Study on temperature characteristics of mineral ferric phosphate lithium-ion battery

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Abstract: Lithium-ion battery (SE60AHA type) is the main power of mine trolleybus. It studies the characteristics of main parameters such as capacity, charging and discharging time and cycle life with temperature, which can effectively ensure safety. This paper designs charging and discharging experiments under different temperature conditions and conducts OCV-SOC curve analysis. The results show that under the charging conditions of different temperature, there is no significant change in the relative capacity of charging, but the lower the temperature is, the shorter the constant-current charging time is and the longer the constant-voltage time is. Under the discharging condition of different temperature, the change of relative discharging capacity is obvious, the voltage drops faster when the temperature is lower than 0℃, and it keeps the same voltage variation when the temperature is higher than 0℃, while the discharging time reduces with decreased temperature. Further more, according to the variation of charging and discharging voltage with different temperature, it analyze the health status and optimal working environment of mine-type lithium-ion battery adopting the characteristics of charging and discharging efficiency. The research results provide a basis of the using and maintenance of large-capacity lithium-ion battery stack in special environments of the coal mining.

1. Introduction

As China's coal mining industry strives to improve its own technological level in adversity, it has formed a diversified pattern of auxiliary transportation. Monorail cranes, trackless rubber vehicles and trams have developed better [1], and the capacity of lithium-ion battery packs using SE60AHA types as traction power has become the most important development tendency [2]. The special environment of underground coal mining, especially the change of temperature, imposes severe requirements on the application of large-capacity lithium-ion phosphate batteries in the field of mining power. Therefore, it is necessary to study the temperature characteristics.

The effect of temperature on the lithium-ion battery is directly reflected on the battery capacity, internal resistance and discharge voltage [3]. The relationship between the state of charge (SOC) and the open circuit voltage (OCV) can be studied. The effect of temperature on the characteristics of lithium-ion batteries was analyzed [4]. Zhang Zhe et al [5] studied the temperature pair with 3.2V/11 Ah lithium-ion phosphate battery as an example. The intrinsic influence of battery capacity, internal resistance and open circuit voltage are the main characteristics of temperature changes for small capacity lithium-ion phosphate battery. Liang Qi et al [6] with 3.7V/45Ah lithium cobalt oxide battery as an example, the influence of ambient temperature on capacity change was analyzed through experiment, and the battery performance was evaluated by the relationship between SOC and...
2. Temperature characteristics study

2.1. Evaluation method of temperature characteristics
According to the law of energy conservation, the differential equation for battery heat conduction [8], the formula of Newton's cool law [9], Bernard battery heat generation rate theory and battery ohmic heat and polarization heat rate formula [10], the relationship can be obtained between heat conduction, capacity and voltage of the battery during charging and discharging process. The relationship between heat conduction, capacity and voltage of the battery is Equation (1).

\[
mC_p \frac{dT}{dt} = IT \left( I \frac{dR}{dT} - \frac{I}{dC} \frac{dT}{dC} \right) + IR^2 + hA(T_{\text{amb}} - T)
\]

(1)

There are many factors that affect the battery temperature, such as the heat generated during charging and discharging, the different ambient temperatures and the design of the battery pack thermal management system. This experiment mainly studies the influence of ambient temperature change on the temperature characteristics of the battery and ignores the temperature influence of the internal resistance of the battery. According to the curve of battery residual capacity and the curve of the open circuit voltage, it evaluates the influence of the ambient temperature on the battery characteristics.

2.2 state of charge
The state of charge is a percentage which represents the battery remaining capacity and is one of the most important parameters for the battery characteristics. Bohlen et al. propose the following definition, the ratio of charge to rated capacity by rated conditions [11], as shown in (2).

\[
SOC = \frac{Q}{C_{N, \text{rated}}}
\]

(2)

Since the SOC can not be directly measured, which is affected by the basic characteristic parameters and the use characteristics of the battery, it is very difficult to measure, and its measurement has been extensively discussed in the literature. Since the SOC and OCV of the battery are closely related, the easiest way is to directly measure the battery voltage and deduce the SOC [12].

3. experiment

3.1 Research objects and experimental equipment
In this experiment, lithium-ion phosphate battery of SE60AHA types produced by AVIC Lithium Battery (Luoyang) Co. The main technical parameters of battery cell are shown in table 1.

| Table 1. Basic technical parameters of SE60AHA battery |
|-----------------------------------------------|
| Parameter             | Value                                      |
| Size: Long * wide * high (mm) | 180*71*279 |
| Rate Capacity          | 60Ah                                      |
| Working current Nominal | 1/3C                                      |
| Maximum Capacity 3C    | 4C (CC-CV)                                 |
| Maximum Discharge 12C  | 2.5V (Cut-off discharge voltage)           |
| Working Voltage        | 3.65V (End-of-charge)                     |
| Working temperature    | 0~45°C (charge Current)                   |
|                        | -20~45°C (Discharge current)              |
3.2 Experimental steps
Considering the factors affecting performance of battery, this experiment uses a single factor method to design the test plan to ensure the reliability of the experimental data. The measurement data method uses a full discharge method, which is capable of detecting the characteristic parameters such as the capacity and voltage of the battery most directly and reliably. The whole is divided into different temperature charging standard discharge and standard charging different temperature discharge two tests: the specific steps of charging standard discharge experiment at different temperatures are shown in Figure 1; the specific steps of the discharge experiment in standard charging different temperature environment are shown in Figure 2.

