SAND2018-7574D

Modeling Internal Battery Temperature for Optimal Control of BESS with Convective Cooling

Frank Austin Mier and David Rosewater

Background

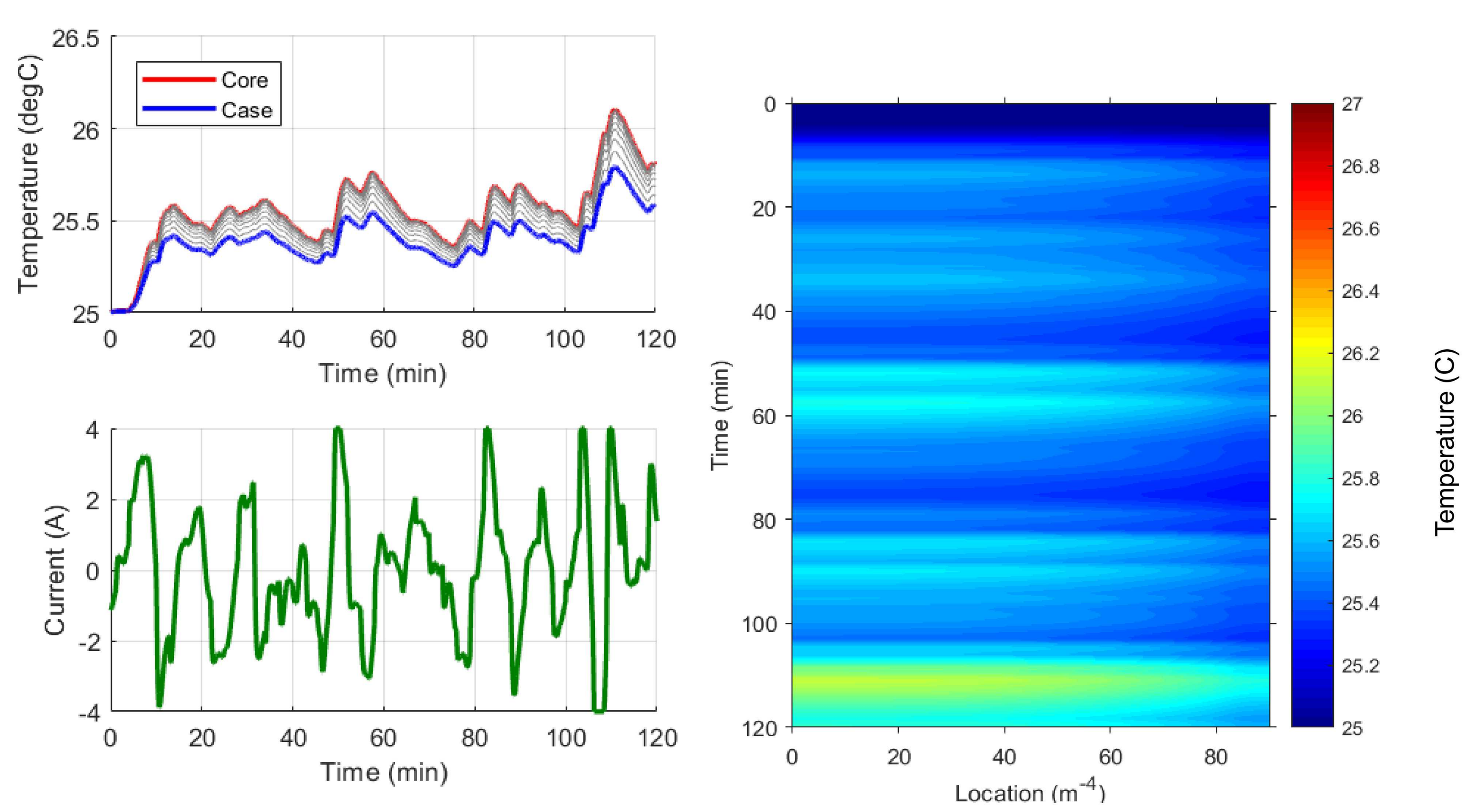
Temperature is a critically important parameter for monitoring battery State of Health (SOH) and can be used to apply real-time current limits to Battery Energy Storage Systems (BESS). Further, limiting the temperature is key to preventing thermal runaway events. While case temperature is easily measurable, a simple model is required to estimate the elevated core temperature. Previous work has shown the potential for using a simple lumped capacitance thermal model with experimentally determined internal conduction and external convection thermal resistances for predicting core temperatures [1,2]. In this work, the thermal resistance network model is expanded to multiple finite volumes within a single cell to better resolve the internal temperature distribution, and Nusselt number relationships are used to calculate the convection resistance as a function of air velocity. By incorporating velocity into the model, an additional decision variable may be added to BESS control systems to help maintain optimal operating conditions. The effects of varying electrical load and air velocity are explored.

