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# Temperature Characteristics of Power Ternary Polymer Li-ion Batteries

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***Abstract***

*The characteristics of power ternary polymer Li-ion batteries are closely connected to ambient temperature. The capacity characteristic, resistance and state of charge-open circuit voltage (SOC-OCV) curve are important parameters to represent the performance of power batteries and to determine battery management system (BMS) design. The experiments at different ambient temperatures are carried out and the laws between temperature and capacity, resistance and OCV are studied. The capacity drops sharply under low temperature, and increases with a relatively slower rate than under low temperature when the temperature goes up. Polarization and ohmic resistances during charge and discharge process decrease when the temperature rises, and the change rate of ohmic resistance is higher than that of the polarization resistance. Moreover, the change of ohmic resistance under low temperature is more significant than under high temperature. With the decrease of temperature, the SOC-OCV curve moves down, but generally, the curve is affected only slightly by the temperature.*

**Keywords:** *Ternary polymer Li-ion battery, Temperature, Capacity, Resistance, Open circuit voltage (OCV)*

## 1. Introduction

Lithium-ion (Li-ion) batteries are a type of rechargeable battery which is comprised of cells that employ lithium intercalation compounds as the anode and cathode materials. The lithium ion moves from the anode to the cathode during discharge and from the cathode to the anode when charging.

The high specific energy and energy density of commercial of lithium ion battery products makes them attractive for weight or volume sensitive applications. Li-ion batteries allow a low self-discharge rate, long cycle life and a broad temperature range of operation [1], enable their utilization in a wide variety of applications. A wide array of sizes and shapes is now available from a variety of manufacturers. Single cells typically operate in the range of 2.5 to 4.2 V, approximately three times that of NiCd or NiMH cells, and thus require fewer cells for a battery of a given voltage. Li-ion batteries can offer high rate capability. In past decades, lithium ion batteries are one of the most popular types of battery for portable electronics with one of the best energy-to-weight ratios, no memory effect, and a slow loss of charge when not in use. Recently, lithium-ion batteries have been paid more and more attention to the popularity for electric vehicle (EV), hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV) as well as aerospace applications, *etc.*, due to their high input/output power, high energy density and

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large power capacity [2]. On all accounts, lithium-ion batteries are becoming the front-runner among rechargeable battery technologies [3]. Ternary polymer Li-ion battery is an emerging type of power lithium-ion battery, which has more excellent performance. It is very necessary to study the characteristic of power ternary polymer Li-ion batteries [4].

## 2. Materials And Methods

The characteristics of power ternary polymer Li-ion batteries are closely connected to ambient temperature [5]. The capacity characteristic, resistance and state of charge-open circuit voltage (SOC-OCV) curve are important parameters to represent the performance of power batteries and to determine battery management system (BMS) design [6]. The change rule of the power battery's capacity has a significant effect on the life management and the state of charge estimation [7]. As shown in formula (1) to (3), the quantity of heat production and the power delivery characteristics of the ternary polymer Li-ion batteries are influenced by the quantity of the internal resistance [8].

$$I_{max} = \frac{U - U_{min}}{R_t} \quad (1)$$

$$P_{max} = U_{min} I_{max} \quad (2)$$

$$Q_g = I^2 R_t \quad (3)$$

Where, $I_{max}$ represents the battery's maximum discharge current, $U$ represents the battery's open circuit voltage (OCV), $U_{min}$ represents the battery's discharge cut-off voltage, $R_t$ represents the total resistance in the process of discharge, $P_{max}$ represents the battery's maximum discharge power, $Q_g$ represents the battery's quantity of heat production, $I$ represents the battery's current.

The battery's open circuit voltage (OCV) can be used to calibrate the battery's state of charge (SOC) [9]. Therefore, in order to represent the performance of power batteries anddesign battery management system (BMS) better, it is very necessary to study the capacity characteristic, resistance and state of charge-open circuit voltage (SOC-OCV) curve [10].

## 3. Experimental Facilities

The testing batteries are shown in Figure 1, which are prepared by Jiangsu Huadong Institute of Lithium-ion Battery. The design capacity is 50 Ah, and the voltage is 3.7V.

**Figure 1. Batteries for Test**

The main facility is Arbin battery test system, which model is EVTS-174075-T-72KVA-IGBT. The system could record the voltage-current characterization. The battery performances at different temperatures are tested in a temperature test box as shown in Figure 2.


