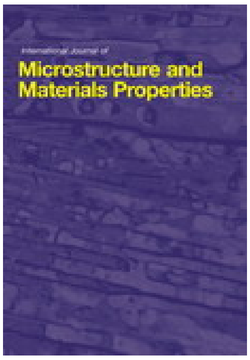

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Study on low temperature discharge performance of lithium ion batteries for new energy vehicles

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Abstract: To explore the operating state of lithium-ion batteries for new energy vehicles at low temperatures, this study conducted a study on the low-temperature discharge performance of lithium-ion batteries for new energy vehicles. Firstly, the establishment of a low-temperature discharge test platform is completed using a battery charging and discharging test system, a host computer, and a thermal thermometer. Then, on the basis of the established platform, a low temperature environment is set up to test the performance of lithium-ion batteries. The results show that the lower the temperature, the lower the maximum available capacity and discharge capacity of the battery. At low temperatures, the battery can reach a thermal equilibrium state, but the accumulation of polarisation in the battery is more severe, which can easily lead to deterioration of its operating conditions. Therefore, operating at low temperatures is not recommended.

Keywords: new energy vehicles; low temperature discharge performance test platform; near adiabatic working condition; natural convection conditions.

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1 Introduction

With the increasing global attention to environmental protection and sustainable development, new energy vehicles have achieved rapid development, and one of the core technologies of new energy vehicles is lithium-ion batteries (Guo et al., 2022; Xie et al., 2022b). In low temperature environment, the discharge efficiency of lithium-ion battery will be reduced, and the battery capacity will also decline, which will affect the driving range of new energy vehicles and the start-up and reliability under extreme low temperature conditions (Xie et al., 2022a). Therefore, the key to improve the performance of new energy vehicles is to study the discharge performance of lithium-ion batteries at low temperatures and optimise their charging and discharge management system, and it is of great significance to study the low-temperature discharge performance of lithium-ion batteries (Quan et al., 2022; Wei and Gong, 2022). Under this background, many scholars have carried out research on it. For example, when Han et al. (2022) studied the discharge behaviour of high-Ni ternary lithium-ion batteries at low temperatures, they analysed them by means of thermodynamic coupling and analysed their discharge speed at low temperatures by means of dynamic theory. Li et al. (2021) studied the structure of lithium-ion batteries for new energy vehicles after considering electrochemical impedance, especially in the aspect of low-temperature discharge characteristics. This kind of research will help to promote the rapid development of new energy vehicle technology of our country. By analysing their electrochemical impedance and charge changes at low temperatures, they obtained scanning electron microscopic characterisation of lithium cobalt oxide and graphite under electron microscope scanning in this state, and then analysed their discharge performance. Zhang et al. (2020) studied the discharge characteristics of lithium ion batteries at low temperature by data mining method, characterised and analysed the capacity attenuation factor and internal resistance characteristics of lithium ion batteries, obtained the low-temperature capacity loss path of lithium ion batteries, and finally analysed its low-temperature discharge performance. The above three methods all analyse the low-temperature discharge performance of lithium-ion batteries for new energy vehicles, but their tests are not rigorous and can not obtain better research results. Based on this, this study carries out the low-temperature discharge performance analysis of lithium-ion batteries for new energy vehicles in the form of experiments. The highlight of this research is to establish a perfect test platform using battery charging and discharging test system, temperature recorder, incubator and other equipment, and build two research conditions based on the experimental platform, namely, Natural convection and near adiabatic conditions, to test new energy lithium ion batteries under different working conditions, so as to study the impact of temperature on battery discharge capacity under different working conditions, and analyse its low-temperature discharge performance.

2 Test platform design

2.1 Test platform construction

First, build a set of experimental platform for testing, as shown in Figure 1.

