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Simplified Heat Generation Model for Lithium ion battery used in Electric Vehicle

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Abstract. It is known that temperature variations inside a battery may greatly affect its performance, life, and reliability. In an effort to gain a better understanding of the heat generation in Lithium ion batteries, a simple heat generation models were constructed in order to predict the thermal behaviour of a battery pack. The Lithium ion battery presents in this paper is Lithium Iron Phosphate ($LiFePO_4$). The results show that the model can be viewed as an acceptable approximation for the variation of the battery pack temperature at a continuous discharge current from data provided by the manufacturer and literature.

1. Introduction

Electric and hybrid vehicle may present the most promising solution for pollution problems caused by the emission of conventional internal combustion engine. These technologies will highly depend on battery packs. The role of battery as the power source in electric drive vehicle is important. Due to the high energy density, Lithium-ion batteries have gained much attention as a viable candidate to increase vehicle range and performance of electric drive vehicle application. However, there is a variety of thermal limitations for Lithium-ion battery. Most common thermal issues related to Lithium-ion batteries are capacity/power fade, selfdischarge, thermal runaway, pack electrical imbalance and cold temperature performance [1]. The battery positive electrode and electrolyte chemistry is said to have an impact of capacity/power fading. Batteries also generate heat during charge and discharge due to enthalpy changes, electrochemical polarization and resistive heating inside the cell [2, 3]. Temperature variation inside the batteries can lead to uneven temperature distribution which creates uneven charge/discharge behaviour within the pack [4]. Worst cases, thermal runaway may occur in a cell when heats are not properly control and possible to cause fire and explosion. For these reason, the need for battery thermal management is vital for electric and hybrid vehicles in order to keep the vehicle at its optimum performance. This paper provides an introduction on the theory and objectives of battery thermal management. The simplified heat generation model was developed to estimate the heat generation inside the battery will be discussed.

2. Basic information of Lithium-ion battery

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2.1.1. Battery structure

The basic structure of a battery consists of five major components as shown in Figure 1. There are electrodes (anode and cathode), a separator that prevents electron flow between the electrodes, a current collector on the outside of each electrode, and a case or enclosure. Electrons enter and leave the current collectors via current collector tabs, which connect the battery to the external circuit that contains the load to be powered or the source for battery charging.

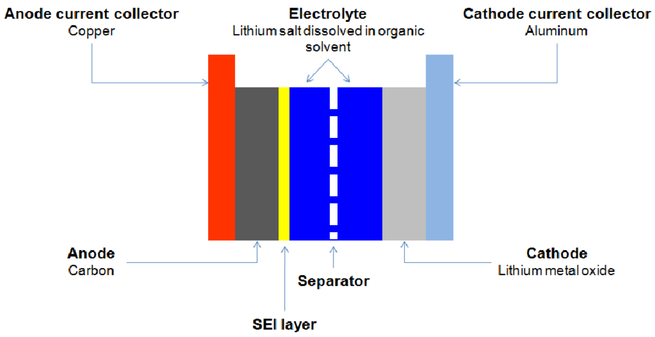

Figure 1.Battery basic structure

2.1.2. Chemical reactions

The Lithium-ion battery discussed in this paper is Lithium Iron Phosphate (LiFePO4). Generally the anode material for LiFePO4 is a form of carbon while the cathode material is LiFePO4 material. During charge or discharge, the reactions occurring in the two electrodes for discharging can be written as in equation (1) and for charging as in equation (2)

$$LiFePO_4 - xLi+ - xe - xFePO_4 + (1-x)\ LiFePO_4 \qquad (1)$$

$$FePO_4 + xLi+ + xe - xLiFePO_4 + (1-x)\ FePO_4 \qquad (2)$$

During the Lithium-ion battery discharge, Lithium ions (Li+) are released from the anode and travel through electrolyte toward the cathode. When the Lithium ions (Li+) reach the cathode, they are quickly incorporated into the cathode material.

2.1.3. Heat generation inside a battery

It is important to understand how heat generated inside a battery. Heat is produced in batteries from two sources; electrochemical operation and Joule heating [5-7]. Reference [8] found a way to calculate the battery heat using a thermodynamic energy balance and cited frequently in the literature in its simplified form is shown in equation 3 below where the first term is the heat generation due to Joule heating and the second term is the heat generation due to entropy changes.

$$q = I(U - V) - I(T\frac{dU}{dT}) \qquad (3)$$

3. Cell modelling

To derive the model it relies heavily on the fundamental of heat transfer. Deriving model for heat transfer is inherently challenging due to the complexity of battery chemistry and composition. Thus, many assumptions and simplification must be made. The Lithium-ion battery considered in this study is a $LiFeYPO_4$ (WB-LYP40AHA).Their main properties can be found in Table 1.