**Figure 2. Temperature Control Box**

## 4. Influence Of Ambient Temperature On The Battery's Capacity

In order to obtain the influence of ambient temperature on the battery capacity, the fully charged batteries were discharged under different temperatures. The test steps are as follows [11].

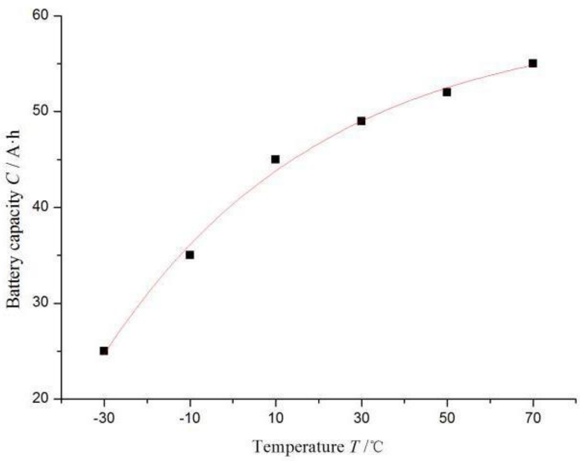



**Figure 3. Diagram of Li-ion Battery's Capacity and Ambient Temperature**

(1) Charge the battery to 4.15V at 1/3C constant current, which is 16.67A
(2) Charge the battery until the current drops to 1A with constant voltage.
(3) Stop charging.
(4) Let the battery stand 1 h.

(5) Discharge the battery to 2V at 1/3C constant current.
(6) Calculate the capacity.

The six ternary polymer Li-ion batteries of the same model were tested under different temperatures, which were -30℃, -10℃, 10℃, 30℃, 50℃ and 70℃. The Li-ion batteries' capacities were shown in Figure 3.

As shown in Figure 3, the capacity drops sharply under low temperature, and increases with a relatively slower rate than under low temperature when the temperature goes up. The capacity is only a half of the normal value at -30℃. However, the capacity rises from 90% to 110% with the temperature from 10℃ to 70℃. The fitting formula of battery's capacity and environmental temperature is obtained and shown as follows.

$$C = -19.38918 \times \exp(-T/50.70324) + 59.73485$$

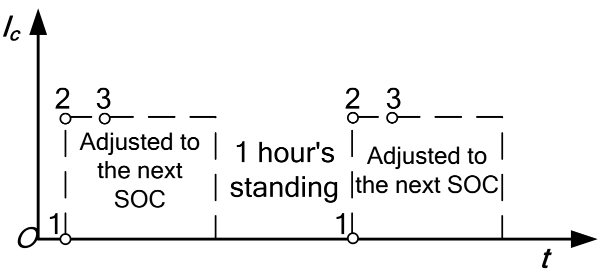
$$R^2 = 0.99229$$

Where, $C$ represents the battery's capacity; $T$ is the ambient temperature; $R^2$ represents the correlation.

## 5. Influence of Ambient Temperature on the Battery's Internal Resistance

The battery's internal resistance was tested by the mixed pulse power characteristics method at the temperature of 10℃, 30℃ and 50℃. The test steps are as follows.

(1) Discharge the battery to empty.
(2) Let the battery stand 1 h, test and record the open circuit voltages (OCV).
(3) Charge the battery and adjust the SOC to 0.025 at 1/3C constant current; Record the voltages in the first 10 seconds; Calculate the charging resistance at the SOC of 0 by formula (4) to (7), including the internal ohmic resistance and the total resistance.
(4) Charge the battery and adjust the SOC to 0.05, 0.075, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0, respectively, at 1/3C constant current; Calculate the charging resistance at different SOC values as the same method in step (2) to (3); While the SOC is close to 1 especially at the temperature of 10℃, the internal resistance will become extremely high and the charging current should be reduced to 1/5 C.
(5) Discharge the battery and adjust the SOC to 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.075, 0.05, 0.025 and 0, respectively, at 1/3C constant current; Calculate the discharging resistance at different SOC values as the same method in step (2) to (3); While the SOC is close to 0 especially at the temperature of 10℃, the internal resistance will become extremely high and the charging current should be reduced to 1/5 C. The test process is shown in Figure 4 and 5.