Figure 1 Test platform architecture diagram (see online version for colours)

The platform basically includes a V100A battery charging and discharge test system with ArbinLBT-60V100A, an electrochemical workstation, a temperature recorder, a thermostat and a mainframe computer. ArbinLBT technology is used to charge and discharge batteries. The electrochemical bench can generate an excitation current which can be determined by the sample to be tested. Temperature controller is a temperature recorder to collect and record the temperature of the sample in real-time. Personal computers control these devices and perform experimental tests When constructing the test platform, it is necessary to pay attention to the following points: When connecting the Arbin battery test system, the channel connecting line needs to enter from the side flange of the temperature box and connect to the battery under test. At the same time, to ensure its communication quality, it is necessary to conduct thermal insulation treatment on the flange of the channel. After connecting the fixture and the test system, close the temperature box door and start the temperature box to correctly set the Arbin battery test system to the target temperature. Through computer communication control, the test of charging and discharging behaviour is started. When conducting EIS testing, the channel lines should be correctly connected according to the connection diagram on the electrochemical workstation, and the corresponding terminals of the connection lines should be connected to both ends of the fixture where the sample is located (Wang et al., 2022). In addition, attention should be paid to avoiding interference with fine equipment such as electrochemical workstations during testing, and the connecting lines between them can be disconnected.

2.2 Selection of test materials

In this paper, the lithium iron phosphate battery of a domestic new-energy automobile manufacturer is selected for research, and the relevant parameters are as follows.

Table 1 Test object parameters

Technical indicators	*Parameter*
Nominal capacity	1,530 mAh
internal resistance	30–50 mΩ
weight	40±2.0 mg
Nominal voltage	3.20 V
Charging voltage	3.65 V±0.05V
Maximum charging current	1,530 mA
Discharge cut-off voltage	2.0V
Maximum continuous discharge current	31,00 mA
Storage temperature	–20°C– + 35°C

Before testing the battery, it is also necessary to conduct an activation experiment, that is, charge and discharge multiple batteries at 0.2C at room temperature, and then select a sample with a high consistency between terminal voltage and capacity as the final test sample, laying the foundation for obtaining accurate test results.

2.3 Test plan design

Using the test platform constructed above and based on the batteries selected above, this study conducted three tests on the maximum usable capacity, discharge capacity, and low-temperature dynamic stress of the batteries to analyse the low-temperature discharge performance of new energy vehicle batteries.

2.3.1 Battery maximum usable capacity test

In practical applications, lithium ion power batteries need to withstand different environmental tests, such as ultra-low or high temperatures. High temperature will accelerate the electrochemical reaction rate inside the battery, improving its charging and discharging performance, but it will also accelerate the degradation of the active material of the battery, leading to capacity degradation (Pan et al., 2022; Kong et al., 2022). Low temperature will inhibit the internal reaction of the electrode and reduce the battery capacity. In addition, overcharging and discharging caused by improper operation can also lead to battery capacity degradation. Therefore, prior to subsequent testing, the battery should be tested for maximum usable capacity. This study uses a small current pulse charging and discharging test method to complete the test, in order to minimise the measurement error caused by long-term heat release, a small current pulse charging and discharging test method is used in this paper. In this way, the temperature of the measured unit can maintain a high stability during the whole test process. Follow the steps below to test.

1 Place the battery at room temperature (25°C) for 3 hours
2 Let the battery charge at 1/3C for 108s and then stand for 1h
3 Judge whether the discharge cut-off voltage has reached 2V. If not, repeat Step 2; If it is reached, record the current discharge capacity and let it stand for 2h
4 Allow the battery to charge at a constant current of 1/3C for 108s and then let it stand for 1h again
5 Judge whether the charging cutoff voltage reaches 3.65V and whether the constant voltage charging is less than the cutoff voltage. If the requirements are not met, repeat Step 4; If the requirements are met, record the current charging capacity and let it stand for 2 h
6 Repeat steps 2–5 to obtain three test results and calculate the average charge and discharge capacity
7 To obtain usable capacity data at different temperatures, repeat the experiment at 10°C, 0°C, –5°C, –10°C, and –15°C to obtain the maximum usable capacity data at various temperature environments.