![Figure 1. Charging standard discharge experiments at different temperatures](image1)

![Figure 2. Experiment of standard charge discharging at different temperatures](image2)

4 results and analysis

4.1 Effect of temperature on capacity and charge and discharge time
The QN obtained by the different temperature charging experiments were: 61.972 A/h, 62.059 A/h, 62.059 A/h, 61.519 A/h, 62.719 A/h, 62.183 A/h, shown in Figure 3. The QN1 obtained by different temperature discharge processes were: 62.342 A/h, 62.43 A/h, 60.751 A/h, 58.514 A/h, 54.386 A/h, 47.66 A/h, 40.31 A/h, shown in Figure 4.

![Figure 3. Curve of relative capacity changing with temperature](image3)

![Figure 4. Curve of cutoff time changing with temperature](image4)

Comprehensive analysis of Figure 3 and Figure 4 shows that charging under different temperature industrial control has no effect on the relative capacity, but has a great influence on the charging cut-off time. Based on the time efficiency by the standard condition of 20°C, the charging time efficiency is: 103%, 102%, 100%, 90%, 80%, 50%, 36%. The discharging process of different temperature conditions has an effect on the relative capacity and discharging cut-off time, and the relative capacity has a great influence. Based on the discharging capacity efficiency by the standard condition of 20 °C, the discharging capacity efficiency is: 102.6%, 102.7%, 100%, 96.3%, 89.5%, 78.5%, 66.3%.
4.2 Effect of temperature on charge and discharge characteristics

Combined with the experimental data, the curve of the open circuit voltage (OCV) with the state of charge (SOC) under different temperature conditions during charging and discharging can be obtained. Figure 5 is a graph of OCV-SOC for different temperature charging-standard discharge conditions, and Figure 6 is a graph of OCV-SOC for standard charging-different temperature discharge conditions.

Figure 5. OCV-SOC curve of charging process

According to the OCV curve of the experimental flow chart 1 and Fig. 5, when the SOC<0.1, the value of the OCV rises significantly, and it is generally believed that the cause of the phenomenon is caused by the ohmic resistance of the battery itself. Due to the high viscosity of the electrolyte under low temperature conditions, the lithium-ion activity inside the battery is reduced, the diffusion resistance is large, and the ohmic internal resistance is increased, so that the OCV value reaches the charge cut-off voltage in order from low temperature to high temperature. This phenomenon has a great influence on the life of the lithium-ion battery. In order to reduce the impact, the constant current constant voltage charging method is used for charging. Experiments show that the lower the temperature is, the shorter the constant current charging time is, the longer the constant voltage charging time is, and the higher the OCV-SOC curve is after the temperature is higher than 20 °C.

According to the experimental flow chart 2 and the OCV curve in Fig. 6, it can be seen that the initial stage is also affected by the ohmic internal resistance of the battery itself. As the SOC decreases, the value of OCV decreases rapidly, and the power consumption is large. After a period of discharging, when the value of SOC is in the range of 0.9-0.1, the temperature of OCV is still significantly lower at low temperature conditions below 0°C. Under high temperature conditions above 20°C, the OCV-SOC curve is basically the same, and the discharging is slower; at the end of discharging, when SOC=0.1, the corresponding voltage is about 3.1V, the value of OCV decreases linearly, and the voltage reaches the cutoff voltage faster.

4.3 The effect of temperature on life

Cycle life (number of times) is an important indicator for evaluating the technical efficiency of lithium-ion battery use. The process of charging and discharging for a lithium-ion battery is called a cycle, or a cycle. During the cycle, there is an irreversible phenomenon due to the falling off, aging and loss of the electrode active material, thereby causing the battery discharge capacity to be attenuated. The lithium-ion battery life was evaluated by studying the difference in charging and discharging voltage with temperature, and the results are shown in Fig. 7.
It can be seen from Fig. 7 that when the SOC is less than 0.1 at 55°C (a), the discharging voltage (3.238V) is greater than the charging voltage (3.171V), and the battery charging and discharging efficiency is 100.35%, which is regarded as a battery. Over-discharging; at 0°C and -10°C (c, d) operating conditions, as the temperature decreases, the difference between the discharging voltage and the charging voltage gradually increases, the charging and discharging energy efficiency decreases; at 20°C (b) In other words, the charging energy is 204.6Wh, the discharge energy is 193.6, the energy efficiency is 94.26%, the energy efficiency utilization is high, and there is no overcharging phenomenon, which is the optimal working temperature.

5. Conclusion
In this paper, through the literature research, the OCV-SOC curve is used as the evaluation method of temperature characteristics, and the SE60AHA type lithium-ion phosphate battery is used as the research object. Under the conditions of constant temperature and adiabatic simulation, different temperature charging-standard discharges and standard charging are completed. Two sets of experiments with different temperature discharging. Through the relative capacity, charging and discharging time and OCV-SOC curve analysis, the effects of charge and discharge characteristics of lithium-ion battery of temperature change and their relationship is studied. The results of this study provide a basis of the use and maintenance of large-capacity lithium-ion battery packs in special environments under coal mines.

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