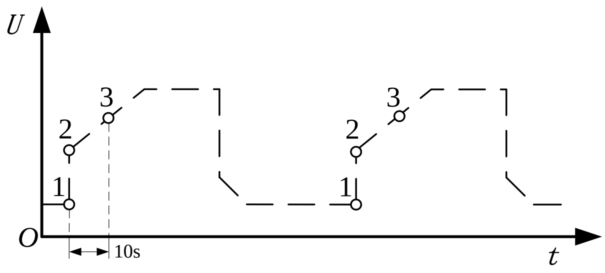



**Figure 4. Schematic Diagram of Battery Charging Resistance Measurement**

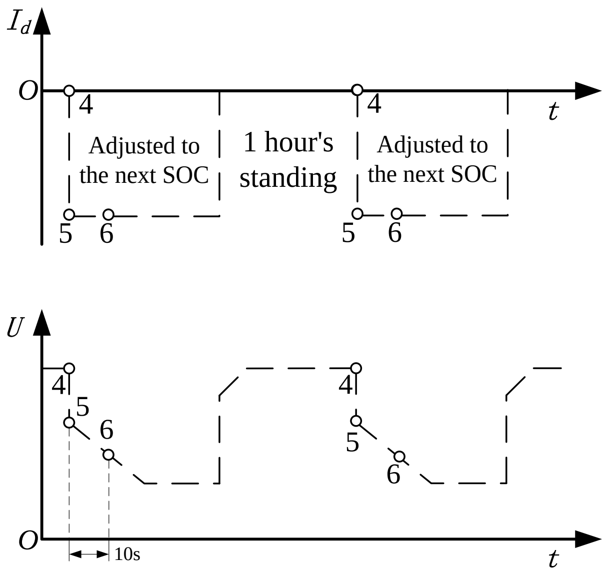



**Figure 5. Schematic Diagram of Battery Discharging Resistance Measurement**

The calculation formulas of the battery's charging internal ohmic resistance $R_o^c$, charging total resistance $R_t^c$, discharging internal ohmic resistance $R_o^d$ and discharging total resistance $R_t^d$ are shown as follows.

$$R_o^c = \frac{\Delta U_c}{\Delta I_c} = \frac{U_2 - U_1}{I_c} \tag{4}$$

$$R_o^d = \frac{\Delta U_d}{\Delta I_d} = \frac{U_5 - U_4}{I_d} \tag{5}$$

$$R_t^c = \frac{\Delta U_c}{\Delta I_c} = \frac{U_3 - U_1}{I_c} \tag{6}$$

$$R_t^d = \frac{\Delta U_d}{\Delta I_d} = \frac{U_6 - U_4}{I_d} \tag{7}$$

Where, $\Delta U_c$ and $\Delta U_d$ represent the changing and the discharging voltage variation before and after the step input; $\Delta I_c$ and $\Delta I_d$ represent the changing and the discharging current variation before and after the step input; $U_1$ to $U_6$ are the corresponding voltages of the point 1 to point 6, respectively; $I_c$ and $I_d$ represent the changing and the discharging current of the battery.

In this article, the polarization resistance represents the sum of the concentration polarization resistance and the electrochemical polarization resistance, which can be obtained by taking the ohmic resistance from the total resistance.

The ohmic, polarization and total resistances during charge and discharge process were tested and calculated, respectively at the temperature of 10℃, 30℃ and 50℃. The results were shown in Figure 6 to Figure 11.

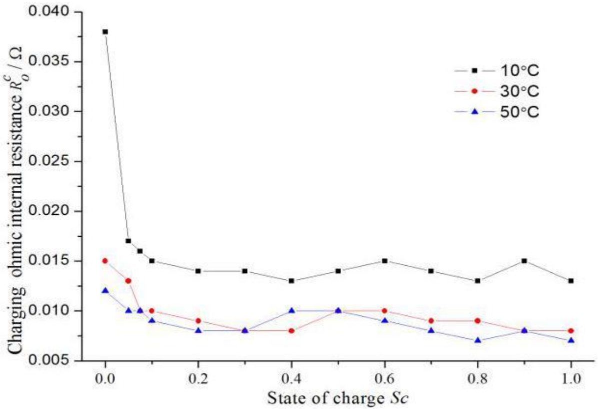



**Figure 6. Diagram of Battery Charging Ohmic Resistance and State of Charge under Three Different Temperature Conditions**

