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Experimental investigation on electro-thermal characteristics of the commercial Li-ion battery

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Abstract. As the most commonly used power battery in electric vehicles, lithium-ion battery is sensitive to the operation temperature. The performance and lifespan of lithium-ion battery are strongly dependent on its working temperature. Various thermal management systems have been developed to maintain batteries' operating temperature within an appropriate range. A properly designed thermal management system relies upon the understanding of battery's heat-generation characteristics and the temperature effect on its discharging performance. In this research, an experimental investigation is carried out to study the electro-thermal characteristics of the commercial prismatic ternary lithium-ion battery under three thermal conditions. Constant temperature condition is built to explore the effect of the operating temperature, while near-adiabatic condition and natural-convection condition are employed to study the heat-generation characteristics of lithium-ion battery. The results show that the effect of operating temperature on discharge performance becomes more pronounced as the discharge rate increases. It is found that the surface temperature decreases when the battery discharges at small rates within the capacity ranged from 17Ah to 27Ah, demonstrating that the reversible heat makes up a large proportion of battery heat generation.

Keywords: lithium-ion battery; operating temperature; discharging performance; heat-generation

1. Introduction

Lithium-ion battery is currently the most common power battery used in electric vehicles due to its advantage of high power density and long life span [1]. However, the performance and lifespan of lithium-ion battery are significantly affected by the operating temperature, and thermal runaway may occur at severely high temperature [2-3]. Therefore, battery thermal managements employing different heat transfer medium for electric vehicle have been studied extensively [4-5].

For different lithium-ion batteries, the effect of operating temperature on their discharge performance or their optimum operating temperature may be different. In addition, amounts of heat may be generated by power battery itself during discharging process and heat-generation may vary with its working condition [6-7]. The determination of the optimum operating temperature range and the



understanding of heat-generation characteristics are the foundation for designing a reliable and economic battery thermal management system.

The latest literature shows that various heat-generation models and thermal models were developed to evaluate the thermal response of lithium-ion batteries during operation [8-10]. Experimental investigation is also a feasible method to evaluate the battery's heat-generation. According to Bernadi's theory [11], it is noted that mathematical models are difficult to accurately predict the heat generation due to the complicated coupling relationship between the battery reaction heat and the operating temperature. Therefore, it is necessary to further explore the thermal characteristics of lithium-ion batteries.

In the present study, the effect of operating temperature on discharging performance of the commercial prismatic ternary lithium-ion battery was experimentally investigated under constant temperature condition. Thermal characteristics of the battery during discharging process were explored through monitoring its surface temperature variations under near-adiabatic condition and natural-convection condition.

2. Experiment setup

The commercial lithium-ion prismatic ternary battery LP2714897-37Ah (Lishen, China) is employed as the research object. The experiment setup is shown in Fig. 1. Charging and discharging processes of the tested battery were performed using the battery test cyler (Neware, BTS-4000) which can also record the variation of battery voltage. Constant temperature condition was achieved through submerging the battery in a thermostat filled with silicon oil. Natural-convection condition was the condition where the battery was suspended in the air. Near-adiabatic condition means that the battery was wrapped with plastic foam to decrease the heat transfer between the battery and the surrounding environment as much as possible. To ensure the almost same environment temperature, all the tests were completed in one room with air-conditioning and the room temperature was maintained $25 \pm 2^\circ\text{C}$.

