

## Analytical assessment of the thermal behavior of nickel-metal hydride batteries

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### Introduction

A three-dimensional analytical thermal model [1] is adapted to describe thermal response of Nickel-metal hydride (NiMH) batteries to heat generation during their operation. The model is based on integral-transform technique [2] that gives a closed-form solution for the fundamental problem of unsteady heat conduction in batteries with orthotropic thermal conductivities, where the heat generation is due to irreversible (polarization) and reversible (entropy change) losses. The full-field solutions take the form of a rapidly converging triple infinite sum whose leading terms provide a very simple and accurate approximation of the battery thermal behavior with modest numerical effort. The accuracy of the proposed model is tested through comparison with numerical and experimental data [3,4]. The method is used to describe spatial and temporal temperature evolution in a sample prismatic NiMH battery (30 A h, NEXcell battery, USA) [cf. Fig. 1] during fast charge processes while subjected to convective cooling at its external surfaces. The obtained results show that this theoretical model can be used as a fast yet accurate tool for the design of battery thermal management systems.

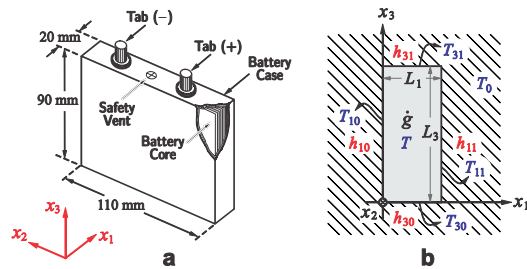


Figure 1. a) Schematic and dimensions of the sample NiMH battery cell. b) Two-dimensional schematic of the battery core in  $x_1$ - $x_3$  plane with internal heat generation rate  $\dot{g}$ , and heat dissipation at boundaries. The ambient temperature is  $T_0$ .

### Some Results

The rate of heat generation inside the battery can be approximated from the well-known energy balance analysis proposed by Bernardi *et al.* [5],

$$\dot{g} = \frac{I}{\mathcal{V}} \left[ (V - V_{oc}) + T \frac{dV_{oc}}{dT} \right], \quad (1)$$

where  $I$  and  $V$  denote operational current and voltage of the battery,  $\mathcal{V}$  is the battery volume,  $V_{oc}$  is the open-circuit battery potential, and  $T$  is the temperature. From an adiabatic calorimetry the term  $T(dV_{oc}/dT)$  is evaluated to be 0.023 V for the considered battery; however, the term  $V - V_{oc}$  is measured from electrical performance of the battery during  $C/2$  and  $2C/3$  galvanostatic charging processes, as shown in Fig. 2.

Based on Eq. (1), and electrical performance of the battery [Fig. 2], the rate of heat generation inside the battery during two different fast-charging processes (15 A and 20 A) are calculated (Fig. 3) and then implemented into the thermal model [1].

In Fig. 4, our analytical solution for maximum temperature at the center of the battery (shown by solid line) is compared to the corresponding numerical result (symbols) from Ref. [4], during a fast-charging process with 15 A and convective cooling of the battery with  $h = 6 \text{ W/m}^2 \text{ k}$ . The comparison shows an excellent agreement between analytical and numerical temperature predictions.

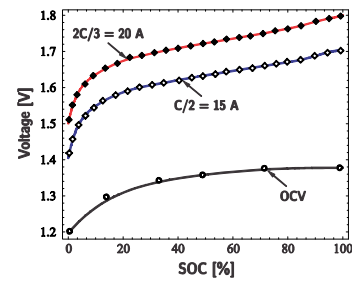


Figure 2: Variations of battery voltage vs. state-of-charge (SOC), measured during fast charging of the battery with 15 A and 20 A are shown. As shown, during a charging process, the open-circuit voltage is lower than the battery voltage.

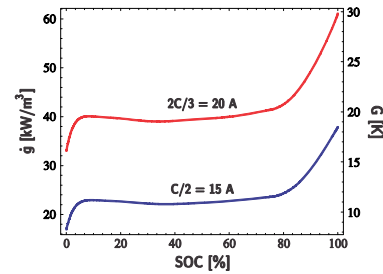


Figure 3: Variation of heat generation rate  $\dot{g}$  vs. state-of-charge (SOC).

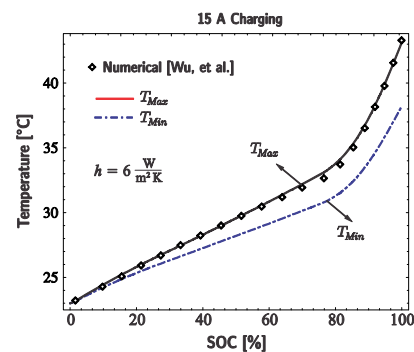


Figure 4: Maximum temperature at the center of the battery predicted from numerical and analytical approaches show a good agreement.

Finally, temperature measurements inside the battery, reported in Ref. [4] are successfully compared to our model predictions, as shown in Fig. (5).

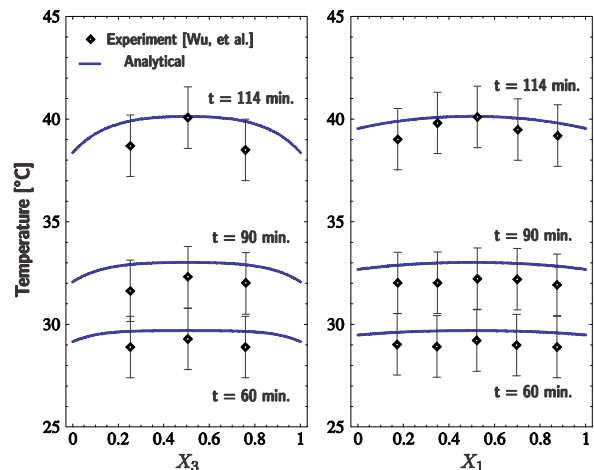


Figure 5: Comparison of experimental temperature data inside the battery (symbols) with our analytical results (lines) shows a good agreement.

### Reference

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