2.3.2 Discharge capacity test

In most studies, the discharge test of lithium battery is in a state of natural convection (constant temperature), which means that the battery surface temperature changes very little and is almost constant (Lv et al., 2022; Liu et al., 2021). In practice, however, lithium batteries are usually in a near-adiabatic state when discharged at work. So the existing batteries are divided into two groups for the experiment. One group was tested under near-adiabatic conditions and the other under natural convection conditions. On this basis, the charging and discharging capacity of the device under standard working condition and variable temperature is measured. Next, the test was carried out at different temperatures and under different working conditions, and the average value of the experimental results was taken. It should be noted that low temperature will also affect the charging process of lithium batteries, resulting in more serious polarisation, lower charging capacity, and possible lithium evolution. In order to avoid the impact of low temperature charging on the battery performance, the battery will be uniformly charged at 25°C, and the battery will be treated nearly adiabatic when fully charged. In addition, low temperature will also slow down the electrochemical changes and slow recovery of polarisation inside the lithium battery. Therefore, the battery will be allowed to sit at the set test temperature for 4 hours to ensure adequate standing time. Specific test steps are as follows:

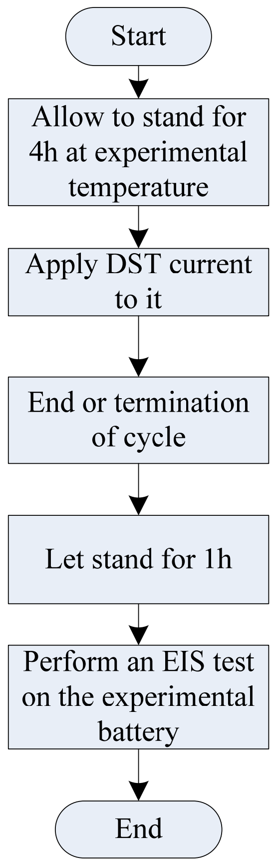
1 Allow the battery to stand for 3 hours at 25°C
2 Charge the two sets of batteries at constant temperature and voltage
3 Judge whether the current is less than 0.02C, and if not, repeat step 2; If reached, let stand for 0.5h
4 One group was subjected to near-adiabatic treatment, and the other group was left standing for 4 hours under natural convection conditions

5 Discharge the two sets of batteries at constant current under standard operating conditions until their discharge cutoff voltage reaches 2V, and record the discharge capacity

6 Repeat steps 2–5 to obtain three results and calculate the average discharge capacity

7 Repeat the experiment at 10°C, 0°C, –5°C,–10°C, –15°C to obtain the discharge capacity data under various temperature environments.

Figure 2 Flow chart of low temperature dynamic stress test



2.3.3 Low temperature dynamic stress test

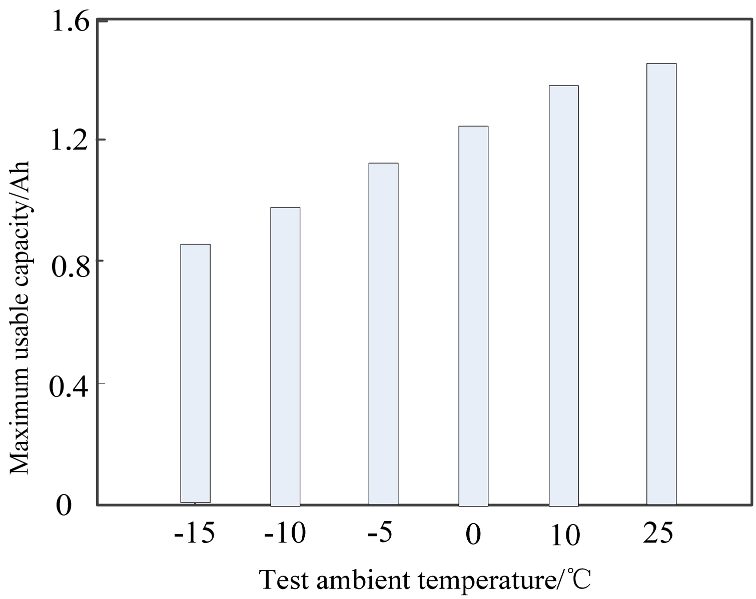
Batteries with high consistency of discharge capacity and DC internal resistance are selected as samples. In order to monitor temperature changes, the test reflected the heat release of the battery by measuring the surface temperature (Wang and Yang, 2022; Bao and Lu, 2021). During the test, three low temperature environments of –5°C, –10°C and –15°C were set to carry out the experiment. The test battery was pre-treated prior to the start of the test, i.e., the SOC of the battery had been unified and the near-adiabatic treatment had been completed. The test process is shown in Figure 2.

