A Comprehensive Research of Electro-thermal Coupling Model for Lithium ion Battery Cells with A Multiphysics Method in COMSOL

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Abstract This article focuses on the thermal issue of lithium ion battery, aims at studying and forecasting the thermal behaviors for lithium ion battery, deeply studies the battery overall temperature rise and inner temperature distribution generated during its working under its applicable environment and the reasons affect the battery monomer thermal performance. An electrochemical distributed heat source thermal model is coupled by a battery thermal model. And basedon this electrochemical-distributed heat source thermal coupling model, the current density, generation rate and voltage inside this 40Ah lithium ion phosphate battery monomer are discussed.

Keywords comsol; temperature distribution; electrochemical-thermal coupling model

1. Introduction

Energy conservation and emission reduction will be the main trend of modern automotive technology. And electric vehicle developing is one of the best ways to achieve this goal. During the vehicle operation, the overcharging, over discharging and high temperature conditions of the battery may lead to fire, explosion. Thus, the research of lithium ion battery thermal model is significant for battery management system. In this paper, electrochemical-thermal coupling model is established by analysis heat generation of battery.

With development of the research, thermal distribution model can be divided into three categories:（1）Ui Seong Kim et al.[1] established a simplified 2D model for Polymer lithium ion battery ’s single pole unit by using finite element analysis .（2）Gi-Heon Kim et al. [2]created multidimensional model for lithium ion battery by using finite volume method. This model referred to 2D diffusion model which was established by J.Newman[3-4].(3)By the end of 2011, Yonghuang Ye et al.[5] built up integrated model based on electrochemical-thermal coupling model for 11.5Ah lithium Mn battery by using lithium ion chemistry model in Comsol.

2. Method

The foundation of electrochemical distributed heat source thermal model is divided into two parts: the calculation of heat source and creation of heat transfer condition. Heat generation rate of electrochemical distributed heat source thermal model needs to be built up on electrode scale. Thus, chemistry electrode model and battery thermal model were established. Heat generation distribution condition was calculated in chemistry electrode model, and then it was applied into battery thermal model. Cell core was combined by electrode unit in parallel. The minimum reaction unit was combined by positive electrode, negative electrode and separator.

In comsol multiphysics simulation platform, lithium ion chemistry module was chosen as foundation platform for electrochemical electrode model. At the same time, solid heat transfer module was chosen as foundation platform for battery thermal model. Six main steps were concluded in model establishment: (1) Battery electrode unit geometry model was built up in battery module, electrochemistry reaction parameter was setting and material property in related domain was defined. (2) Battery geometry was created in solid heat transfer module, and material property in related domain was defined. (3) Coupling operator between models was set up. (4) Initial condition and boundary condition were settled. (5) Meshing and choosing proper calculator. (6) Analyzing and verifying the results.

3. Results and Discussion

3.1 Battery electrode unit model

In the simulation results,heat source thermal coupling model. The current density, generation rate and voltage were included.

A. During 2C constant current discharge period, the current density distribution on positive current collector.

During period of charging and discharging, the current density is a 3D space vector. The Z axial component represents current and it has nothing to do with the distribution on the surface of the electrode. Therefore, only X axial and Y axial components were taken into consideration.

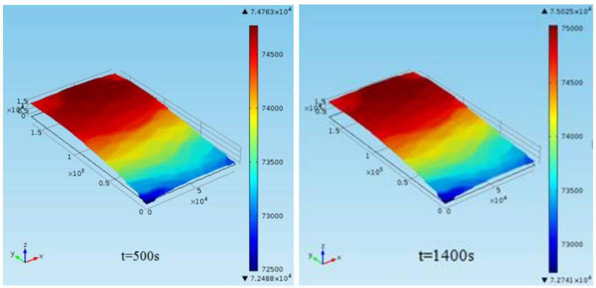
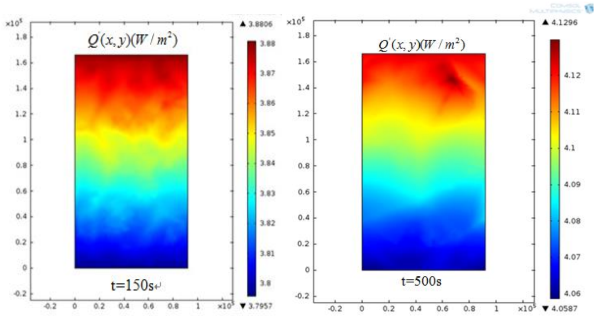


