INVESTIGATING AN INFLUENCE OF TEMPERATURE AND RELATIVE HUMIDITY ON THE ELECTRICAL PERFORMANCE OF LITHIUM POLYMER ION BATTERY USING CONSTANT-CURRENT AND CONSTANT VOLTAGE PROTOCOL AT SMALL SCALE FOR ELECTRIC VEHICLES

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Abstract

Lithium-ion batteries suffer from insufficient electrical performance due to the unpredictable thermal effect and dynamic behaviour during the charging and discharging process. However, the comprehensive impact of relative humidity (RH) on the charging process rate has yet to be investigated. In this paper, a set of experimental tests is implemented to investigate the charging and discharging thermal and electrical behaviour of lithium-ion batteries represented by a single-cell 1000 mAh and battery pack 2200 mAh. The charging process is employed using the constant current-constant voltage (CC-CV) protocol, according to the safety specifications of the manufacturer. The proposed scenarios applied in this paper are initiated by investigating the behaviour of the charging current, total interval time, and battery terminal voltage whilst varying the ambient temperature between 30°C and 40°C at a fixed RH of 52%. Then a set of experiments are conducted by changing the RH conditions (35%, 52%, and 70%) at a fixed ambient temperature of 40°C. Finally, the impact of changing the RH at a fixed ambient temperature during the charging process is scrutinized. The results of the investigations of lithium-ion battery charging behaviour reveal that charging at low RH ensures the fastest charging rate response using the CC-CV protocol. At low RH (35%) the charging interval time is reduced by almost 23% corresponding to high RH (70%).

1 Introduction

Electric vehicles (EVs) have emerged as the most promising solution to the automobile industry's environmental and energy issues in recent years [1]. Typically, EVs are divided into three main categories based on the connection to the energy sources: Plug-in hybrid electric vehicle (PHEV), hybrid electric vehicle (HEV), and battery electric vehicle (BEV). PHEV and HEV are relying on both electric and internal combustion engines, whereas BEV is referring to electric vehicles that exclusively operate on batteries [2]. The key element to the long-term stability of these systems is the thermal management of the battery technology where lithium-ion batteries are the backbone of EVs. Lithium-ion batteries have a high energy density, good life cycle, low self-discharge, and are friendly to the environment[3]. Several charging protocols have been developed to ensure a good impact on charging time, charging efficiency, cell temperature, and cycle life span[3-5]. Studies are ongoing to achieve faster battery charging however, the main drawbacks that face batteries during charging are the slow charging rate, the unpredictable temperature effect on the battery performance, subsequent energy loss and degradation[4, 6]. Charging protocols can be categorized into four main protocols: pulse charging protocol[6], constant current-constant voltage (CC-CV) protocol[4], multi-stage charging current protocol[4, 5, 7], and Constant-Temperature Constant-Voltage protocol (CT-CV)[3, 8]. The most widely adopted charging technique is the CC-CV charging protocol[1, 3, 9, 10]. Where the concept is charging the battery according to the manufacturer's specification with a constant current (CC) ranging from 0.5C to 1C, where the C-rate is a measure of the rate at which a battery is charged/discharged relative to its maximum capacity. The CC charging mode is held until the terminal voltage reaches 4.2N V then the voltage is held constant while the current decays to the minimum value of 0.1C, where, N is the number of cells connected in a series and 4.2 V is the cut off voltage for lithium polymer ion cell [4].

Due to the complexity of the working environment and the sensitivity of lithium-ion batteries specifically in EVs where temperatures vary according to the ambient conditions, researchers investigated the impact of variable ambient temperature on the optimal cycle rate of the lithium-ion batteries in [9-12]. In [8], the susceptibility of the ambient temperature on the lithium-ion battery charging protocols has been presented and investigated. It is concluded that the performance of the batteries is depending on the surrounding temperature and to gain maximum efficiency, the battery must be charged within an acceptable temperature range [13, 14].

