EXPERIMENTAL STUDY OF BATTERY TEMPERATURE UNDER CONSTANT DISCHARGE RATE

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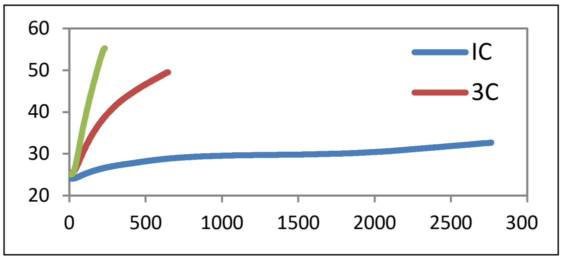
GRAPHICAL ABSTRACT



ABSTRACT

This research is about an experimental study of battery temperature under constant discharge rate. This study consider constant discharge rates, constant air velocities, gap between battery cells in the battery module and placement of Resistance Temperature Detector (RTD) sensors to achieve the objective of this experiment studies. The relationship of temperature and discharge rates for different point on battery cell surface is compared. The Lithium-ion battery cells is discharged with several constant discharge current rates. The heat generation on the battery surface as a function of discharge time are linked to the LabVIEW software. An axial fan creates constant air velocities that help in removing heat away from battery module during discharge process. The factors that are considered in this experiment are the discharging rate, air velocities and the thermal behaviour of the Lithium-ion battery cell on various point across the battery surface.

KEYWORDS

Battery temperature; discharge rate; temperature; air velocity; Lithium-ion

INTRODUCTION

In recent years, many car manufacturers leaning towards producing alternative powertrain apart from conventional internal combustion (ICE) vehicle. The production of Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) are growing fast. The main purpose of using these alternatives powertrain is reducing the usage of crude oil and exhaust emission which instigating greenhouse effect. Most HEV and EV available in the market previously using NiMH batteries, but Lithium-ion Batteries (LiB) are expected to grow fast in HEV and EV markets. The LiBis a more preferable power storage for HEV and EV since it has high energy density, low self-discharge rate, low maintenance and long cycle life [1].

Temperature is one of the parameters of a lithium ion battery that has to be carefully controlled, because the battery's working temperature greatly influences efficiency, cell degradation, and the battery's life time [2]. The temperature of each cell inside the battery pack varies, depending on the battery pack's design. Temperature variations may lead to over-charge or over-discharge during cycling which further contribute to premature failure in the battery packs in the form of accelerating capacity fading or thermal runaway [3,4].

Various experimental works regarding battery cell surface temperature can be found in literature. These works can be divided into several groups, depending on the methods used in temperature measurement, number of cells, charge/discharge methods, and type of cooling system used. Some works only consider a homogeneous temperature [5-7], but most recent works consider non homogeneous temperature throughout the cell surface [8-14]. For non-homogeneous temperature, normally, cell temperature near the positive and negative terminal is higher than in other locations, with temperature differences varying from one work to another. The number of cells used in experiment can vary from a single cell to several cells combined in a battery pack.

In this experimental study, 3 cell Lithium-ion battery packs will be placed in the airflow tunnel while surface temperature sensors are placed on the battery cell surface and equipped with anemometer to measure the cooling air temperature and velocity in determining the distribution of temperature of various points on the battery cell surface during the discharging process with different discharging rates and cooling conditions.

EXPERIMENTAL

Installation of the Lithium-ion battery cells

All 3 battery cells are packed into a module, 40Ah each. The gap between each battery cell is about 3mm, thickness of acrylic sheet. Acrylic sheet is used as the divider between battery cells and also the outer cover on two sides of the battery module. Acrylic sheet is a suitable material because of low cost and high melting point, 150˚C, while the battery temperature in this experiment is expected to be less than 60˚C. Acrylic sheet with thickness of 3mm, width of 15mm and length of 187mm is used in the making of gap divider. Since the battery cells are quite fragile, 4 units of gap divider are placed on each side of the battery cells. The distance between them has no other reasoning than the placement of RTD sensor on the battery cell surface. The surfaces that has no gap divider are going to be the pathway of the air flow to go between the battery cells to let cooling happens. Figure 1 shows the arrangement of the gap divider on the battery surface.