Fig.1. The current density distribution on positive current collector @ 500s (left), 1400(right)

As shown in the figure 1, the current density near the tab is bigger than other parts of the battery. At different time, the current density distribution trend remains the same. As a result, SOC isn't the main factor of the current density distribution.

B. During 2C constant current discharge period, the heat generation rate on the 2D projection plane.



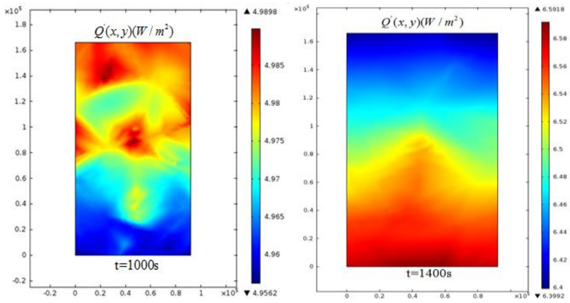


Fig.2. The heat generation rate distribution @150s(upper left)、500s(upper right)、1000s(lower left)、1400s（lower right）

As shown in the figure 2, the distribution trend on the 2D projection plane during discharge period shows: when t = 150s, 500s and 1000s, the heat generation rate near the tab is higher than the other parts of battery. The D-values are respectively 0.0849W/m^2, 0.0709W/m^2, and 0.0336 W/m^2. When t = 1400s, the heat generation rate near the tab is lower than the other parts of battery.

C. During 2C constant current discharge period, the voltage distribution on positive current collector.

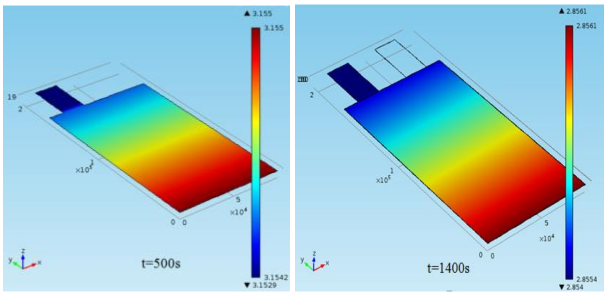


Fig.3. The voltage distribution on positive current collector@ 500s(left),1400s(right)

As shown in the figure 3, the voltage near the tab is lower than other parts of the battery.

D. During 3C constant current discharge period, the current density distribution on positive current collector.

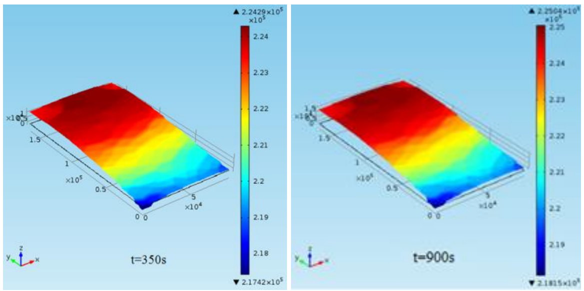


Fig.4. the current density distribution on positive current collector @ 350s (left), 900(right)

As shown in the figure 4, the current density near the tab is bigger than other parts of the battery. As a result, SOC isn't the main factor of the current density distribution.