Internal Temperature Model Results

Material and electrical properties for A123 LFP 18650 cell with 1.1 Ah capacity and 4 A maximum charge current [4]. Experimentally determined thermal conductivity and specific heat values were used [5].

Aggressive frequency regulation duty cycle [6]

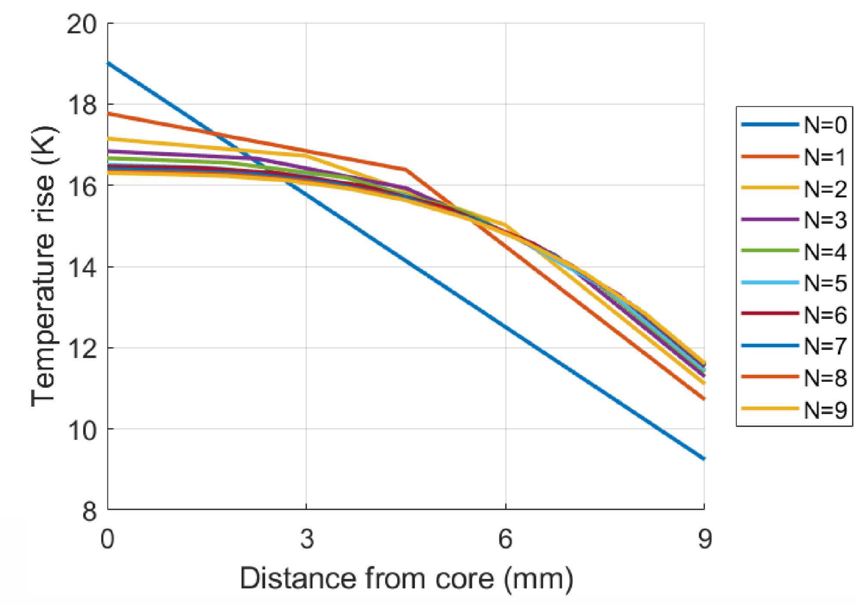
Normalized cycle is adapted to maximum charging rate with zero SOC change. 1 m/s air velocity maintains minimal temperature increases.



Increased Model Node Count

- 1.0% change in T_0 and T_c at four interior temperature nodes (N=4)
- Refined model shows 2.7 K lower core temperature and smaller difference between core and case temperatures (4.7 K) than N=0 model (9.8 K)*

* Heat transfer is calculated based on material properties physical dimensions.



Conclusions

- Model refinements allow internal temperature gradient quantification for multiple electrical loads and air velocities
- Mean and maximum temperatures are significantly lowered with air cooling: T_0 decreases 62% maximum and 60% mean at 1 m/s air velocity.
- Future work includes experimentally determining model parameter by cycling batteries and monitoring temperature within a wind tunnel.

Thermal Resistance Model

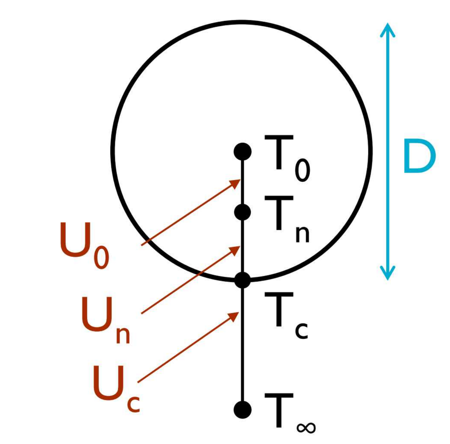
General form: $\dot{E}_{sys} = \dot{E}_{gen} + \dot{E}_{in} - \dot{E}_{out}$

Core node: $C_0 \dot{T}_0 = \frac{V_0}{V_t} I^2 R_e + U_0 (T_1 - T_0)$

Internal node ($n \in [1, N]$):

$$C_n \dot{T}_n = \frac{V_n}{V_t} I^2 R_e + U_n (T_{n+1} - T_n) - U_{n-1} (T_n - T_{n-1})$$

