Model Study of Lithium-Ion Battery Temperature Field

Hong-Yu Xu, Pan Zhang, Kua-Hai Yu and Xu-Hui Zhang

ABSTRACT

Using finite element analysis software - ANSYS, numerical simulation on temperature changes was done for the CA60 lithium-ion battery under different rate constant current charge and discharge status in this paper. The temperature distributions of every part of lithium-ion battery have been computed. And the data comparison of numerical simulation and actual measurement was carried out. The temperature changes in different part of the lithium-ion battery were analyzed. This study shows that the temperature distributions are significantly influenced by discharge time and thermal conductivities of component materials of lithium-ion battery. The research can provide the basis for the development of the thermal management system of lithium-ion battery.

INTRODUCTION

Lithium-ion batteries requires good working temperature during its special charge and discharge chemical reaction process, which is to ensure the effective play of battery performance and make full use of the battery capacity. Monomer lithium-ion battery would produce internal heat in using process. When the ratio of charge and discharge is different, it makes each part of the lithium battery temperature distribution is different, this conditions may cause battery explosion burning-out and other major safety accident in some extreme conditions. Research of batteries temperature model could accurately predict the battery temperature distribution, thus a series of corresponding cooling or preheat measures, it could provide technical support for lithium-ion batteries thermal management system.

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LITHIUM-ION BATTERY HEATING RATE CALCULATION

The measured material and thermal characteristic parameters of the composition of CA60 lithium-ion battery are shown in table 1.

TABLE I. COMPOSITION AND THERMAL PROPERTIES OF BATTERY MATERIALS.

<table>
<thead>
<tr>
<th>Component</th>
<th>material</th>
<th>Density/ Kg/m$^3$</th>
<th>Specific heat /J/(Kg.K)</th>
<th>Heat conductivity coefficient/W/(m.K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>Polymer</td>
<td>930</td>
<td>1837</td>
<td>0.42</td>
</tr>
<tr>
<td>Battery core</td>
<td>Mixture</td>
<td>1685</td>
<td>2430</td>
<td>$K_x=21.1, K_y=1, K_z=21.1$</td>
</tr>
<tr>
<td>Electrolyte</td>
<td>Colloid</td>
<td>924</td>
<td>1900</td>
<td>0.13</td>
</tr>
<tr>
<td>Positive pole piece</td>
<td>Aluminum alloy</td>
<td>2702</td>
<td>903.1</td>
<td>238</td>
</tr>
<tr>
<td>Negative pole piece</td>
<td>Brass</td>
<td>8933</td>
<td>385</td>
<td>398</td>
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<td>385</td>
<td>398</td>
</tr>
</tbody>
</table>

In table 1, value of battery cell density, specific heat and thermal conductivity is the overall average. According to the heat production rate of Bemardi model:

$$q = \frac{I}{V_b} \left[ (U - U_0) + T \frac{du_0}{dt} \right] = \frac{I}{V_b} \left[ R + T \frac{du_0}{dt} \right]$$

(1)

Calorific value of Q is

$$Q = I^2 R + IT \frac{du_0}{dt}$$

(2)

For finished product CA60 battery, lithium-ion battery internal resistance is slightly different according to the charging and discharging rate, charged state and temperature, we adopt the average resistance is 1.1 m in the calculation model. The positive pole column resistance about 0.05 mΩ and negative pole column resistance about 0.03 mΩ. According to battery working state, the lithium battery total calorific value Q is thermal sum of column's resistance and battery cells.

When lithium battery 1C discharge, I = 72A, according to 0.5 mv/K calculate, then

$$Q = 72^2 \times 1.1 \times 10^{-3} + 72 \times 35 \times 0.5 \times 10^{-3} = 6.96 W$$

(3)

Similarly, in the condition of constant current charge and discharge, different ratio could be calculated, thermal production rate of positive and negative electrodes and battery cells as shown in table 2.
TABLE II. HEAT GENERATION RATE OF EACH PART OF THE BATTERY.