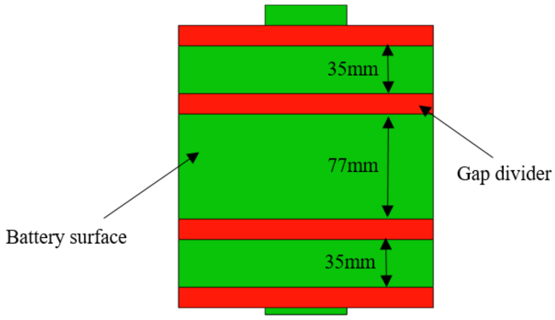


Figure 1: Gap divider arrangement

The width of the wind tunnel is 103mm and the width of the battery module is 39mm, leaving the gap of 32mm on each side of the battery module and the wind tunnel. The alignment of battery module is as shown in Figure 2. The gap between the battery module and the wind tunnel is then covered with corrugated plastic board which acts as air funnel to channel the air flow through the battery module for better cooling

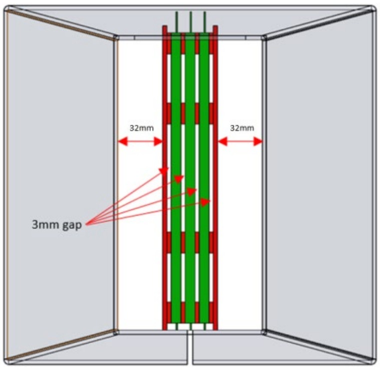


Figure 2: Gap divider arrangement

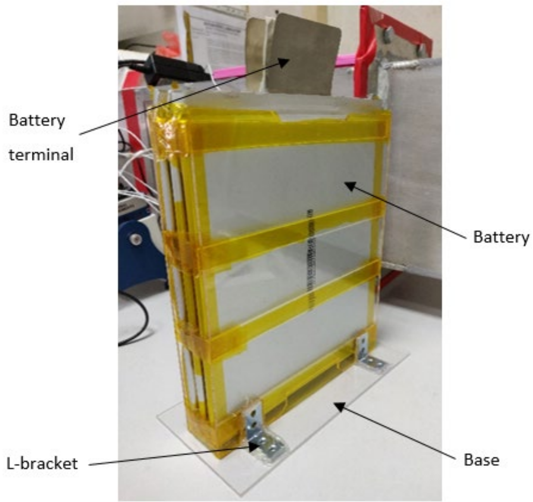


Figure 3: Gap divider arrangement

Next, the battery terminal is extended using custom copper plate to allow connection to the cable for discharging process. Figure 3 shows the completed battery module.

Battery connection to electronic load

After alignment of battery module is done, the battery module is then connected for discharging process. ITECH IT8514C+ DC Electronic Load machine is used to discharge the battery. The connection is simple, positive terminal from the battery module is connected to positive terminal on the machine, labelled in red while negative terminal from the battery module is connected to negative terminal on the machine, labelled in black. After the mechanical connection is done, the machine is turned on. Firstly, Constant Current mode is selected by pressing [CC] button. Then, battery test program is selected. All the following details such as current, stop voltage, stop capacity and stop timer for the discharging process is keyed in. Then, the discharging process started until the battery voltage reached the cut-off voltage of 8.4V. Detailed manual on operating this machine will be attached in the appendix. Figure 4 shows the connection of battery to electronic load.

Figure 4: Battery connection to electronic load

Positioning of Resistance Temperature Detector (RTD) sensors

The resistance temperature detector (RTD) sensors are placed on 3 different are on battery cell surface. The placement of 3 RTDs is on the middle battery since the middle battery cell is expected to have the most critical temperature among those 3 battery cells as it is packed in between to battery cells. Both sides of the middle battery cell are exposed to the weak convection, while the another 2 battery cells have only one side exposed to weak convection and another side to the outer cover of the battery module with the air flow gap with higher convective heat transfer rates[15]. The placement of RTDs on battery cell surface is as shown in Figure 5.

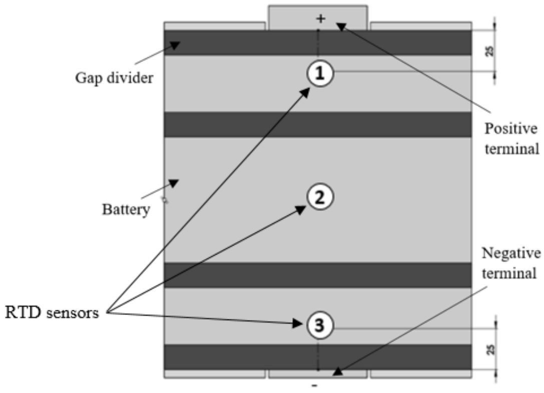


Figure 5: Placement of RTD sensors

Discharging strategy

The air room temperature is set about 24˚C. The discharging rate is varied with 1C, 3C and 5C. The C-rate is the unit of discharge relative to battery capacity [16]. For example, 1C for 40Ah battery means the battery can be discharged at the rate of 40A current in 1 hour. If at 5C it will discharge at 200A but at 1/5 of the time of 1C. While the air velocities is varied with 1.5m/s and 3m/s. Figure 6 shows the discharge rate and experiment run strategy.