Case node: $C_c \dot{T}_c = U_c (T_{env} - T_c) - U_N (T_c - T_N)$

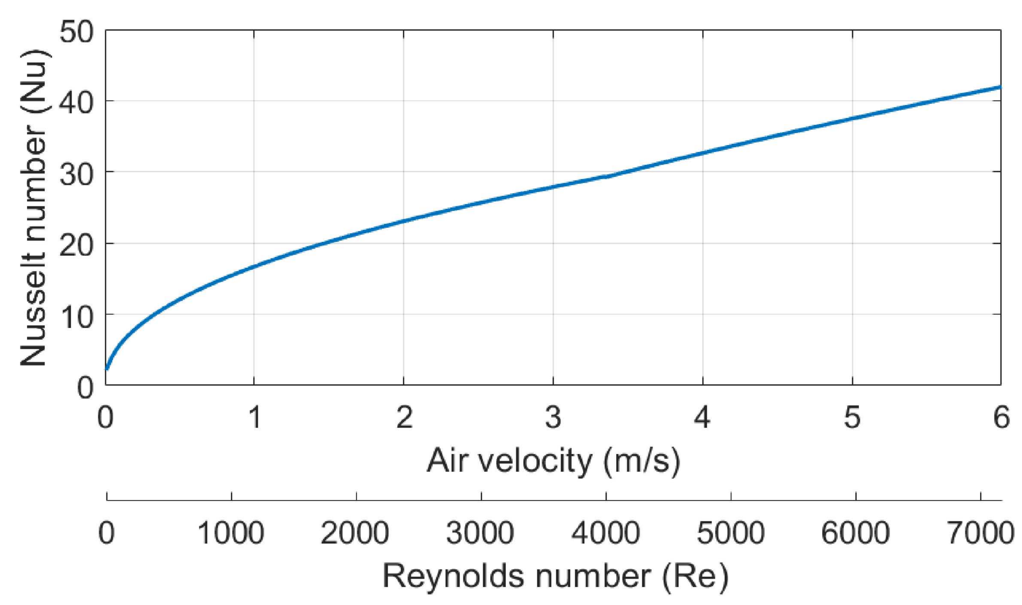


Convective Heat Transfer Coefficient

Convection resistance can be calculated as a heated cylinder in cross flow where: $U_c = hA$ and $\mathrm{Nu} = \frac{hD}{k_{air}} = C\mathrm{Re}^m \mathrm{Pr}^n$ [3].