The ageing behaviour of cycled lithium-ion batteries within a wide temperature range from -20°C to 70°C is investigated in[10]. In the temperature range of -20°C to 25°C, the ageing rate increases while decreasing the temperature from its nominal value. In the other range from 25°C to 70°C, the ageing rate increases with an increase in temperature from its nominal operable value. The influence of low ambient temperatures on lithium-ion battery performance was examined in [1, 15], where a drop in activity and amount of useable active material, as well as an increase in resistance, resulted in a decrease in operating voltage and energy supplied. The performance of batteries at higher temperatures of 26°C and 70°C has been investigated in [9] and it is observed that the charging capability of the batteries at 70°C is relatively higher than that of the 26°C. Moreover, it is noticed that with an increase in cycle rate, the degradation behaviour is worsened. In [11] the effect of electrode porosity on lithium plating and the performance of the battery while charging and discharging protocol at the range from 20°C to 50°C temperature have been scrutinized. The performance of the lithium-ion battery at elevated ambient temperatures of 50°C, 60°C, and 70°C was investigated by [12]. In addition, the application of phase change material (PCM) under these conditions was studied on the thermal management of the battery. It is observed that heat generation of the battery decreases with the increase of ambient temperatures and the decay rates of batteries under high-temperature circumstances accelerated greatly.

The hypothesis of this research is that any change in ambient temperature is accompanied by variation in relative humidity (RH) which affects the electrical and thermal behaviour of lithium-ion batteries. A very few researchers investigated the humidity effect on lithium-ion batteries such as Z. Guo et. al [16] investigated the performance of Li-O_2 batteries in pure/dry O_2. The humidity effect on the reactions inside the battery has been analysed in two conditions, Pure O_2 with RH of 15% and ambient air with an RH of 50%. In [17] the high temperature and high humidity storage behaviours of LiNi0.6Co0.2O2 cathode material were scrutinized where a great degradation in electrochemical performance after being stored at 55°C and RH of 80%.

Battery charging behaviour at various temperatures and RH circumstances is critical to battery safety and electric vehicle driving range. However, the electro-thermal charging behaviour at various RH was not investigated by researchers. The main contributions of this paper can be summarized as investigating the influence of both temperatures and relative humidity on the electrical performance of lithium polymer ion charging behaviour while applying the CC-CV protocol under various circumstances of temperature and relative humidity.

2. Experimental Setup and Procedure

2.1 Samples

The battery samples utilized in this paper are fresh Lithium Polymer ion batteries: one battery with a nominal capacity of 1000 mAh, and a pack of balanced batteries with 2200 mAh capacity. The specifications of both lithium polymer ion batteries used in this research are stated in [18] and presented in Table 1. The working temperature for both batteries during the charging process was stated 0°C-40°C, and for long-time storage temperature and humidity are 20°C ± 5°C and 65% ± 20% respectively. However, no data concerning the charging humidity is mentioned in the datasheets.

A sequence of procedures is employed during the experimental tests, as expressed in Figure 1. Starting from the full discharge of the batteries with 0.9C till the voltage reaches 2.8N V where the C-rate is a measure of the rate at which a battery is charged/discharged relative to its maximum capacity and N is the number of packed batteries used in the test and after 10 mins relaxing discharge by 0.1C until the voltage reaches to 2.8N V. After relaxing for 12 hrs, the batteries under test placed in the temperature/humidity chamber for 10 mins then charged at different values of temperature and relative humidity with the CC-CV protocol with a CC of 0.9C until the voltage reaches 4.2N V followed by a CV 4.2N V for a time period while the current decays to 0.1C and then 12 hrs relaxing interval rime of the battery.

Table 1 Specifications of the selected Lithium Polymer ion batteries

Item	Specifications	
Type	Polymer lithium-ion single-cell battery	Polymer lithium-ion battery Pack
Manufacturer name	063450 LPB power Lipo	LPB power Lipo
Nominal capacity	1000 mAh	2200 mAh
Maximum charging current	1C	1C
Maximum discharging current	2C	2 C
Charging cut-off voltage	4.2 ± 0.05 V	12.9 V
Discharging cut off voltage	2.75 V	8.4 V
Working temperature	0-40°C	0-45°C
Storage humidity	65% ± 20%	65% ± 20%

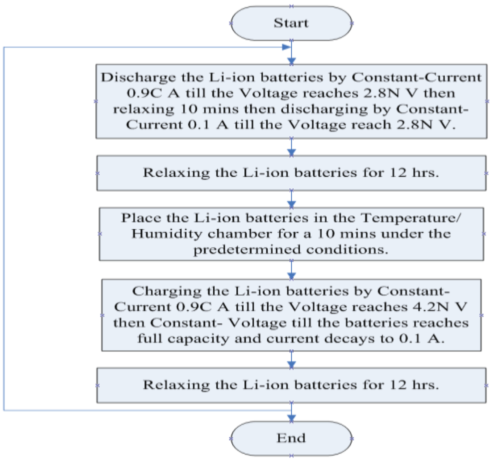


Figure 1. Discharging/Charging procedures of the lithium-ion batteries under test.

