Energy Storage: 3-D CFD Thermal Modelling of Lithium-Ion Batteries

In this project, a transient three-dimensional computational fluid dynamics (CFD) thermal model of a single lithium-ion cell is proposed based on the actual structure of the cylindrical 18650 lithium-ion battery. The temperature distribution of the cell during discharge process was simulated and verified by comparing simulation results with experimental data. Commercial CFD software was applied in the simulation studies. The simulation is accurate and reliable as the input parameters are themselves obtained from experiments. Thermal behaviours of battery under adiabatic and normal conditions are studies in this research. In addition, temperature behaviours under other conditions can be easily simulated using our model by changing the ambient conditions in the software. The proposed model offers the potential in improving battery management systems (BMS) in terms of their monitoring and control capabilities.

The interior cell structure can be treated as uniform when considering its thermal characteristics because the current collectors comprising coaxial rolls of copper and aluminum foil are good heat conductors as shown in Figure 1. The interior cell structure is regarded as a heat source in the model. The safety valve is a safety mechanism which opens in response to a sudden increase in cell pressure, allowing built-up gases to escape. If the pressure inside a cell builds up, a plastic laminate membrane is punctured by a spike incorporated in the valve usually located in the top surface of the cell. A safe release of internal pressure precludes any dangerous rupture of the cell casing. The plastic safety valve included in our model.

The three-dimensional single cell CFD model is illustrated in Figure 2. The simulated temperature distributions of the cell under adiabatic condition at 2C and 3C discharge rates were found to be relatively uniform under adiabatic operation conditions. However, a slight temperature difference occurs after a certain time, where the temperature is slightly lower on the top surface of the cell because the internal heat source within the cell is located on the bottom of cell case as is shown in Figure 2. At 2C discharge rate, the highest temperature reaches 45ºC at the end of discharge (1800s) whereas at 3C discharge rate, the temperature rises to 53ºC within 1200s. High current discharge leads to high heat generation rate. The simulation under adiabatic condition is conducted for verification of the model. The comparison of simulation and experiment results are shown in Figure 3(a) and (b) for 2C and 3C discharge rates respectively.

From the results, we concluded that the battery temperature distribution is generally uniform under adiabatic condition while under normal discharge condition. Temperature difference is significant on the cell surface during transient discharge process because of the unbalance between heat generation and dissipation. Temperature is always lower on the top surface of the cell due to the internal cell structure where the heat is generated by the electrode rolls located at lower area in the cell case. Moreover, the current collectors also have little effect on the temperature distribution of the cell under normal conditions. High rate discharge lead to high temperature increases. Under normal operating condition, the cell temperature exceeds 40ºC at 3C discharge, which is beyond the acceptable working temperature range of lithium-ion battery (0-40ºC). Another possible application of the proposed model is to predict potential safety hazard of cells, when the temperature goes beyond the safe temperature range and actions could then be taken in advance to protect the cell and keep the battery system safe and healthy. This model is especially useful in the assessment of battery thermal behaviour under high current rate discharge process.

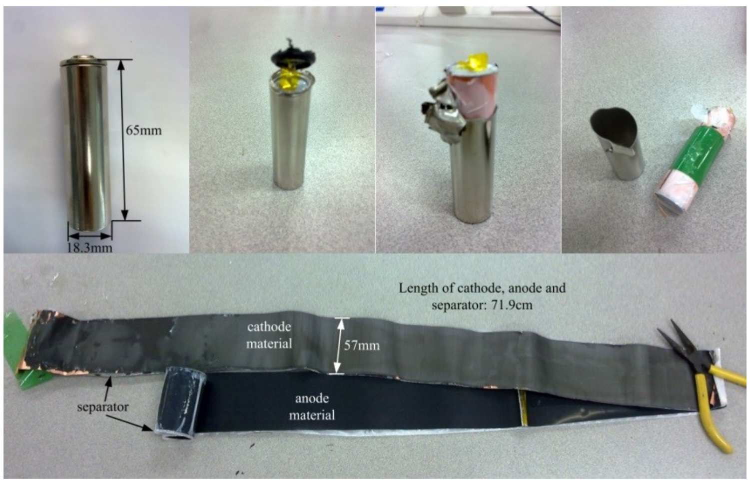


Figure 1

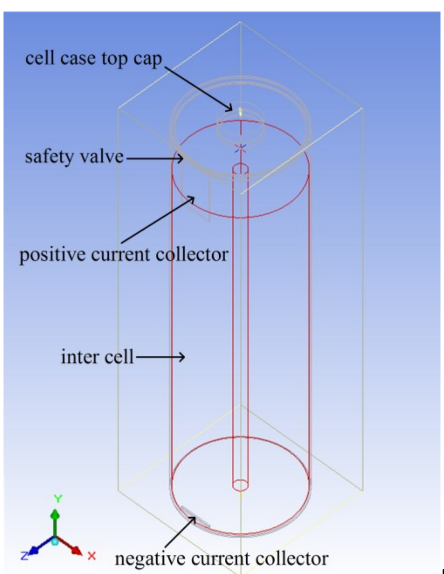
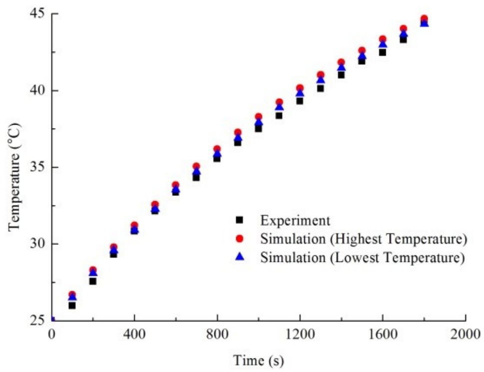
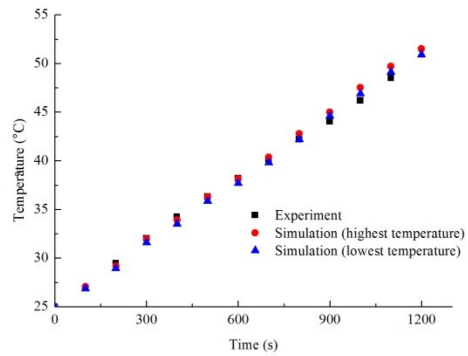


Figure 2



(a) under 2C discharge rate



(b) under 3C discharge rate

Figure 3