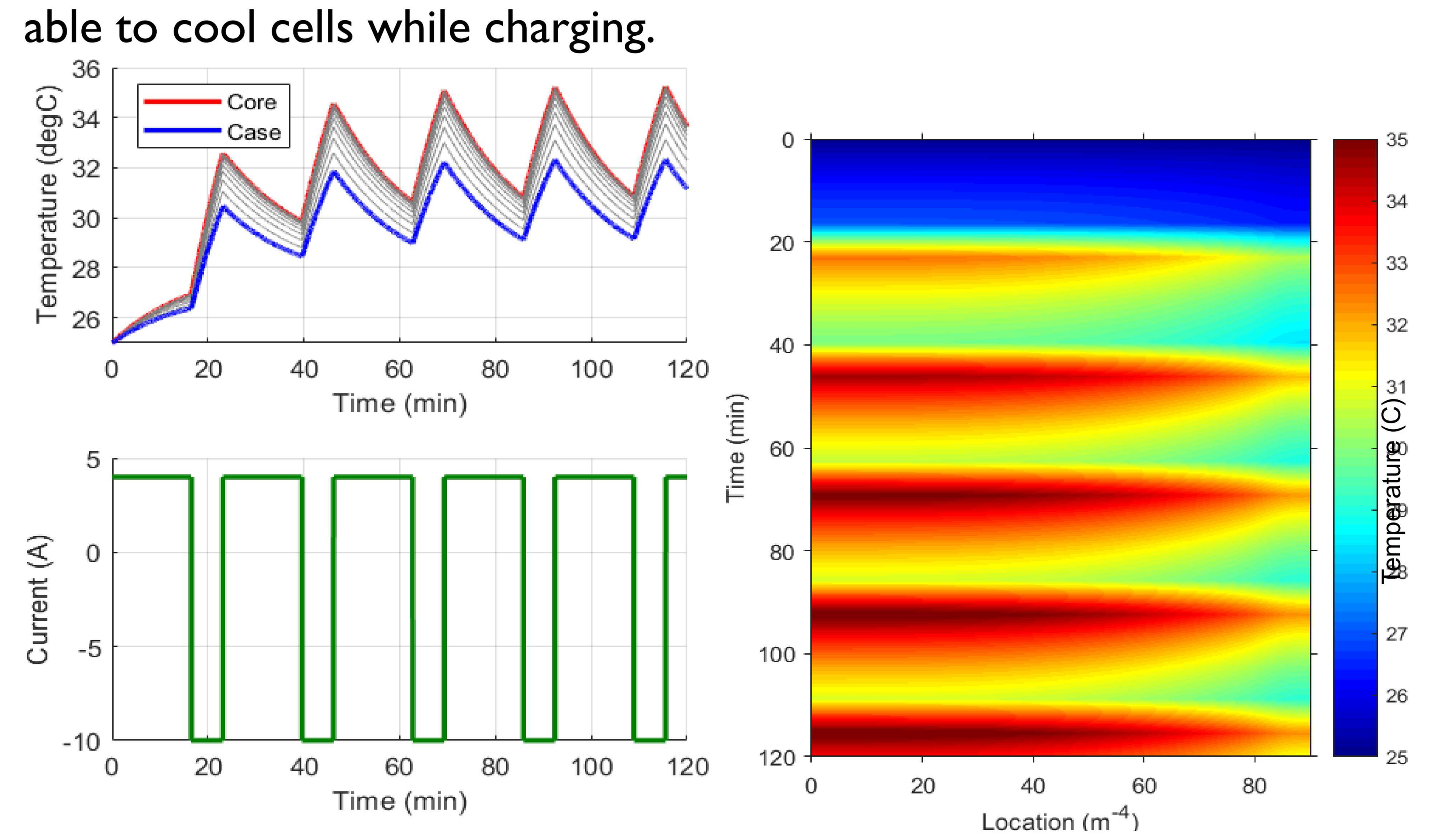
Model Parameters

	C	m	n
4<Re≤40	0.911	0.385	1/3
40<Re≤ 4,000	0.683	0.466	1/3
Re>4,000	0.193	0.618	1/3



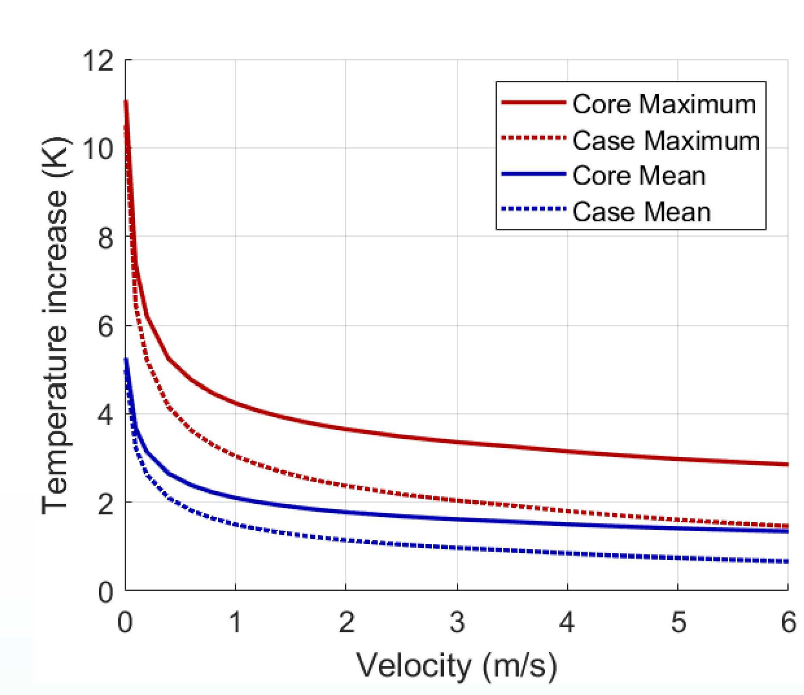
Repeated full charge and discharge

Cycling between 0% and 100% SOC at maximum charge current and discharge current limited by Arbin battery tester. Air velocity of 1 m/s is able to cool cells while charging.



Varied Air Velocity

- Highly effective cooling of core and case at low velocities
- 62% maximum core temperature decrease between 0 m/s and 1 m/s
- Diminished cooling at increased velocities: 4.2% decrease in maximum core temperature between 5 m/s and 6 m/s



References

[1] Park, C. and Jaura, A. K. (2003) Dynamic Thermal Model of Li-Ion Battery for Predictive Behavior in Hybrid and Fuel Cell Vehicles, Fuel Transportation Technology Conference, Costa Mesa, California, 2003. SAE.
[2] Lin, X, et. al. (2012) Online Parameterization of Lumped Thermal Dynamics in Cylindrical Lithium Ion Batteries for Core Temperature Estimation and Health Monitoring, *IEEE Transactions on Control System Technology, 10* (10).
[3] Cengel, Y.A. and Ghajar, A.J. (2007) *Heat and Mass Transfer Fundamentals and Applications.* New York, NY: McGraw Hill.
[4] 18650 Cylindrical Cell: Nanophosphate Lithium-Ion Specification Sheet, A123 Systems.
[5] Drake, S.J. (2014) Measurement of anisotropic thermophysical properties of cylindrical Li-ion cells, *Journal of Power Sources, 252.* 298-304
[6] Frequency Regulation Duty Cycle, Sandia National Laboratories, SAND2013-7315P.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND No. ____________