2.2 Apparatuses and experimental design

Experimental tests are carried out at various temperatures in the fabricated test chamber between 30°C and 40°C at three values of RH 35%, 52%, and 70%, having the temperature and humidity tolerance of ±2°C and ±3% respectively. The chamber, that has been designed and controlled is presented in Figure 2. It is utilized to ensure a fixed ambient temperature and relative humidity however the variation in the surrounding environmental conditions. In the experimental test area, the batteries are placed upon pottery to be isolated from the body of the chamber. The ambient temperature and relative humidity are measured by DHT11. The relative humidity is controlled by an on/Off humidifier and the temperature control thermostat is used to control the electric heater. In addition, the charging current and terminal voltage of the batteries under test are measured by the NI-myRIO-1900 microcontroller.

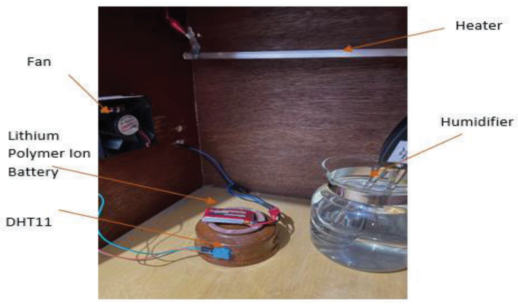


Figure 2. The experimental test area in the Temperature/Humidity chamber.

3 Results and Discussion

3.1 Verification and validation of the fresh polymer lithium-ion batteries

In this paper, three typical fresh polymer lithium-ion batteries with 1000 mAh capacity and a battery pack of 2200 mAh are investigated under different ambient temperature and relative humidity conditions. But firstly, The CC-CV protocol has been utilized to charge the batteries to ensure the verification and validation of the three lithium-ion batteries under the same ambient conditions at 24°C and 40%. The results are expressed in Figure 3 where the applied charging currents of the proposed batteries with respect to the interval time are the same, all the batteries reached the maximum voltage at a range from 2,828 sec (47.1333 min) to 2,959 sec (49.3167 min). In addition, all the batteries were fully charged at the same time 5,244 sec (87.4 min) with the same charging current topology. The Proposed lithium-ion batteries are charged with CC-CV protocol according to the specification of the manufacturer under various circumstances where the charging behaviour is investigated in the following sections

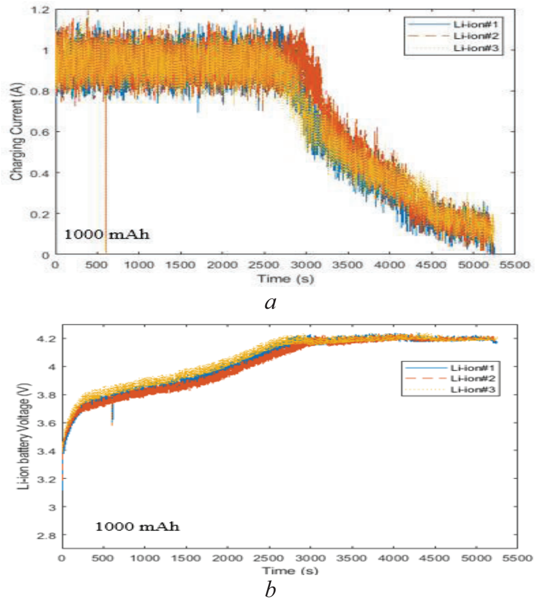


Figure 3. Verification and validation of the three lithium-ion batteries of 1000 mAh under test at the same temperature and relative humidity at 24°C and 40% respectively.

3.2 The electro-thermal charging behaviour of Lithium Polymer ion battery 1000 mAh and battery pack 2200 mAh cycled with the CC-CV protocol under different temperature/humidity conditions

3.2.1 Charging at different ambient temperatures with constant relative humidity

The electro-thermal charging behaviour of the proposed batteries 1000 mAh and 2200 mAh is investigated at two various temperatures between 40°C and 30°C with the same relative humidity of 52%. It is observed from Figure 4 that at 30°C the battery reached full capacity faster than at 40°C. The battery of 1000 mAh capacity in Figure 4-a and Figure 4-b is fully charged at 30°C in 4,742 sec (79.0333 min) and at 40°C in 4,919 sec (81.9833 min). Also, the battery of 2200 mAh capacity in Figure 4-c and Figure 4-d is fully charged in 3,784 sec (63.0667 min) and 3,845 (64.0667 min) at 30°C and 40°C respectively. It is concluded that the variation in temperature leads to a change in the total charging interval time process but with a small variation according to the manufacturer charging specifications (1 to 3 mins).