Table 1. Battery specification

Type	Nominal Capacity (Ah)	Nominal Voltage (V)	Upper cut-off voltage (V)	Lower cut-off voltage (V)	Operating Temperature (T)
$LiFeYPO_4$	40	3.7	4	2.8	$-45^0C \sim 85^0C$

The simulation work for this study was done based on PROTON's electric drive vehicle demonstrator battery's pack. The battery pack comprises of 12 modules in series. 4 modules were arranged 10 cells in series while the rest of the 8 modules were arranged 9 cells in series. As such, there will be a total of 112 cells.

3.1.1. Governing equation

The heat transfer inside the battery can be divided into three parts, i.e., the heat generated by the cell's internal resistance, the change of entropy that occur in the cell components during discharge and heat transferred to ambient conditions by convection [3] and could be written as equation (4)

$$mc_{cell}\frac{dT_{cell}}{dt} = I^2 R + T_{cell}\Delta S\frac{I}{nF} + Ah(T_{cell} - T_{amb}) \qquad (4)$$

Use of this equation assumes that the cell temperature is uniform. Hence a lumped capacitance model must be assumed in order to apply the equation correctly. In heat transfer theory, the validity of this assumption through the use of the Biot number. It is a dimensionless number that compares heat transfer occurring inside a body and at its surface using equation (5)

$$B_i = \frac{hL_c}{k} \qquad (5)$$

The characteristic length was calculated with the manufacturer's cell specification. For thermal conductivity and heat transfer coefficient, typical values were taken from literature [9], gave k = 3 W/mK.

3.1.2. Parameter values

Typical values from literature were used for the value of the entropy change [10]. ΔS= -30 J/molK. ΔS can be obtained in the function of state of charge in simplified as a second order polynomial as in equation (6). Table 2 describes the model parameters use.

$$\Delta S = -179(SOC^2) + 274.29(SOC) - 116 \qquad (6)$$

Table 2. Model parameters

Parameter	Unit	Value
Mass	kg	1.5
Specific heat capacity	J/kg.K	1350
Internal resistance	Ω	0.02
Entropy change	J/molK	-30
Surface area	m^2	0.21228
Heat transfer coefficient	W/m^2K	18.9

4. Results and discussion

The output data for the Matlab model is shown in Figure 2 for 3A discharge current. Assumed within the single cell Matlab model was that the cell transferred heat from its entire surface and it was in an environment where the ambient conditions were constant. The discharge process was also treated as being 100% efficient irrespective of the discharge current used.

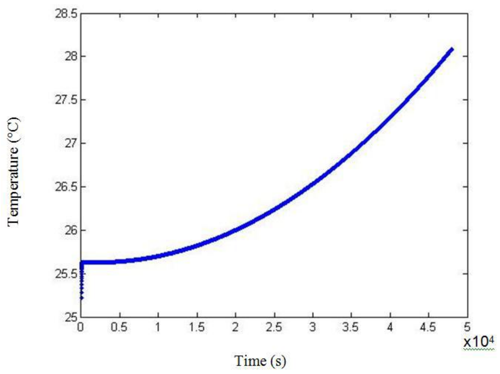

Figure 2. Cell temperature for 3A discharge current in Matlab simulation

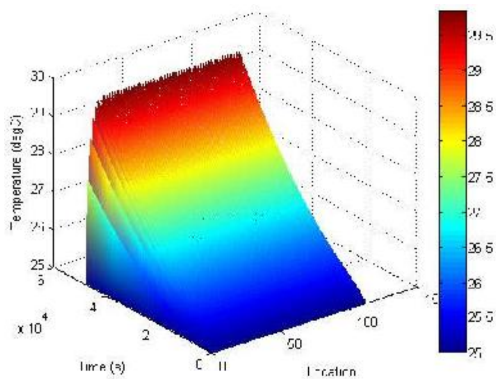

Figure 3. Matlab results for modelling the battery pack

This single cell model was then used to construct a second Matlab model for a battery module. Whilst each of the two battery modules was contain 112 cells in series, symmetry allows for only the first 56 to be modelled. The result of this simulation is shown in Figure 3, where the peak cell temperature for the central cell at the end of the 3A discharge is 29.8°C based on an initial ambient temperature of 25°C.

5. Conclusion

The simplified battery model may not be accurate enough to represent the thermal behaviour of Lithium ion battery. There is a great scope for improvement and future work in this area of battery heat generation modelling. If an experiment investigating the cell temperature can be performed in advanced, the Matlab model for the single cell could have been altered to include the actual data to generate acceptable results.

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