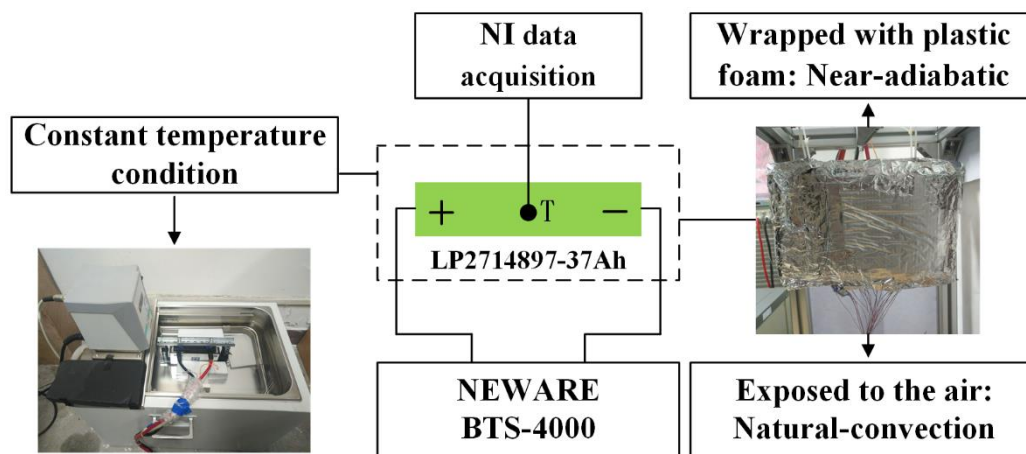


Figure 1. Schematic diagram of the experimental setup

Due to the direct contact with the battery, the thermostat temperature can be regarded as the battery operating temperature under constant temperature condition. The investigation on the effect of operating temperature on battery discharging characteristics was carried out at different thermostat temperature, namely, 10°C , 20°C , 30°C , 40°C and 50°C . The battery surface temperature under natural-convection condition and near-adiabatic condition were monitored to obtain its thermal behavior during discharging process. Total 24 T-type thermocouples were arranged on the battery surface and connected to NI data acquisition to acquire its overall temperature distribution during discharging at different rates. For all thermal conditions, the battery was charged to full state with the same charge regime before discharging. The battery charge regime was as follows: first, battery is charged to 4.2V with constant current rate 1C;

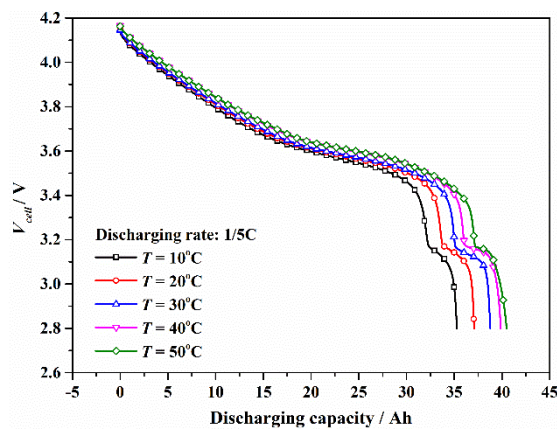
then battery is charged with constant voltage regime until charging current is less than 0.1A. For constant temperature condition, battery charging temperature was set as 25°C. The battery discharge regime is relatively simple and it discharges to the cut-off voltage 2.8V with different constant current rates, 1/5C, 1/3C, 1/2C, 1C.

3. Results and discussion

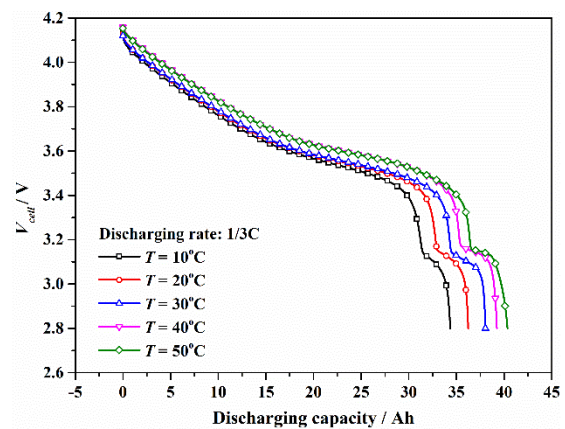
3.1. Effect of operating temperature on battery discharging characteristics

Figure 2 shows the battery voltage variation while discharging under different temperature at different rates of current. The discharging process can be divided into three stages. At the first stage, the battery maintains a relatively high discharging voltage platform and the voltage decreases slowly. At the end of discharging, there are two stages where the voltage decreases rapidly. The available energy and power are determined by the level of discharging voltage, current and the maintainable time. Therefore, attempts should be made to balance the number of batteries packed and the battery capacity range.

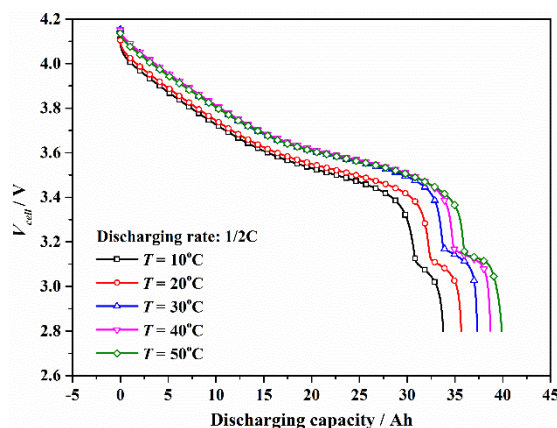
It was found that the effect of operating temperature on discharging performance is related to discharging rate and obvious for large discharging rates. However, it should be noted that the effect of operating temperature is strong at the end of discharging regardless of the discharging rates. In addition, the relation between discharging voltage and operating temperature is not proportional. The elevated operating temperature cannot significantly improve the voltage platform. The lower the operating temperature is, the earlier the discharge enters the process of rapid voltage decay. It can be inferred that when the operating temperature is low, it is necessary to preheat the battery or adjust the maximum depth of discharge.