3 Analysis of low temperature discharge performance of lithium ion batteries for new energy vehicles

3.1 Analysis of maximum usable capacity of battery at low temperature

According to Section 2.3.1, after conducting the maximum usable capacity test of new energy lithium ion batteries, the results are shown in the following figure.

Figure 3 Relationship between maximum capacity decay rate of battery and ambient temperature (see online version for colours)



As shown in Figure 3, in low temperature environments, the maximum usable capacity of lithium ion batteries decays rapidly, usually reaching its optimal state at 25°C at room temperature. Compared with the maximum usable capacity at 25°C, the maximum usable capacity of the battery at 10°C, 0°C, –5°C, –10°C, and –15°C decreased by 9.62%, 14.43%, 21.53%, 27.21%, and 35.52%, respectively. And as the temperature decreases, the maximum usable capacity of the battery decays faster and faster.

3.2 Analysis of the influence of near adiabatic condition on low temperature discharge capacity

The discharge capacity of lithium ion discharge battery under natural convection and near-adiabatic temperature is shown in Figure 4.

As can be seen from Figure 4, in both cases, the discharge capacity of the test battery decreases as the temperature decreases, with a similar downward trend in the maximum available capacity. Under low temperature conditions, it decreased significantly. This is due to a significant decrease in the initial discharge voltage, which is lower at the beginning of the discharge than at room temperature, and the discharge platform quickly approaches the discharge cutoff voltage of 2V. Because the discharge form is relatively simple, there is no significant difference between the experimental groups under the two conditions. After further analysis of discharge capacity deviation, the image obtained is shown in Figure 5.

Figure 4 Discharge capacity of lithium batteries under natural convection and near adiabatic temperature conditions (see online version for colours)

