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Sensitivity Study of Battery Thermal Response to Cell Thermophysical Parameters

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Abstract

Lithium-ion batteries (LiBs) have been widely used in electrified vehicles, and the battery thermal management (BTM) system is needed to maintain the temperature that is critical to battery performance, safety, and health. Conventionally, three-dimensional battery thermal models are developed at the early stage to guide the design of the BTM system, in which battery thermophysical parameters (radial thermal conductivity, axial thermal conductivity, and specific heat capacity) are required. However, in most literature, those parameters were estimated with greatly different values (up to one order of magnitude). In this paper, an investigation is carried out to evaluate the magnitude of the influence of those parameters on the battery simulation results. The study will determine if accurate measurements of battery thermophysical parameters are necessary. A unified method based on the understanding of the sensitivity of the key battery thermophysical parameters is proposed to identify the impact of measurement accuracy of thermophysical parameter measurements in battery thermal modeling. Thermal simulations of battery thermal models at the cell level (cylindrical 18650) and module level are developed with COMSOL Multiphysics® to perform the sensitivity analysis. The simulation results indicate that the specific heat capacity is the most remarkable thermophysical parameter affecting the temperature rise, temperature difference between cells, and heat dissipation rate of the battery model. The temperature difference between cells in a module exhibits a high sensitivity to axial conductivity, up to 1.05. Therefore, the specific heat capacity of the battery and axial thermal conductivity needs to be accurately measured for battery thermal modeling, while the radial thermal conductivity can be measured with lower accuracies.

Introduction

The technological innovation and development of the automobile industry face a tremendous challenge in preventing and reducing environmental damage. Powertrains electrification is regarded as an essential solution to address the challenge. Lithium-Ion batteries (LiBs) with a high specific power and energy density are the advanced energy storage technology for battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) [23]. With the increase of the energy density and the expansion of applications of lithium-ion batteries, the problems of battery degradation and safety have become increasingly prominent. Battery performance is strongly dependent on temperature. The battery electrochemical reaction of the battery occurs faster as the temperature increases. Excessively temperature accelerates battery degradation, and even causes thermal runaway and fire in the worst scenario. It was reported that the lifespan of LiBs will be shortened by 60 days for every 1°C increase in temperature in the operating temperature range of 30–40°C [8]. The battery surface temperature exceeding 160°C will lead to electrolyte ignition [6]. Therefore, the temperature tolerance of lithium-ion batteries is narrowly limited. The optimal operating temperature range for lithium-ion batterie is typically 15°C–35°C, and the temperature non-uniformity of batteries in a module/pack should be limited to below 5°C [9]. Consequently, LiBs in vehicles require a BTM system to maintain their performance and safe operation. Besides, numerical models are widely used to simulate the thermal behavior of LiBs during the charging/discharging when designing a battery thermal management system [7,25]. Depending on the simplification of the physical model, the dimension of the numerical model ranges from one dimension to three dimensions [26]. Smith et al. [24] developed a three-dimensional 18650 single-cell model and a battery module model with 16 parallel cells to evaluate the thermal safety margin. Research on the battery temperature distribution at the cell level and pack level demonstrates that the accuracy of underlying thermophysical properties (thermal conductivity, specific heat capacity, and density) are fundamental for developing numerical models to predict the thermal behavior of battery [9,20]. Bandhauer et al. [1] reviewed thermal phenomena related to LiBs and mentioned the lack of thermophysical properties data. They discovered that a limited number of papers measured the heat capacity of the battery

FIGURE 14 Sensitive of the temperature difference between cells in a module.

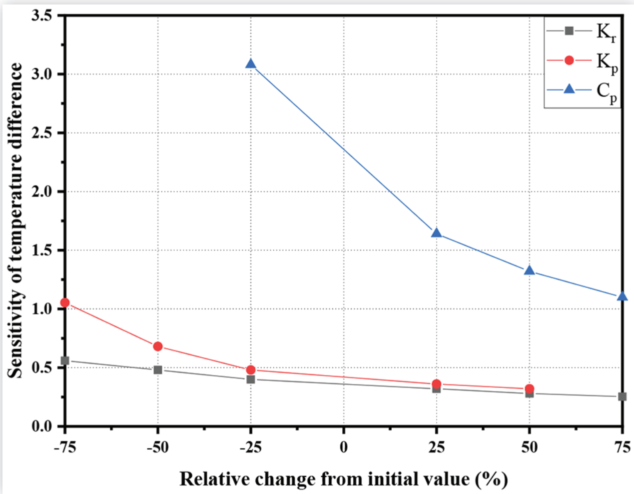
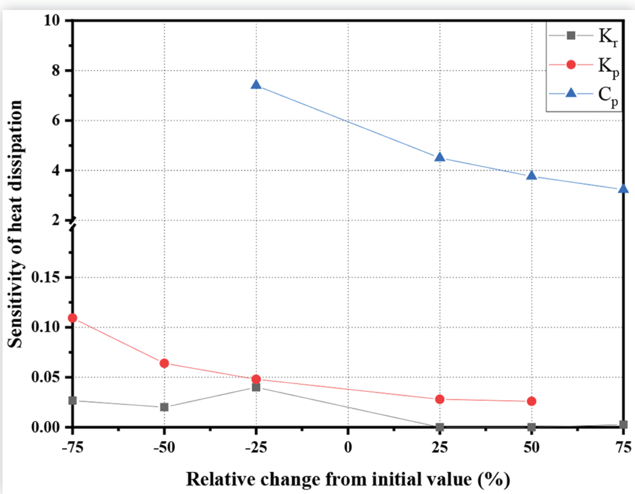


FIGURE 15 Sensitive of the heat dissipation rate of the module model.



(1). The specific heat capacity is the most influencing thermophysical parameter on various simulation results of the battery thermal model. Therefore, accurate measurement of the specific heat capacity is important for battery thermal modeling.

(2). The influences of radial thermal conductivity on battery thermal modeling are less prominent. The sensitivity of the max temperature of the cell model to radial thermal conductivity is only 0.2–0.38. Therefore, radial thermal conductivity values of the battery cell with lower measurement accuracy can be used in battery thermal modeling.

(3). The sensitivity range of temperature difference between cells to axial thermal conductivity is 0.32–1.05 while that of the temperature difference between cells to radial thermal conductivity is 0.28–0.56. For the simulation of the temperature difference between battery cells, the axial thermal conductivity of the battery needs to be accurately measured.

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