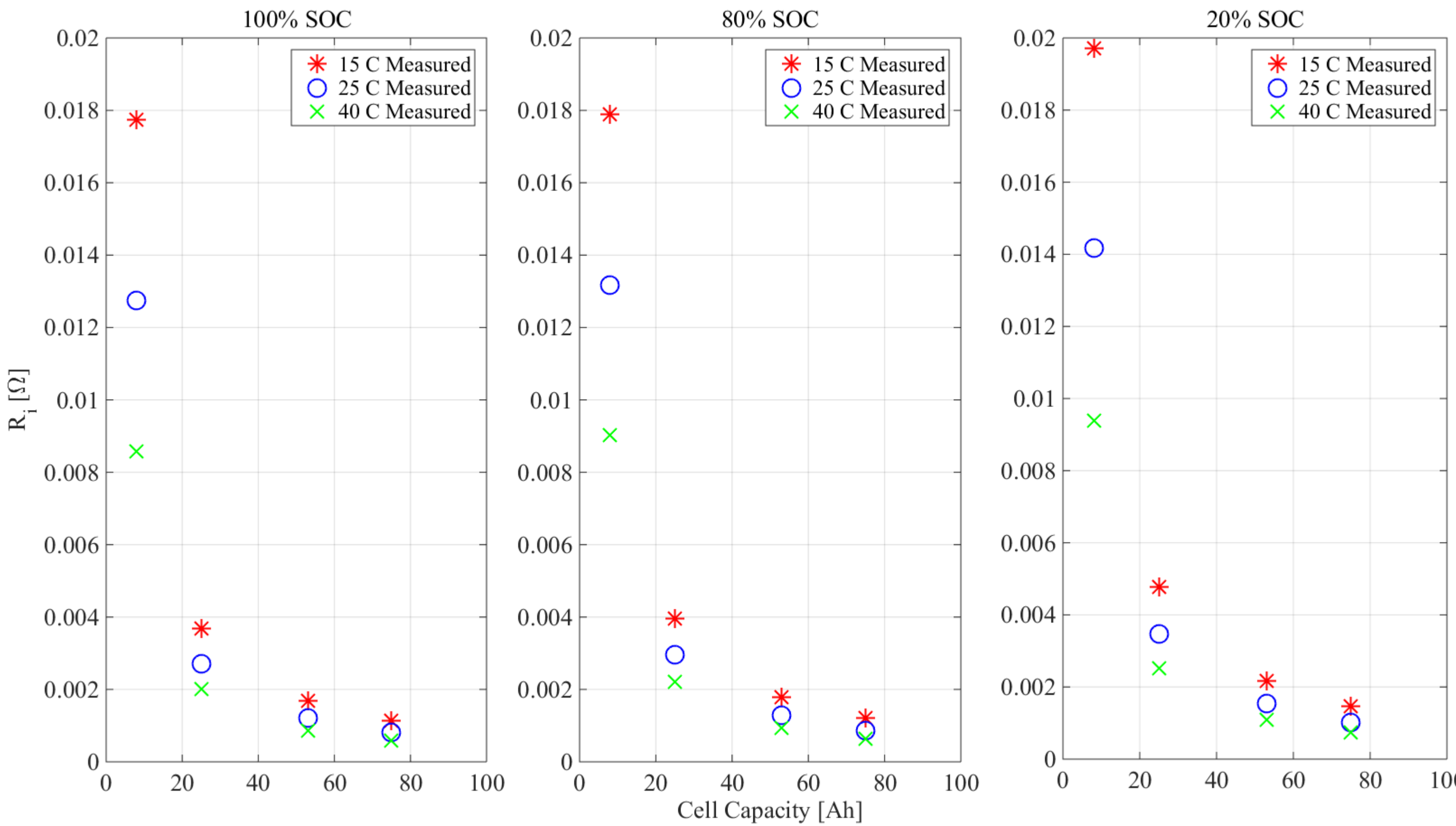
(d) 75 Ah

Results & Discussion (5/10)

- ΔT_{MAX} is highest at low ambient temperature
- ΔT_{MAX} increases with increase in cell size, with the exception for 25 Ah cell
- ΔT_{MAX} is higher for Al. cooling plate in comparison with forced air cooling method

Results & Discussion (6/10)

Internal Resistance of Cells measured from Electrochemical Impedance Spectroscopy

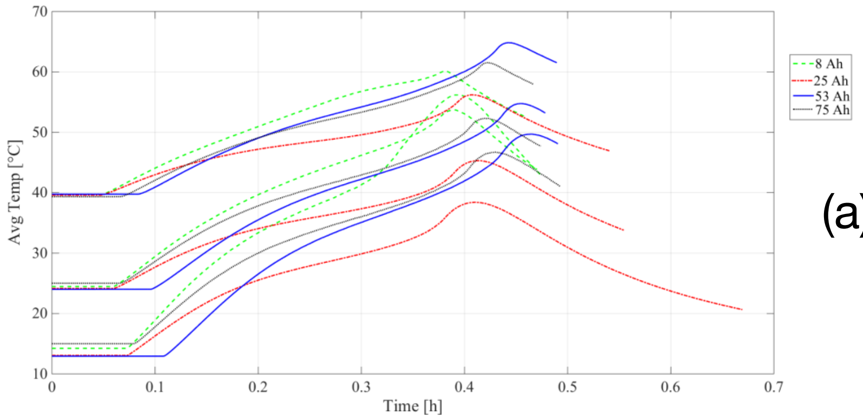


Results & Discussion (7/10)