E. During 3C constant current discharge period, the heat generation rate on the 2D projection plane.

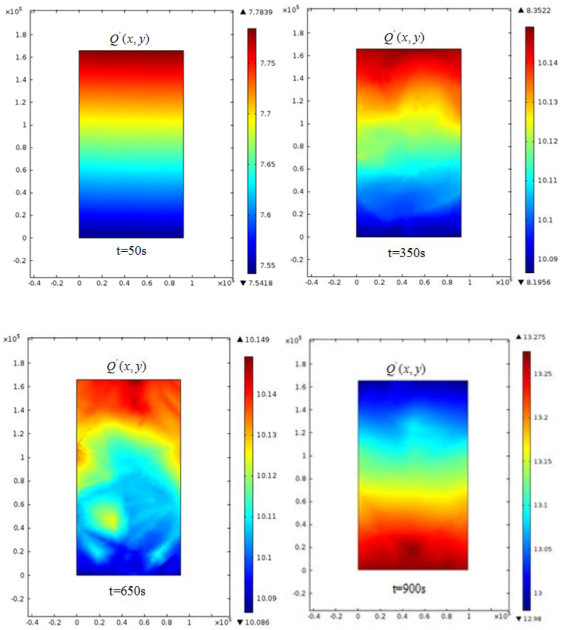


Fig.5. the heat generation rate distribution @50s(upper left)、350s(upper right)、650s(lower left)、900s（lower right）

As shown in the figure 5, the distribution trend on the 2D projection plane during discharge period shows: when t = 50s, 350s and 650s, the heat generation rate near the tab is higher than the other parts of battery. The D-values are respectively 0.2421 W/m^2, 0.1566W/m^2, and 0.063 W/m^2. When t = 900s, the heat generation rate near the tab is lower than the other parts of battery.

F. During 3C constant current discharge period, the voltage distribution on positive current collector.

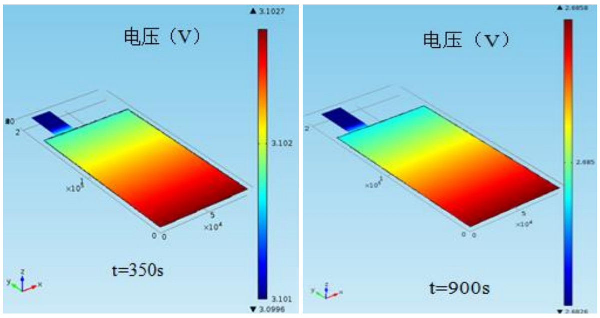


Fig.6. the voltage distribution on positive current collector@ 350s (left), 900s (right)

As shown in figure 6, the voltage near the tab is lower than other parts of the battery.

3.2 Battery thermal model

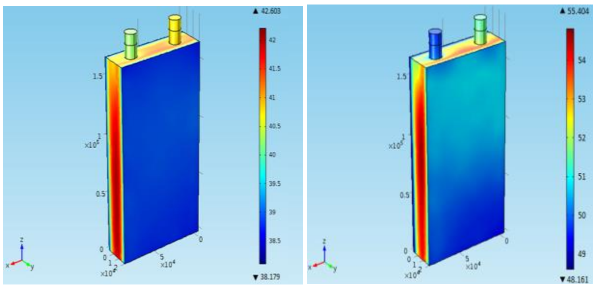


Fig.7. Battery core temperature map of 2C (left) and 3C (right) current discharge@ 1000s

As shown in the figure, temperature on the top of battery core is lower than the other parts of the battery core during 2C current discharge. However, the trend of heat generation distribution during 3C current discharge is as the same. In a word, the current density distribution of the electrode has no obvious influence on temperature distribution.

4. Conclusion

Electrochemical-thermal coupling model was applied to analyse the 2C and 3C constant current discharge mode. Heat generation distribution was mainly caused by current density and voltage distribution on the electrode according to the results. At the same time, SOC and impedance also has impact on heat generation distribution. At the beginning of discharge, the heat generation near the tab is higher than the other parts. At the end of discharge, the heat generation near the tab is lower than other parts of the battery.

5. Reference

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