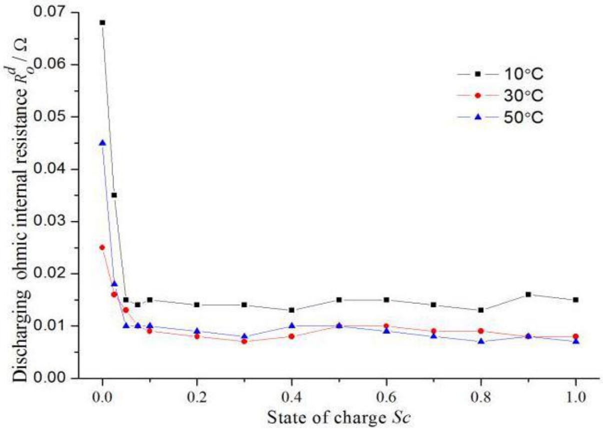



**Figure 7. Diagram of Battery Discharging Ohmic Resistance and State of Charge under Three Different Temperature Conditions**

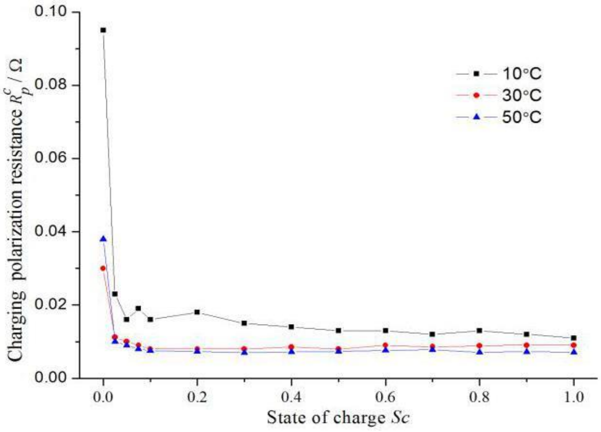



**Figure 8. Diagram of Battery Charging Polarization Resistance and State of Charge under Three Different Temperature Conditions**

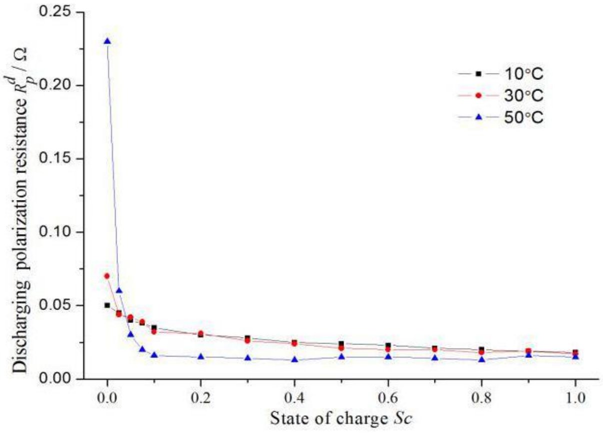



**Figure 9. Diagram of Battery Discharging Polarization Resistance and State of Charge under Three Different Temperature Conditions**

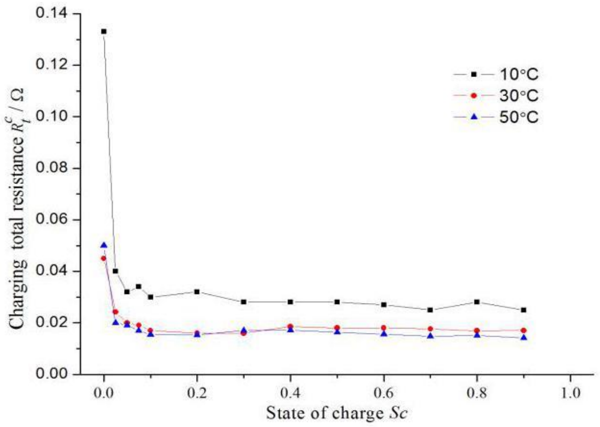



**Figure 10. Diagram of Battery Charging Total Resistance and State of Charge under Three Different Temperature Conditions**

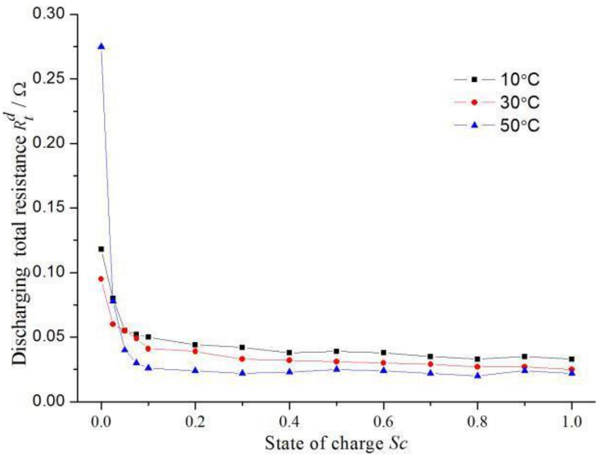



**Figure 11. Diagram of Battery Discharging Total Resistance and State of Charge under Three Different Temperature Conditions**

In a wide range of SOC, as the SOC value from 0.2 to 1.0，the battery internal resistances under the same temperature, either the ohmic resistances, the polarization resistances, or the total resistances, are essentially constant. While the SOC value is less than 0.1, the battery internal resistances increase sharply with the decreasing SOC value. And the rising rate of the polarization resistance is considerably larger than the ohmic resistance, especially at the temperature of 10℃.