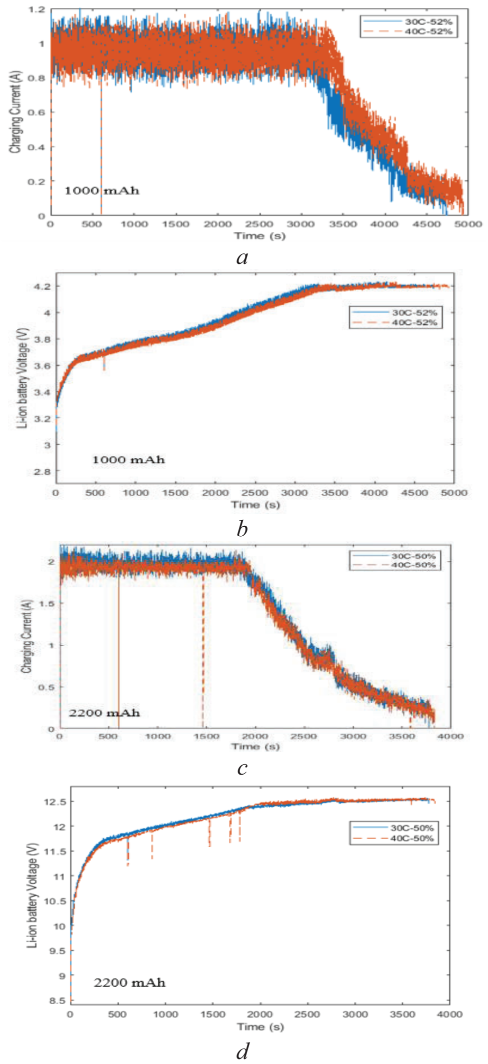


Figure 4. Charging topology of the 1000 mAh and 2200 mAh polymer Li-ion batteries respectively at two various temperatures (40^{0}C and 30^{0}C) and the same humidity (50%).

3.2.2 Relative humidity effect on the charging process

In this section, the electro-thermal charging behaviour is introduced cycled by 0.9C using the CC-CV protocol at the same ambient temperature of 40°C but with different RH (35%, 52%, and 70%). As shown in Figure 5 there is a significant impact of RH on the terminal voltage and charging current. While increasing the relative humidity, the charging interval time becomes slower than the low humidity. The total charging time for the battery with 1000 mAh capacity at RH of 35%, 52% and 70% are 4,606 sec (76.7667 min), 4,938 sec (82.3 min), and 5,690 sec (94.8333) respectively as expressed in Figure 5-a and Figure 5-b. To verify the hypothesis, the battery with 2200 mAh capacity also is tested at RH 30%, and 50%, where the charging time for both conditions is 3,700 sec (61.6667 min), and 3,845 sec (64.0833 min) respectively as shown in Figure 5-c and Figure 5-d.

It is observed from Figure 5 that while using the battery of 1000 mAh capacity, a significant slow variation in the total interval charging time at both RH 52% and 70% with respect to 35% reached around 7.2% and 23.53% respectively. In addition, while using the battery with 2200 mAh capacity, the slow variation reached 4% between RH-30% and RH-50%. In addition, It is concluded that while increasing the RH the moisture effect is revealed in the chemical reactions of the battery. Hence, the terminal voltage is reached the cut-off value faster than in the low RH conditions, the CC charging stage spent a short interval time and the CV stage spent much more time to reach the battery's full capacity.

