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Numerical Optimization of Cooling System Parameters for Multilayer Lithium Ion Cell and Battery Packs

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Abstract : Lithium-ion batteries are a commonly used type of rechargeable batteries because of their high specific energy and specific power. With the growing popularity of electric vehicles and hybrid electric vehicles, increasing attentions have been paid to rechargeable Lithium-ion batteries. However, safety problems, high cost and poor performance in low ambient temperatures and high current rates, are big obstacles for commercial utilization of these batteries. By proper thermal management, most of the mentioned limitations could be eliminated. Temperature profile of the Li-ion cells has a significant role in the performance, safety, and cycle life of the battery. That is why little temperature gradient can lead to great loss in the performances of the battery packs. In recent years, numerous researchers are working on new techniques to imply a better thermal management on Li-ion batteries. Keeping the battery cells within an optimum range is the main objective of battery thermal management. Commercial Li-ion cells are composed of several electrochemical layers each consisting negative-current collector, negative electrode, separator, positive electrode, and positive current collector. However, many researchers have adopted a single-layer cell to save in computing time. Their hypothesis is that thermal conductivity of the layer elements is so high and heat transfer rate is so fast. Therefore, instead of several thin layers, they model the cell as one thick layer unit. In previous work, we showed that single-layer model is insufficient to simulate the thermal behavior and temperature nonuniformity of the high-capacity Li-ion cells. We also studied the effects of the number of layers on thermal behavior of the Li-ion batteries. In this work, first thermal and electrochemical behavior of the $LiFePO_4$ battery is modeled with 3D multilayer cell. The model is validated with the experimental measurements at different current rates and ambient temperatures. Real time heat generation rate is also studied at different discharge rates. Results showed non-uniform temperature distribution along the cell which requires thermal management system. Therefore, aluminum plates with mini-channel system were designed to control the temperature uniformity. Design parameters such as channel number and widths, inlet flow rate, and cooling fluids are optimized. As cooling fluids, water and air are compared. Pressure drop and velocity profiles inside the channels are illustrated. Both surface and internal temperature profiles of single cell and battery packs are investigated with and without cooling systems. Our results show that using optimized Mini-channel cooling plates effectively controls the temperature rise and uniformity of the single cells and battery packs. With increasing the inlet flow rate, cooling efficiency could be reached up to 60%.

Keywords : lithium ion battery, 3D multilayer model, mini-channel cooling plates, thermal management
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