DISCHARGE RATE	CURRENT
1C	40A
3C	120A
5C	200A

- Run 1 – 1C with 1.5m/s
- Run 2 – 1C with 3.0m/s
- Run 3 – 3C with 1.5m/s
- Run 4 – 3C with 3.0m/s
- Run 5 – 5C with 1.5m/s
- Run 6 – 5C with 3.0m/s

Figure 6: Discharge rate and experiment run

Results and Discussion

Three graphs were plotted from the obtained data. These graphs are plotted according to the discharge rate 1C, 3C and 5C respectively. T1, T2 and T3 are the notations for location 1, 2 and 3 respectively on the battery surface. The first graph shown in figure 7 shows the battery module being discharged at 1C with 3 locations of RTD sensors also with 2 constant air velocities of 1.5m/s and 3m/s.

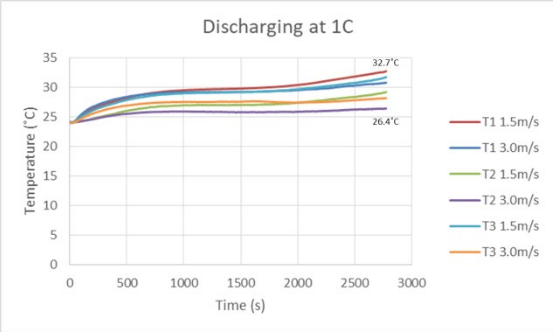


Figure 7: Battery discharging under constant rate at 1C

For 1C discharging, the experiment lasted until 2777 seconds before the battery reach the stop condition of 8.4V of the battery module voltage to preserve the battery. For cut-off voltage, the battery is believed to be in 20% state of charge (SOC). So, the theoretical time for discharging for 80% of the capacity is 2880 seconds. Experimental time is not really far off from theoretical time. From the observation of the graph, the highest temperature is T1 with 1.5m/s air velocity at 32.7˚C, sensor located nearest to the positive terminal, which the point that is expected to be the most critical. While the lowest temperature is at T2 with 3.0m/s air velocity at 26.4˚C, sensor located on the centre body of the battery cell, which the point has least heat compared to the other region which is near the positive and negative terminal. The sensor located near negative terminal, T3 marked higher temperature compared to sensor at the centre of the battery cell, T2 with both constant velocities of 1.5m/s and 3.0m/s. For all the sensor locations indicated that discharging with higher constant air velocity of 3.0m/s resulted in lower temperature logged compared with lower constant air velocity of 1.5m/s. So, the air velocities does play big role in heat removal during battery discharging process.

The second graph shown in figure 8 shows the battery module being discharged at 3C with 3 locations of RTD sensors also with 2 constant air velocities of 1.5m/s and 3m/s.

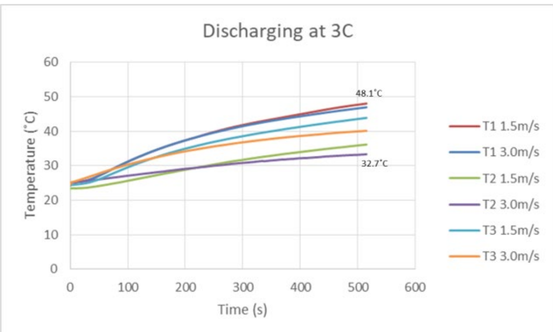


Figure 8: Battery discharging under constant rate at 3C

For 3C discharging, the experiment lasted until 517 seconds before the battery reach the stop condition of 8.4V of the battery module voltage to preserve the battery. For cut-off voltage, the battery is believed to be in 20% state of charge (SOC). So, the theoretical time for discharging for 80% of the capacity is 960 seconds. Experimental time is slightly more than half of the theoretical time. From the observation of the graph, the highest temperature is T1 with 1.5m/s air velocity at 48.1˚C, sensor located nearest to the positive terminal of the battery cell, which the point that is expected to be the most critical. While the lowest temperature is at T2 with 3.0m/s air velocity at 32.7˚C, sensor located on the centre body of the battery cell, which the point has least heat compared to the other region which is near the positive and negative terminal. The RTD sensor located near negative terminal, T3 shows higher temperature compared to the sensor on the centre body of battery cell, T2 and lower temperature compared to sensor nearest to the positive terminal, T1. All sensors showing less temperature with experiment with higher air velocity of 3.0m/s compared to lower velocity of 1.5m/s

The third graph shown in figure 9 shows the battery module being discharged at 5C with 3 locations of RTD sensors also with 2 constant air velocities of 1.5m/s and 3m/s.