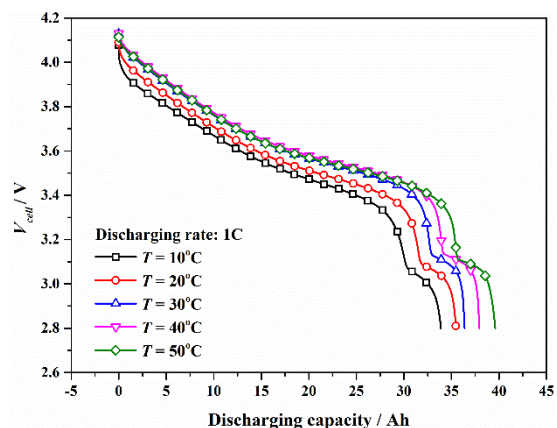
(a) 1/5C.



(b) 1/3C.



(c) 1/2C.



(d) 1C.

Figure 2. Voltage variation during discharging process under different temperatures

3.2. Battery thermal characteristics under two different thermal conditions

For near-adiabatic condition and natural-convection condition, the operating temperature is not constant anymore. Therefore, these two thermal conditions were employed to explore the battery thermal characteristics during the discharging process. As shown in Figs. 3 and 4, the maximum surface temperature differences under different discharging rates were calculated first for two thermal conditions. The maximum surface temperature differences for all working conditions are less than 2.5°C, which indicates the battery temperature uniformity is fine. In the present study, the temperature at the central position of battery large surface was used to represent the battery overall temperature and analyse the battery thermal characteristics.

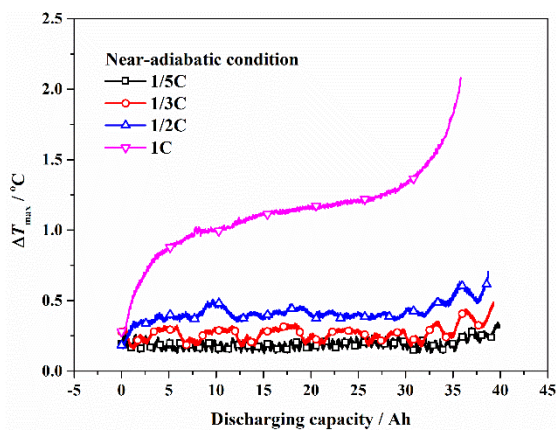


Figure 3. Maximum surface temperature difference during discharging under near-adiabatic condition.

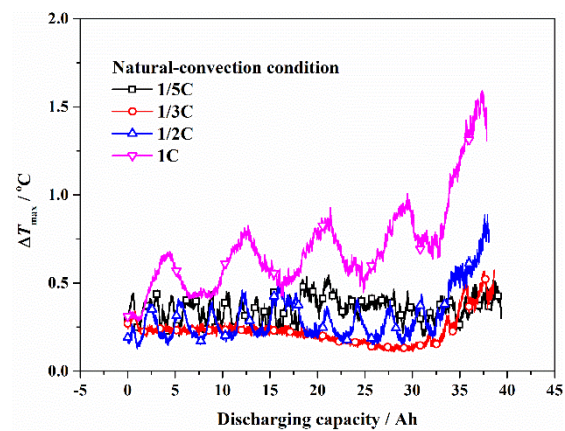


Figure 4. Maximum surface temperature difference during discharging under natural-convection condition.

Figure 5 shows the surface temperature variations while the battery discharged at different rates under two thermal conditions. Once the discharging process begins, the surface temperature increases first and the increasing rate is higher for large discharging rates. The surface temperature under near-adiabatic condition is higher than that under natural-convection condition, which is because the heat dissipation can be efficiently reduced by wrapping the battery with plastic foam.

It is found that the surface temperature decreases when the battery discharges within the range from about 17Ah to 27Ah at small discharging rates. For large discharging rates, although the decrease of surface temperature does not appear in the whole discharging process, the increasing rate gets notably slower within the corresponding discharging range. Such temperature variation can be explained by the composition of lithium-ion battery heat-generation.

As is well-known, lithium-ion battery heat-generation consists of the reversible heat and the irreversible heat. The reversible heat is also known as reaction heat, which is positive in exothermic reaction and negative in endothermic reaction. The irreversible heat is always positive. Therefore, it can be inferred that the electro-chemical reaction is endothermic and the reaction heat is more than the irreversible heat in the discharging range where the surface temperature decreases. When the discharging rates increases, the proportion of the irreversible heat increases and the sum of the irreversible heat and reversible heat is greater than zero, thus the surface temperature increases. In order to maintain battery operating temperature within an appropriate range, the heat-generation of lithium-ion battery under different working conditions should be exactly predicted before the design of thermal management system.