Ohmic, polarization and total resistances during charge and discharge process increase when the temperature drops. The resistances measured by the above test methods are the battery's DC internal resistances, which are mainly the internal ohmic resistances of the electrolyte. In a certain scope of temperature, the migration speed of ions slows down with the decreasing temperature, making the internal ohmic resistances of the electrolyte rising. Therefore, the ohmic resistances of batteries increase when the temperature decreases. The rate of chemical reactions also slows down with the decreasing temperature, and the polarizations of concentration and electrochemical reaction increase rapidly, making the internal polarization resistances of batteries rising. While the SOC value is in the wide later range, the internal polarization resistances under different temperatures are very close, but the internal ohmic resistances under different temperatures have larger difference. Therefore, the internal ohmic resistances are more sensitive to the temperature than the internal polarization resistances.

It can be seen from the curves of the ohmic resistances during charge and discharge process that the 30℃ curve is between the 10℃ curve and the 50℃ curve, but the 30℃ curve is much closer to the 50℃ curve, which means that the internal ohmic resistances are more sensitive to the low temperature and the change of ohmic resistance under low temperature is more significant than under high temperature. And the lower the temperature, the greater the increase magnitude and rate of the ohmic resistances with the decreasing SOC value.

## 6. Influence of Ambient Temperature on the Battery's Open Circuit Voltage

The battery's open circuit voltage (OCV) can be used to calibrate the battery's state of charge (SOC) because the SOC-OCV curve has good repeatability at the same temperature and under the same test rules. The battery's SOC-OCV curve is a very important curve which can reflect the basic performance of the battery. And batteries of different types have different SOC-OCV curves. Therefore, it is very necessary to study the SOC-OCV curves at different temperatures.

The SOC-OCV curves are measured as the test procedures in Section 3.

The SOC-OCV curves under three different temperature conditions are shown in Figure 12 and Figure 13, respectively, during charge and discharge process.