<table>
<thead>
<tr>
<th>Charge-discharge rate</th>
<th>Single battery current/A</th>
<th>Total thermal power/W</th>
<th>Battery cell heat generation rate/ W/m²</th>
<th>Copper column Calorific c/W</th>
<th>Heat generation rate/ W/m³</th>
<th>Aluminum column Calorific c/W</th>
<th>Heat generation rate/ W/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3C</td>
<td>21.6</td>
<td>0.89</td>
<td>835</td>
<td>0.392</td>
<td>882</td>
<td>0.401</td>
<td>1440</td>
</tr>
<tr>
<td>1C</td>
<td>72</td>
<td>6.96</td>
<td>5969</td>
<td>1.416</td>
<td>9730</td>
<td>1.519</td>
<td>16212</td>
</tr>
<tr>
<td>2C</td>
<td>144</td>
<td>25.33</td>
<td>23612</td>
<td>3.142</td>
<td>38883</td>
<td>3.557</td>
<td>64806</td>
</tr>
</tbody>
</table>

LITHIUM-ION BATTERY TEMPERATURE FIELD NUMERICAL SIMULATION UNDER CONSTANT-CURRENT DISCHARGE

Figure 1 is lithium-ion battery temperature distribution of shell, column and center section at 0.3C discharge. The highest temperature on shell is about 28°C, appears on the aluminum bar, copper and aluminum pole column. Temperature difference is about 6°C, battery shell temperature is about 23°C because upper part of battery is no cell generate thermal. The highest temperature appears on the position of column, temperature change is not obvious between battery shells, the highest temperature is about 28°C. Temperature difference is about 3°C between the position of battery cell and the column. Center section temperature is higher which is about 25°C.

![Figure 1](a) Shell (b) Cell and the column (c) Central section
Figure 1. Temperature distribution of lithium-ion battery at 0.3C discharge.

Figure 2 is 0.3C discharge condition, the highest temperature is about 52°C which is appear on aluminum column, copper column temperature is about 50°C. Battery cell temperature distribution are similar, temperature difference is about 2°C, column temperature is about 55°C which is relatively high. Temperature in center section is relatively uniform, temperature range is about 38°C-42°C, temperature difference is about 4°C.

![Figure 2](a) Shell (b) Cell and the column (c) Central section
Figure 2. Temperature distribution of lithium-ion battery at 1C discharge.
Figure 3 is 2C discharge condition, the highest temperature appears on aluminum column and copper column which is about 109°C, the temperature of battery shell center is about 84°C. The highest temperature at column and battery cell is about 117°C and 78°C, temperature difference is about 6°C. We can shorten discharge time, increase cooling measures and ensure the safety of temperature in the range. Center section, the highest temperature in the central location is about 91°C which is mainly due to the battery cell’s lower thermal conductivity.

COMPARISON OF NUMERICAL SIMULATION AND EXPERIMENTAL RESULTS

We take six points for temperature test at 20°C, 1C discharge. From figure 4 we can see that numerical simulation and experimental result has good consistency with the experiment results. The maximum temperature difference is about 10°C, the reasons for error may be: ① Parameters has certain influence to the battery temperature ② Discharge is not stable ③ High thermal conductivity material.

CONCLUSION

Numerical simulation of temperature curve has good consistency with the experiment results. Discharge time and thermal conductivity of lithium-ion battery materials has significant influence on the battery temperature distribution under different ratio. In order to ensure good working performance of lithium-ion battery, we could choose reasonable battery material composition and thermal property parameters, at the same time control discharge time.
ACKNOWLEDGEMENT

This research work was supported by the National Natural Science Foundation of China (No.51075124), Foundation of Henan Educational Committee (No. 13A480267), Luoyang science and technology planning project (No.1301004A-1) and Henan University of science and technology innovation ability cultivation in science fund project (No.2013ZCX001).

REFERENCES

3. Dong Chao. Research and design of lithium battery management system for electric vehicle[D]. Qingdao: Qingdao University, 2012.
4. Chen X Q, Li H. Research and design of intelligent management system for lithium battery[D]. Taiyuan: Taiyuan University of Science and Technology, 2013.