Thermal Battery Cell Modeling in a Spirally-Wound Geometry

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Abstract

Introduction: The characterization of Li-ion batteries is a relevant topic due to the recent developments in Electric Vehicles (EV's) and Hybrid Electric Vehicles (HEV's) applications. In order to manage these devices, accurate models are required.
At NEXT ENERGY a two dimensional cell-level thermal model was created based on the discharge characteristics of a Li-NiMnCoO2 secondary battery cell. With focus on the spirally-wound geometry the heat transfer in solids interface of COMSOL Multiphysics® version 4.4 was used to describe the temperature gradient in radial direction during discharge at different C-Rates. Thermal parameters of the cell materials were measured with Differential Scanning Calorimetry (DSC) and Laser Flash Analysis (LFA) in our laboratory and averaged corresponding to the cell sheet lengths.

Use of COMSOL Multiphysics®: The geometry consists of three domains (cp. Figure 1) [1]:
- Battery canister (steel; 0,25mm thickness)
- Active Material (sheets of cell quantities)
- Mandrel

The heat transfer equation (1) (cp. Figure 4) is the governing equation based on a time dependent study.
Additional arguments, listed in Figure 4 (2-7), are needed to solve (1) uniquely (cp. Figure 2 "Used parameters" and Figure 3: "Assumptions made") [2].
The heat flux boundary condition on the battery canister surface specifying convective cooling by the air is given by the heat transfer coefficient. The Initial temperature condition on all domains is given by the battery temperature.

Results: In order to validate the modeling approach in this work we built an experimental setup to measure the surface temperature distribution in a cylindrical Li-ion cell inside of a climate chamber during several charge and discharge cycles. Already at this early stage of the modeling study we can see a good tendency towards realistically predicting the temperature gradient from the inside to the outside of the cell. Yet, the model prediction does not fit the experimental data accurately, thus further improvement of the model approach will be done by validating the assumptions made.

Conclusion: After validating the models approach it can be used to describe the thermal behavior inside of a battery cell accurately. The model developed will be adapted and used for a comparative study of different cell geometries, i.e. prismatic or pouch cell structures, or even to investigate the thermal behavior in battery stacks with multiple battery cells. From an engineer's point of view especially the prediction of thermal hotspots inside of a battery stack is interesting, since it is directly related to the development of decent cooling technologies and safety questions.

Reference

[1] P.M. Gomadam, R.E. White, and J.W. Weidner, “Modeling Heat Conduction in Spiral Geometries,” J. Electrochem. Soc. , vol. 150, no. 10, pp. A1339–A1345, 2003
[2] M. Muratori, “Thermal characterization of Lithium-ion battery cell”, Ph.D thesis, Politecnico di Milano, 2009.

Figures used in the abstract

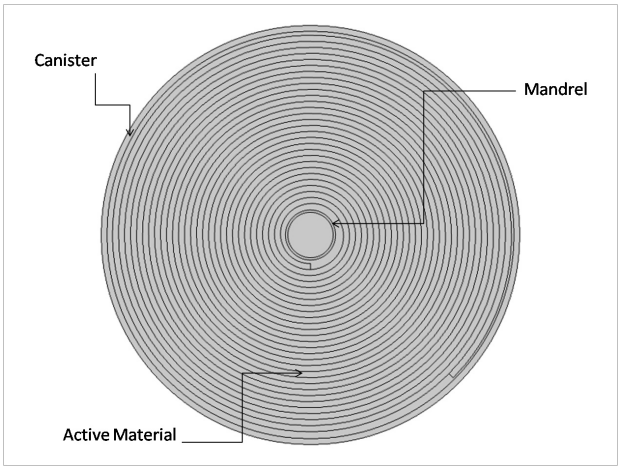

Figure 1: Spirally-wound battery geometry with one layer consisting of five cell sheets.

Input parameter		Unit
E_{OCV}	Open Circuit voltage	$[V]$
E	Electrical voltage	$[V]$
I	Applied Current	$[A]$
C_n	Nominal Capacity	$[A\,\mathrm{h}]$
Vol	Volume of Active material	$[m^3]$
ρ	Density	$[kg\ m^{-3}]$
C_P	Specific heat capacity	$[J\ K^{-1}\ kg^{-1}]$
α	Thermal diffusivity	$[m^2\ s^{-1}]$
Calculated Variables		
k	Thermal conductivity	$[W\ m^{-1}\ K^{-1}]$
Q	Heat source	$[W\ m^{-3}]$
SoC	State of Charge	$[n/a]$
Output parameter		
T	Temperature	$[K]$

Figure 2: Table for used parameters. [1] [2]

Assumptions		Unit
$\eta = 1$	Coulombic Efficiency	$[n/a]$
$\frac{\partial E_{OCV}}{\partial T} = 0$	Temperature derivative of the Open Circuit Voltage	$[V]$
I= const.	Applied Current	$[A]$
$\rho = \rho_{ave}$= const.	Over cell sheet length averaged Density	$[kg\ m^{-3}]$
$C_p = C_{p_{ave}}$	Over cell sheet length averaged Specific heat capacity	$[J\ K^{-1}\ kg^{-1}]$
$\alpha = \alpha_{ave}$= const.	Over cell sheet length averaged Thermal diffusivity	$[m^2\ s^{-1}]$
$h = 20$	Heat transfer Coefficient	$[Wm^{-2}K^{-1}]$
$T_{init} = 298,15$	Initial Temperature	$[K]$

Figure 3: Table for assumptions made. [1] [2]

Arguments	Formula	Unit	Reference
Heat equation	$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u \cdot \nabla T = \nabla \cdot (k \nabla T) + Q$		(1)
$SoC(t)$	$SoC(0) + \int_0^t \frac{\eta \cdot I(t)}{C_n} dt$	$[n/a]$	(2)
$Q(SoC)$	$\left(\frac{I}{Vol}\right) \cdot \left(E_{OCV}(SoC) - E(SoC) - T \cdot \frac{\partial E_{OCV}}{\partial T}\right)$	$[V]$	(3)
$k(T)$	$\rho(T) \cdot C_P(T) \cdot \alpha(T)$	$[W\ m^{-1}\ K^{-1}]$	(4)
ρ_{ave}	$\frac{\sum(L_i \cdot \rho_i)}{\sum L_i}$	$[kg\ m^{-3}]$	(5)
$C_{p_{ave}}$	$\frac{\sum(L_i \cdot C_{p,i})}{\sum L_i}$	$[J\ K^{-1}\ kg^{-1}]$	(6)
α_{ave}	$\frac{\sum L_i}{\sum\left(\frac{L_i}{a_i}\right)}$	$[m^2\ s^{-1}]$	(7)

Figure 4: Table for used arguments. [1] [2]