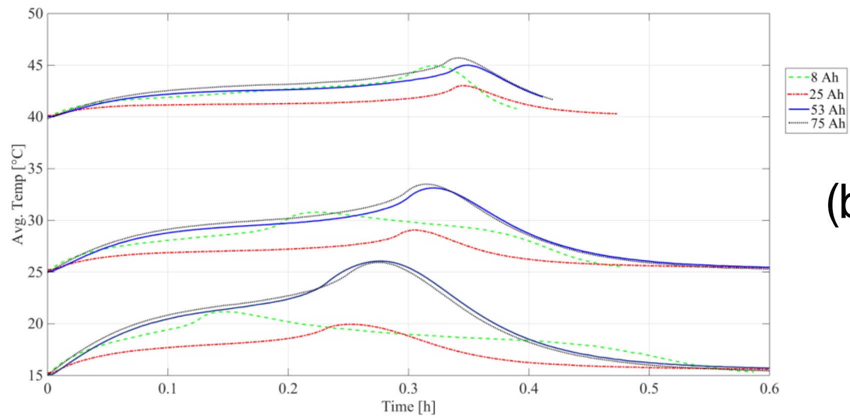
- R_i is sensitive to temperature change. Hence ΔT is highest at low ambient temperature
- It does not increase significantly with SOC decrease, except near end of discharge

Results & Discussion (8/10)

Average cell temperature at 3C discharge Current



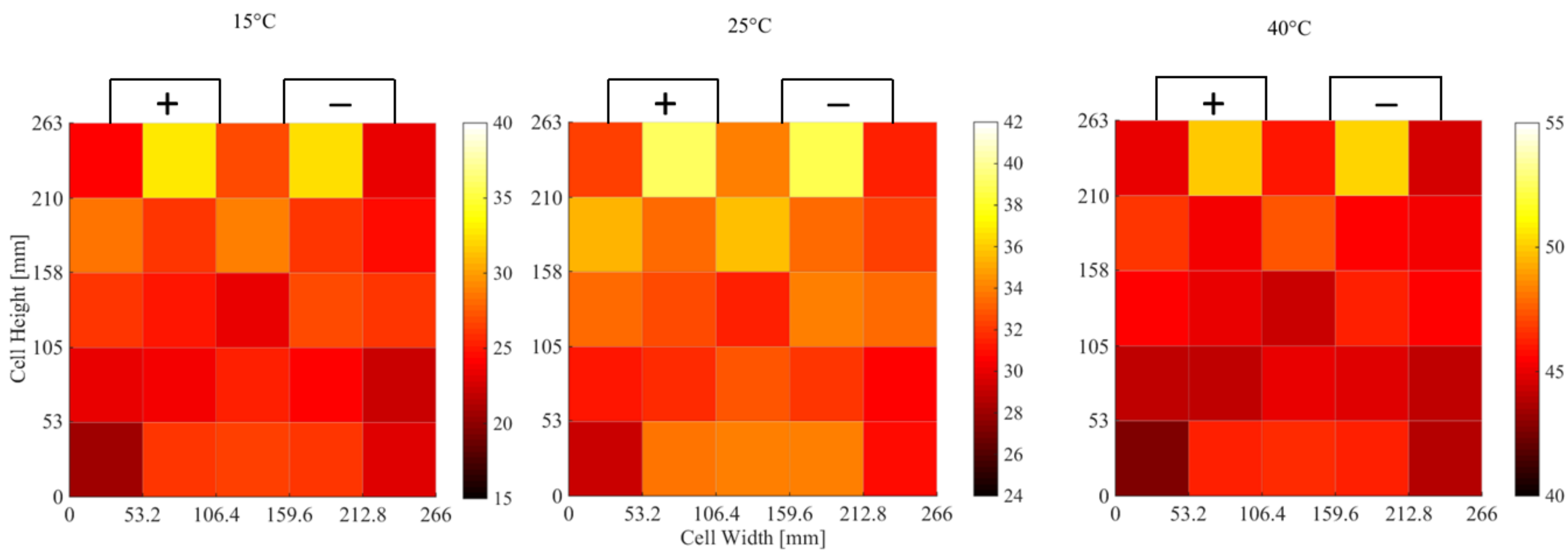
(a) Forced Air Circulation



(b) Al. Cooling Plates

Results & Discussion (9/10)

Surface temperature distribution (5X5 matrix) at the time of maximum average temperature for 75 Ah cell at 3 C discharge current with Al. cooling plate setup



Results & Discussion (10/10)

- Average cell temperature can be decreased significantly with Al. cooling plates, but ΔT increases

- Maximum surface temperature can be observed near the cell tabs

Conclusion and Outlook (1/2)

- Scale up models can be used to study the performance of large format cells
- ΔT is influenced by ambient temperature, c-rate and cell size
- Improved thermal management should be the main focus for working with large format cells

Conclusion and Outlook (2/2)

- The cell model can be improvised by including more sub-models per unit area to simulate spatial inhomogeneity
- ΔT could lead to localized ageing in long term, especially for large format cells
- Aged cells should included in future studies

Thank you for your attention