Abstract #290, 223rd ECS Meeting, © 2013 The Electrochemical Society

An analytical electro-thermal model for Lithium-ion Batteries

Maryam Yazdanpour*, Peyman Taheri, Majid Bahrami

Laboratory for Alternative Energy Conversion (LAEC),
Mechatronic Systems Engineering, School of Engineering Science,
Simon Fraser University, Surrey, BC V3T 0A3, Canada

Introduction

Batteries with lithium-ion chemistry are the preferred candidate to power hybrid and electric vehicles (HEVs), due to their high power density (up to 150 Wh/kg), short charging time, minimal memory effects and self-discharge (around 5% per month), and long cycling life [1]. Nonetheless, thermal management of large-scale lithium-ion (Li-ion) batteries during high current charge and discharge processes has remained as a challenging task. Design of an effective battery thermal management system (BTMS) is vital for the safety, efficiency, and longevity of Li-ion batteries. In order to develop a practical BTMS for Li-ion batteries, an accurate understanding of heat generation inside the batteries is required.

To investigate the thermal behavior of prismatic Li-ion polymer batteries, particularly during discharging, an analytical electro-thermal model is proposed in this study. The model uses the concept of electrical constriction resistance (ECR) to describe excessive heating at the battery tabs with the modest numerical effort. Results from the proposed analytical model are validated by experimentation.

Model Description

The model consists of a two-dimensional electro-thermal model, which predicts the voltage, current density, heat generation, and temperature distributions at the battery electrodes.

The numerical studies by Kwon et al. [2] and Kim et al. [3] prove that in a prismatic Li-ion polymer battery, non-uniformities associated to the charge (Li^+) transfer between the positive and negative electrodes, at different locations of the electrode pair, do not affects the thermal behavior of the battery significantly. However, their results show that the width and the position of battery tabs must be considered as the most important parameters in design optimization of Li-ion batteries, to prevent excessive local heating at the battery terminals. Accordingly, in this study, a uniform charge transfer between electrodes is assumed, which makes an analytical solution feasible. Electrical performance of the battery is described by exact (series) solutions of the Poisson equation for potentials of the positive and negative electrodes. Furthermore, the electrical model is coupled to the thermal model through a heat generation term. The incorporated thermal model describes the temperature distribution inside the battery as a result of non-uniform heat generation, orthotropic heat conduction, and convective heat dissipation at surfaces of the battery. The proposed two-dimensional thermal model is based on integral-transformation technique.

Irreversible and reversible heat generation terms for the thermal model are estimated experimentally from voltage variation during galvanostatic discharge processes, and the ohmic heat generation term are estimated via electrical model. Figure 1 shows the rate of heat generation at the cell volume after 5 min of 5C discharge.

Results and Discussion

In particular, ECR at battery tabs is investigated. ECR is a direct result of electrical current through constricted areas of battery electrodes, i.e., battery tabs, and acts as a local ohmic resistance.

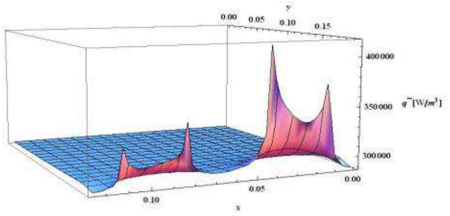

Figure 1. The net volumetric heat generation rate at the cell volume after 5 min of 5C discharge.

Using the developed electrical model, a parametric study has been conducted on the effects of electrodes configuration (width and position of the tabs). As shown in Figure 2, the minimum constriction resistance exists for a centric tab configuration; the tab eccentricity e (distance of tab's center from y-axis) is half of the battery width. Also, it has been proved that a reduction in the tab's width ill result in an increase in the constriction resistance. It can be concluded the constriction resistance can have strong effect on the potential, current density, and temperature distribution on the electrodes, which influence the utilization of active materials [3].

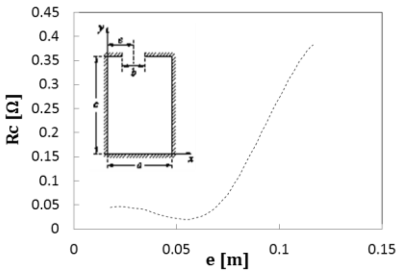

Figure 2. Effect of tab eccentricity on the constriction resistance.

By employing the analytical electro-thermal model, thermal response of a Li-ion battery during galvanostatic discharge process is predicted, and the results are examined against experimental results. Figure 3-a, implies that the maximum temperature occurs near the battery's tabs which is as a result of ECR through constricted area (tabs).

Due to ECR at the battery tabs, the maximum temperature was observed in the vicinity of the tabs as it is presented in Figure 3-a.

In Figure 3-b, the average temperature obtained from the proposed electro-thermal model for a 1C discharge process of a 20 Ah battery is compared to the experiments. The comparison shows a good agreement between the analytical and experimental results.

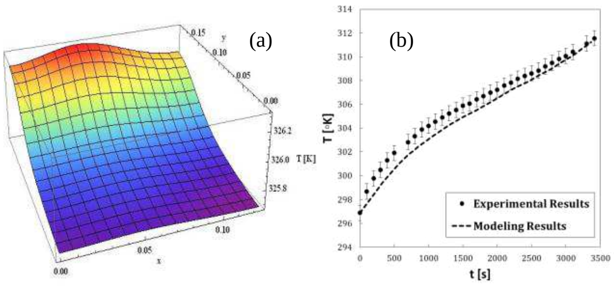

Figure 3. a) Temperature contours in cell at the end of 5C discharge, b) Average temperature variation vs. time for 1 C discharge, Analytical results (dashed line) are compared to experimental results (symbol).

Reference

[1] S Chacko et al. J. Power Sources, 296-303, 213(2012).
[2] K.H. Kwon et al. J. Power Sources, 151-157, 163 (2006).
[3] U.S. Kim et al. J. Power Sources, 909-916, 180 (2008).