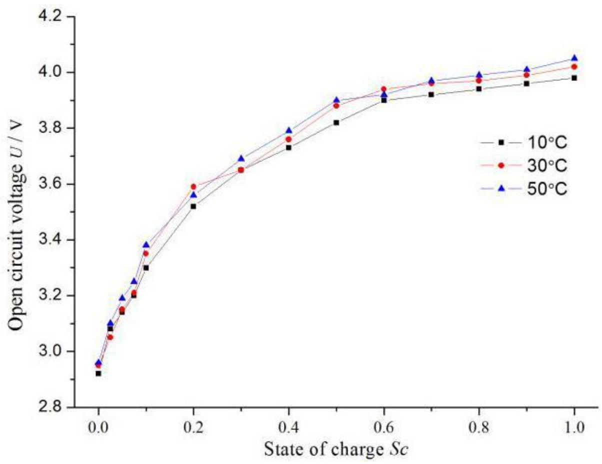



**Figure 12. Battery SOC-OCV Diagram under Three Different Temperature Conditions during Charge Process**

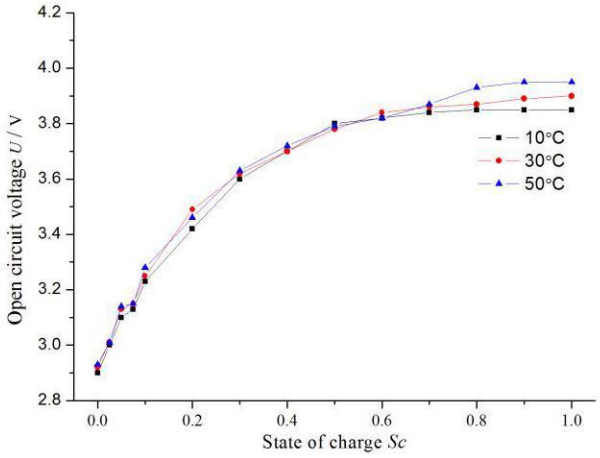
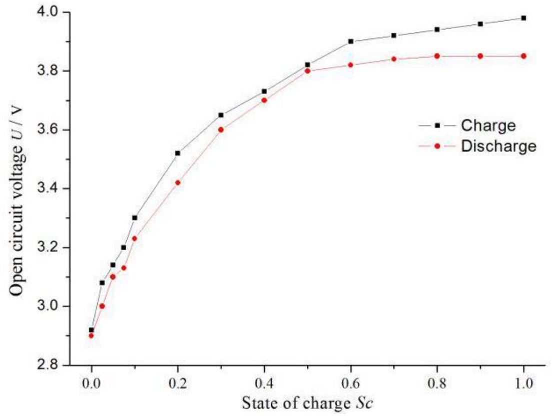
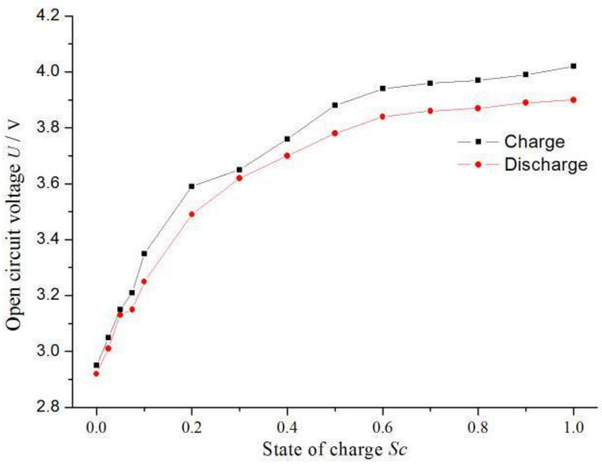


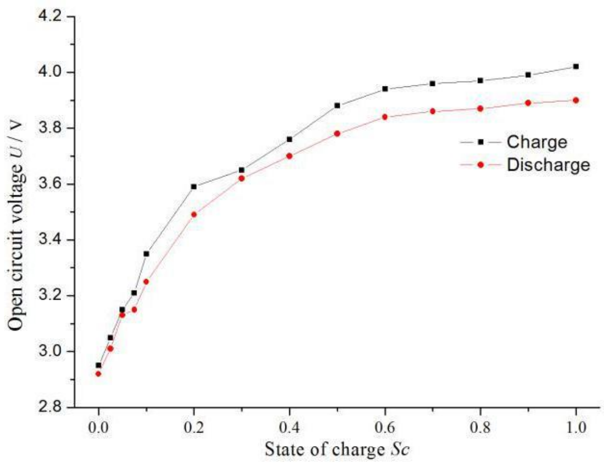

**Figure 13. Battery SOC-OCV Diagram under Three Different Temperature Conditions during Discharge Process**




(a)10℃




(b)30℃




(c)50℃

**Figure 14. Battery Charging and Discharging SOC-OCV Diagram under Three Different Temperature Conditions**

The battery's OCV increases monotonically when the SOC value goes up. In a wide range of SOC, as the SOC value from 0.5 to 1.0, the battery's OCV increases slowly, with almost no change. While the SOC value is less than 0.5, the battery's OCV decreases sharply with the decreasing SOC value.

The SOC-OCV curves of the charge and the discharge process exist differences. The SOC-OCV curve of the charge process is slightly lower than the discharge process. The differences of the SOC-OCV curves under different temperature conditions are very small. In general, the lower the temperature, the lower the curve. However, there are exceptions at some SOC value.

## 7. Conclusion

The capacity characteristic, resistance and OCV are important parameters to represent the performance of of power ternary polymer Li-ion batteries. The experiments at different ambient temperatures are carried out and the laws between SOC and capacity, resistance and OCV under different temperature conditions are studied.

(1) The temperature has great influence on the battery's capacity. The capacity drops sharply under low temperature, and increases with a relatively slower rate than under low temperature when the temperature goes up.

(2) The temperature has obvious influence on the ohmic resistances and the total resistances. In general, polarization and ohmic resistances during charge and discharge process decrease when the temperature rises. The internal ohmic resistances are more sensitive to the temperature than the internal polarization resistances. The internal ohmic resistances are more sensitive to the low temperature and the change of ohmic resistance under low temperature is more significant than under high temperature.

(3) With the decrease of temperature, the SOC-OCV curve moves down, but generally, the curve is affected only slightly by the temperature.

The above conclusions represent the temperature characteristics of of power ternary polymer Li-ion batteries, which is significant to determine battery management system (BMS) design.

## Acknowledgment

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