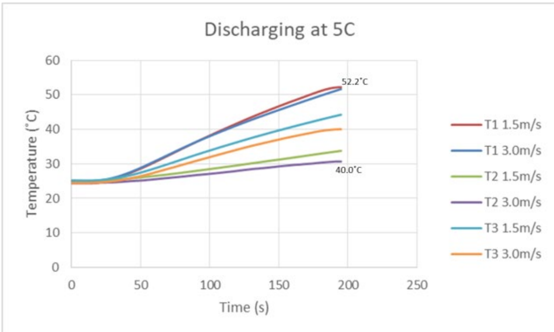


Figure 9: Battery discharging under constant rate of 5C

For 5C discharging, the experiment lasted until 197 seconds before the battery reach the stop condition of 8.4V of the battery module voltage to preserve the battery. For cut-off voltage, the battery is believed to be in 20% state of charge (SOC). So, the theoretical time for discharging for 80% of the capacity is 576 seconds. Experimental time is only about one-third of theoretical time. From the observation of the graph, the highest temperature is T1 with 1.5m/s air velocity at 52.2˚C, sensor located nearest to the positive terminal of the battery cell, which the point that is expected to be the most critical. While the lowest temperature is at T2 with 3.0m/s air velocity at 40.0˚C, sensor located on the centre body of the battery cell, which the point has least heat compared to the other region which is near the positive and negative terminal. For 5C result, the discharging time is a lot less than theoretical because of the limitation of the hardware. It is believed that the battery not supporting for 5C discharge rate. So, the experimental discharging time is way off the theoretical discharging time as the battery is not capable of deep discharge, discharge rate of 5C and above

The fourth graph shown in figure 10 shows the temperature behaviour at point 1 with different discharge rates, 1C, 3C and 5C with the same air velocity of 1.5m/s.

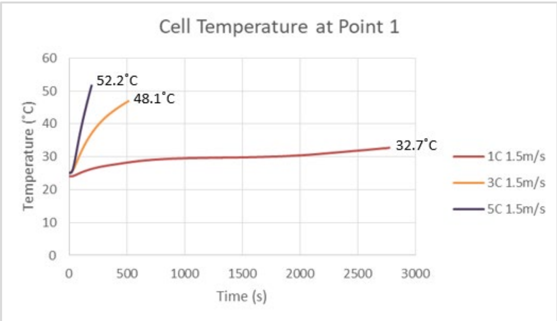


Figure 10: Cell temperature at point 1

For the comparison between the discharge rates, the data is taken at the most critical condition which is at point 1, where in all condition of discharge rates, it produced the highest temperature compared to the other 2 points, point 2 and point 3. While data also taken with the least cooling effect, which is with the air velocity of 1.5m/s. It is clear that with discharge rate of 5C, marked the highest temperature at 52.2˚C, while discharge rate of 3C, marked 48.1˚C and discharge rate of 1C, marked the lowest temperature at 32.7˚C. In contrary, the discharging time, 1C discharge rate has the longest time of 2777s, while 3C discharge rate marked 517s and 5C has the shortest time of 197s. From this data, we can conclude that the higher the discharge rate, the higher the temperature produced. While in the aspect of discharging time, the higher the discharge rate, the shorter the discharging time.

Conclusion

Throughout this experimental study, it is clear that the distribution of temperature across the surface of battery cell is not uniform during discharging process undervarious constant discharge rates and different cooling air velocities. In overall, the battery temperature increases with the increasing of discharge rate (C-rate). The higher the C-rate, more heat is produced thus the higher the temperature of the battery. The cooling fan helped in reducing the overall battery operationby means of forced convection.Heat distribution is not uniform across the battery surface during discharging process. The most critical point with the highest temperature is at positive terminal, followed by the negative terminal. This is due to high current density near the positive terminal and low electrical conductivity of the positive electrode current collector.The battery specification given by suppliers indicates that it is only suitable to the maximum of 3C discharge rate. But, after testingat 3C discharging rate, the discharging time is only half the theoretical time. So, the battery is actually not suitable for a 3C discharge rate.

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