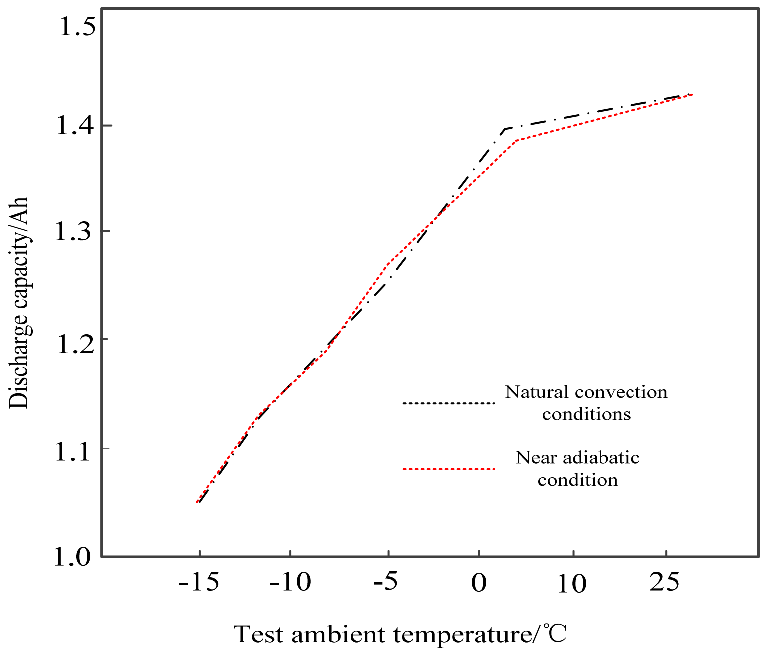


Figure 5 Discharge capacity deviation

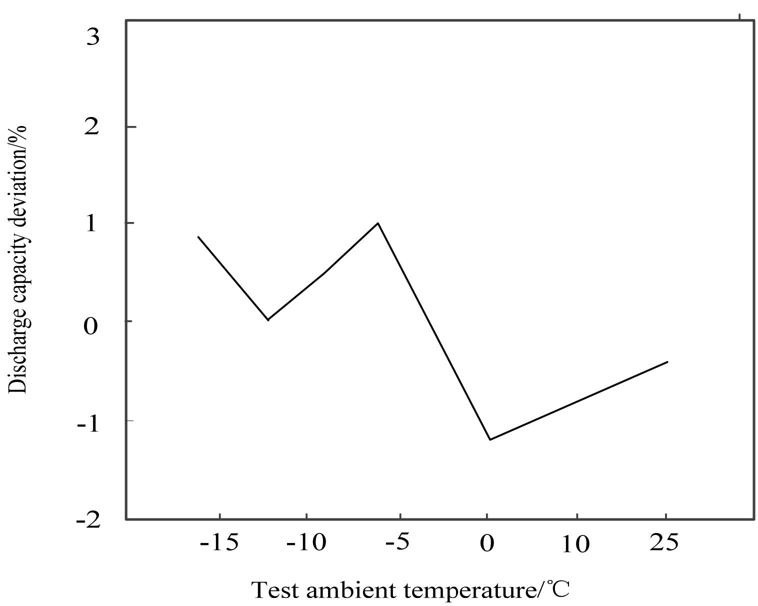


Figure 5 shows that the relative error of discharge capacity under near adiabatic conditions is less than ± 2%, and the difference is not significant compared to natural convection conditions. It can be seen that relying too much on a single discharge test and discharge capacity evaluation often cannot accurately reflect the true performance of batteries in low-temperature environments. Therefore, it is necessary to apply dynamic stress testing after combining low temperature and near adiabatic conditions.

3.3 Low temperature dynamic stress test condition test

3.3.1 Battery surface temperature analysis

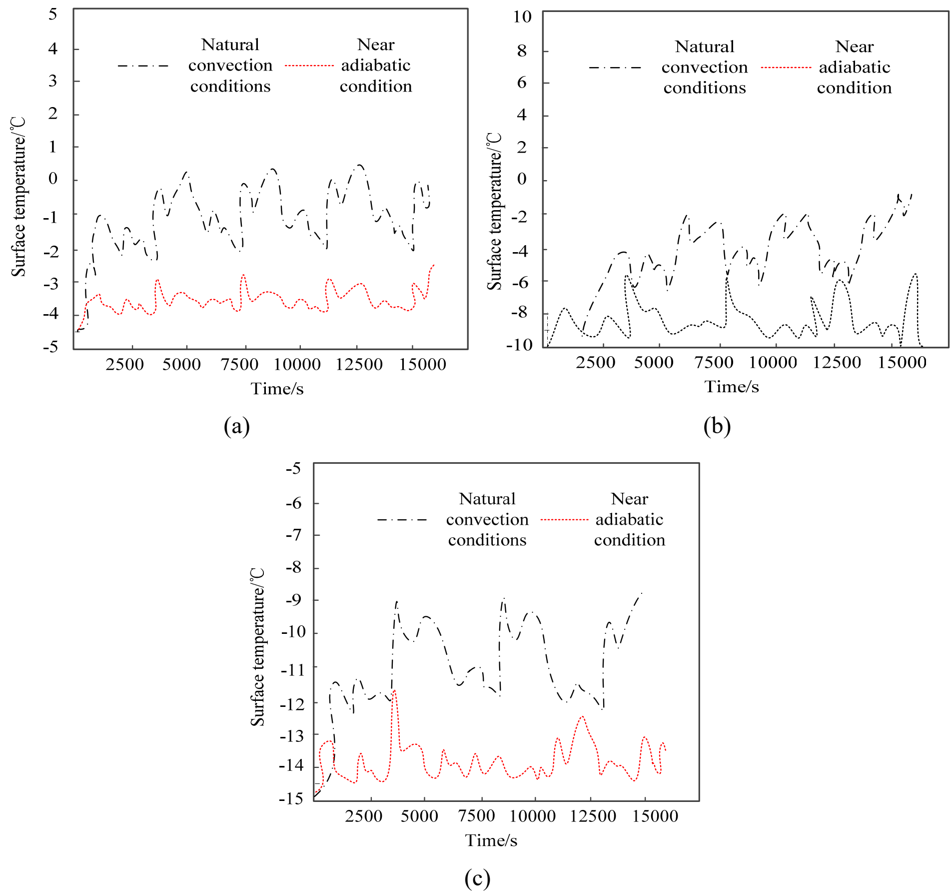
Changes in heat energy in lithium batteries can be reflected by the temperature of the battery. However, due to the closed structure of the lithium iron phosphate battery, it brings great challenges to the experiment. The lithium battery used in this paper is small in size, fast in heat transfer and small in heat loss. On this basis, a new design method suitable for lithium battery is proposed. During the test, a thermocouple is connected in the middle of the surface of the lithium battery, and its temperature is collected 30 times per minute to compare the difference of the battery surface temperature under the two conditions. The specific numerical results are shown in Figure 6.