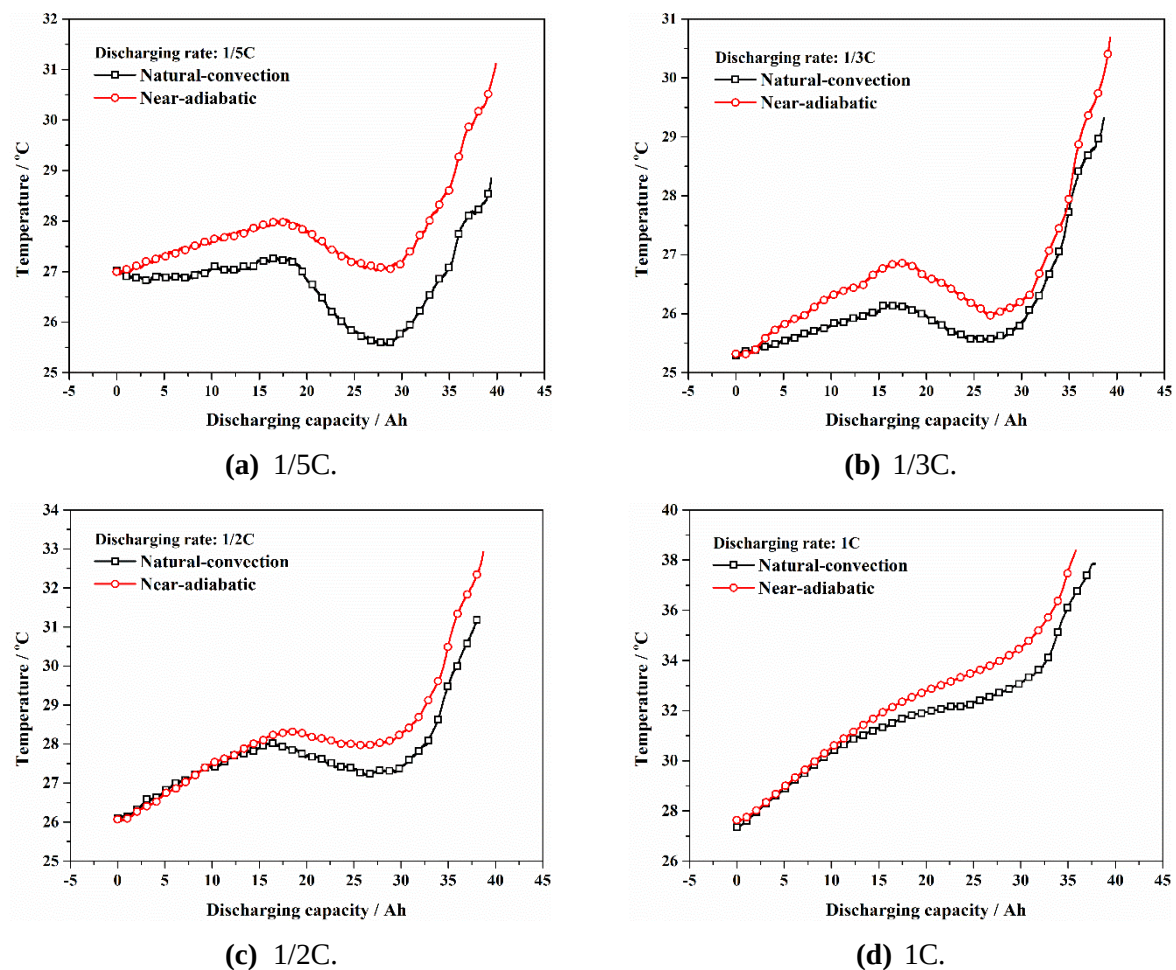


Figure 5. Surface temperature variation during discharging under natural-convection condition and near-adiabatic condition

4. Conclusion

Experimental investigation was carried out to study thermal characteristics while battery discharges at different rates under different thermal conditions and the effect of the operating temperature on the discharging performance of lithium-ion battery. The experimental results show that the effect of the operating temperature is related to discharging rates and pronounced subject to large discharging rates. At the initial stage of the discharging process, the surface temperature of the battery first rises, and is then found to decrease as the battery discharges in small rates from 17 Ah to 27 Ah. It can be inferred that when the lithium ion battery is discharged at a small rate, the reversible heat accounts for a large proportion of battery heat generation.

Acknowledgements

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