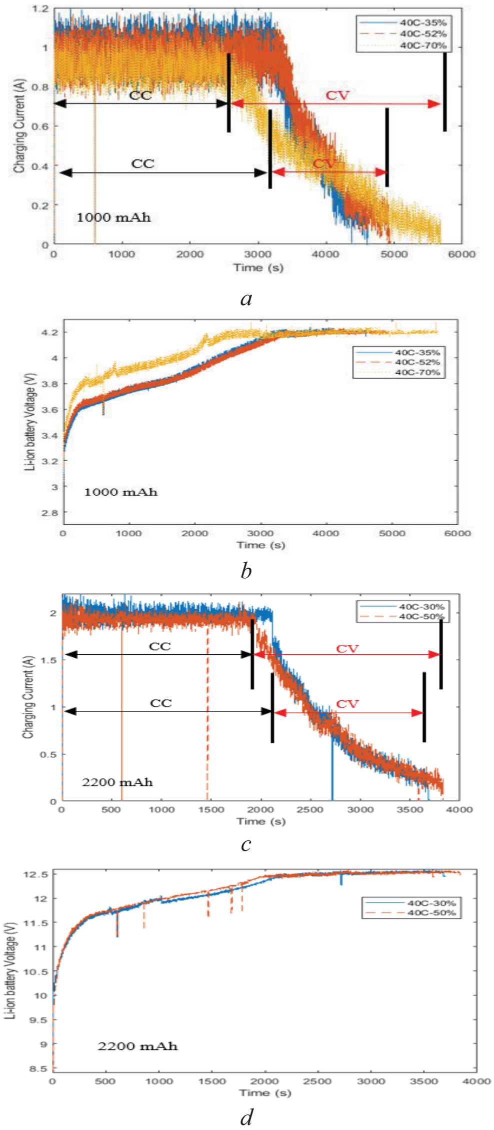
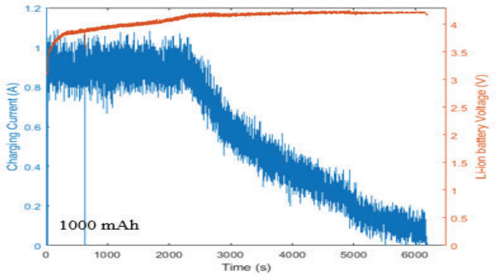


Figure 5. The charging topology of the polymer Li-ion batteries at the same temperature (40^{0}C) and various RH (30%, 50%, and 70%) and (30%, and 50%) for 1000 mAh and 2200 mAh respectively.

3.2.3 Changing the RH conditions while charging the battery at the same charging cycle

In this section, an investigation of changing the RH conditions from 70% to 31% during the charging process using cycling of the CC-CV protocol at the same ambient temperature of 40°C is implemented and presented in Figure 6. The selection of these conditions was based on the previous section to utilize the fast CC stage at high RH, but It is observed that this variation in the RH conditions resulted in a very slow charging rate that reached 6,197 sec (103.2833 min). Thus, it is recommended that the lithium-ion battery must be charged at the same RH condition to avoid any slow charging rate with respect to low RH working conditions.



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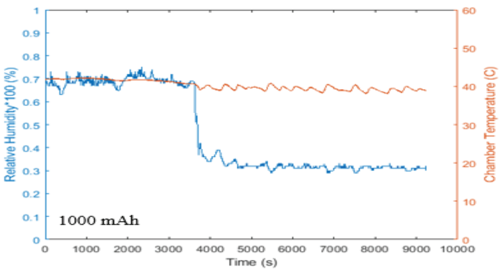

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Figure 6. Impact of changing RH conditions from 70% to 31% while using the CC-CV charging protocol on lithium-ion 1000 mAh battery (a) the relation between the charging current and terminal voltage, and (b) the chamber temperature and RH measurements while testing.

4 Conclusion

This paper proposes an experimental set of tests to investigate the effect of temperature and relative humidity (RH) on the charging current, interval time and battery terminal voltage of lithium polymer ion batteries. Our results demonstrate that relative humidity has a significant effect on the charging performance of the lithium-ion battery using the constant current-constant voltage (CC-CV) protocol. A set of different scenarios has been implemented and investigated in this study: 1) Charging at different ambient temperatures with constant RH, 2) Charging at different RH with a fixed ambient temperature and finally 3) Investigating the behaviour of the battery while varying the RH of the surrounding environment during the charging process. Meanwhile, it can be proposed that charging at low RH (35%) is helpful to reach full capacity at a minimum time where a 23% reduction in the total charging interval time is obtained with respect to charging at high RH of 70%, and a reduction of 4% to 7% is obtained with respect to medium RH (52%). This conclusion is ensured by different tests implemented on two categories of lithium polymer ion batteries: single-cell 1000 mAh and battery pack 2200 mAh. This paper can be developed by modelling the lithium-ion battery at the different ambient humidity/temperature circumstances to perform all the required charging protocols without any additional experimental tests. Also, the same temperature/humidity impact could be generalized to be tested on large scall EVs.

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