The heat generation during the operation of lithium batteries mainly consists of four parts: reaction heat, Joule heat, polarisation heat, and side reaction heat. According to the principle of heat transfer, heat can be transmitted through three ways: conduction, convection, and radiation. Usually, due to the weak flow of electrolytes, the thermal convection inside lithium batteries can be ignored, and their external thermal radiation is also weak. Therefore, the heat generated during the operation of lithium batteries is basically transmitted from the inside of the battery to the shell through thermal conduction, and the main way of heat exchange with the outside world is through thermal convection. Therefore, the total heat production of lithium battery is the sum of the heat dissipated by the environmental heat exchange and the heat accumulated by the lithium battery itself, which is also the Thermal equilibrium during its operation. Under the Natural convection condition, all the heat generated by the lithium battery is used for heat exchange with the environment, so the accumulated heat tends to zero. Under near adiabatic conditions, due to the fact that the heat dissipated by environmental heat exchange approaches zero, the accumulated heat is relatively large, resulting in an increase in the temperature of the battery body. According to the data in Figure 6, the temperature of lithium batteries under near adiabatic conditions shows an upward trend in each cycle, with the largest increment in the second cycle. For example, under the working condition of –15°C, the battery rises from –14.5°C to 11.8°C, and then gradually stabilises. The experimental results show that the battery can achieve dynamic balance between heat release and slow heat release under this condition. Compared with the Figure 5, it can be seen that the influence of near-adiabatic state on surface temperature decreases with the decrease of temperature.

