Thermal modeling of cylindrical Li-ion battery

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Introduction

The Li-ion batteries attract much interest as an energy storage device since they are capable of providing high energy density and wide range of its application. However high fabrication cost, long-term stability and poor safety characteristics caused by high heat generation during charge/discharge cycles are the challenges [1].

This paper provides comprehensive understanding about the thermal behaviour of Li-ion battery by illustrating temperature distributions and profiles at various discharge rates. The effects of cooling condition and the LiNiCoMnO₂ cathode on the temperature distribution are investigated to suggest a temperature reduction.

Model description

The transient simulation was performed by finite element analysis (FEA) solver for the energy conservation in the cylindrical battery.

\[
\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (\kappa \nabla T) + \dot{q}
\]

(1)

The Li-ion battery considered in this study is illustrated in figure 1. A cylindrical SONY-18650 with 1.5Ah capacity is modelled. Although the jelly-roll is designed with cylindrically spiral type, we modeled it as round structure for the simplicity of the 2D model.

During discharge cycle, the heat generations caused by flowing of current \( i \), through the cell. The heat generations due to joule heating and entropy change are considered as follows.

\[
\dot{q}_{\text{joule}} = i(V^o - V)
\]

(2)

\[
\dot{q}_{\text{entropy}} = \frac{\sigma}{\partial T} \frac{\partial T}{\partial t} - T \Delta S \frac{i}{nF}
\]

(3)

The entropy change data are taken from open literatures.

Result and discussion

The temperature contour at a discharge rate of 1C and SOC = 0.1 is illustrated as shown in figure 2. High temperature is observed at the inside of cell and low temperature is presented at the top cap. The temperature difference between the inside and the outer surface is small. The maximum temperature was found below the center of battery and its rise is 12.3 °C from the initial temperature. This corresponds well to the result of Chen et al. [2]. Moreover the overall appearance of the temperature distribution is good agreement with Inui et al. [3].

Figure 3 shows the temperature profiles of cylindrical Li-ion battery. The contribution of heat generation due to entropy change, \( \dot{q}_{\text{entropy}} \), is larger than that due to joule heating, \( \dot{q}_{\text{joule}} \) at a discharge rate of 1C as shown in figure 3. (a). It is observed that the contribution of \( \dot{q}_{\text{joule}} \) becomes significant at high discharge rates as shown in figure 3 (b). This is because the heat sources are strongly dependent on the current density as \( \dot{q}_{\text{joule}} \sim i^2 \) and \( \dot{q}_{\text{entropy}} \sim i \).

Conclusion

The cylindrical Li-ion battery was simulated to provide thermal behaviour during discharge cycle. The transient model developed a set of energy equations considering heat generations due to both joule heating and entropy change at each cell components.

The contribution of heat generation due to entropy change was dominant at a low discharge rate, whereas that due to joule heating was significant at a high discharge rate. The maximum temperature was observed inside the cell, but the temperature difference between the maximum and the surface was small.

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References