3.3.2 Analysis of battery terminal voltage changes at low temperature

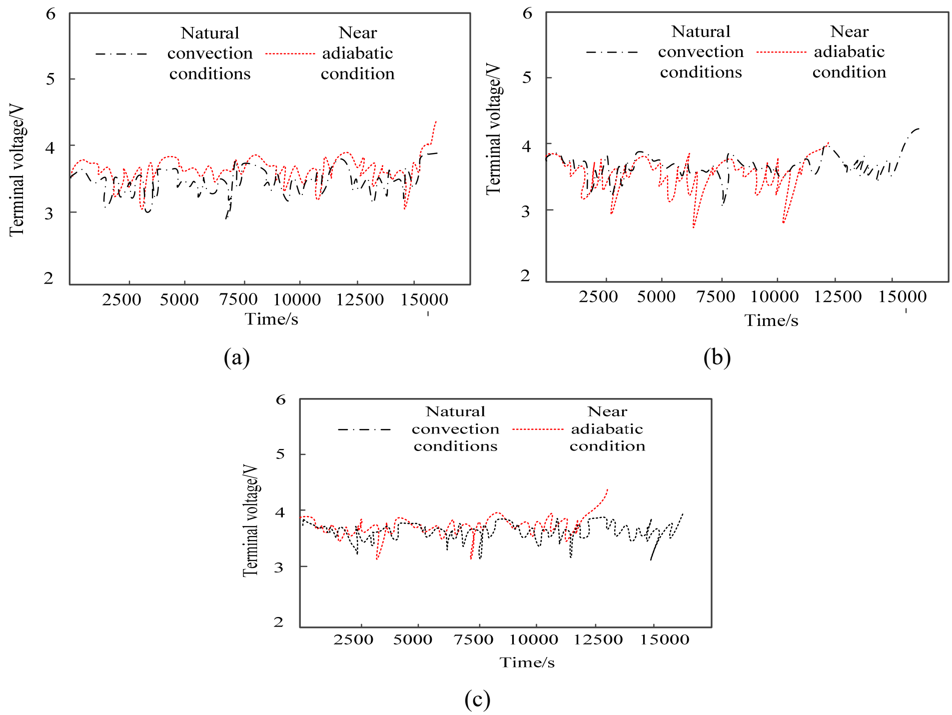
In both cases, the terminal voltages of cells with different temperature effects are compared, as shown in Figure 7.

Figure 6 Comparison of battery surface temperature changes under different working conditions (a) under 5°C working condition, (b) under –10°C working condition, (c) under working condition of –15°C (see online version for colours)



As shown in Figure 7, under the condition of low temperature, natural convection can make the battery run for 4 cycles, but the battery will stop running after 5 cycles due to high pressure. In a near-adiabatic environment, the battery can only make four cycles at –5°C. At near-adiabatic temperatures of –10°C and –15°C, the battery can run for only three cycles before it fails after four. In the cycle, near adiabatic, the battery charge voltage is higher than in natural convection, but in discharge, the battery charge voltage is lower than in natural convection. This indicates that the polarisation accumulation of the battery is more serious in the near adiabatic state, leading to deterioration of its working state. In order to more clearly demonstrate the voltage variation under near adiabatic and natural convection conditions, this study also compared the results of the relative voltage deviation between them. It can be found that as the temperature decreases, the relative voltage deviation of the battery becomes larger and larger, especially in low temperature environments. During each cycle, when a large current is charged or discharged, a significant voltage deviation occurs, which exceeds 5%, This indicates that the low temperature state has a more significant impact on the high current charging and discharging process.

Figure 7 Comparison of battery terminal voltage changes under different working conditions, (a) under –5°C working condition, (b) under –10°C working condition (c) under working condition of –15°C (see online version for colours)



4 Conclusions

In order to promote the further development of new energy vehicles, the research on the operational performance of lithium ion batteries in low-temperature environments is being carried out. Complete the low-temperature discharge performance analysis of lithium ion batteries by establishing an experimental platform. By comparing the low-temperature discharge performance parameters of batteries under different operating conditions, study and analyse the impact of low-temperature environment on the discharge performance of lithium ion batteries and its mechanism. The experimental results show that the lithium ion battery can maintain thermal balance in low temperature environments, but its performance will decrease to a certain extent. At –5°C, the battery can complete four cycles, while at –10°C and –15°C near adiabatic conditions, the test battery can only complete three cycles. The main reason for this phenomenon is that under low temperature conditions, the internal reaction rate of the battery decreases, and the charge transfer is blocked. At the same time, the polarisation phenomenon of the battery also intensifies, resulting in an increase in internal resistance and a lower energy and power density. In order to solve these problems, the article proposes some feasible improvement schemes, such as adjusting the battery structure, optimising battery materials, and improving control strategies.

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