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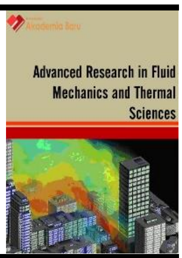

Evaluating Thermal Performance of Pouch Type Lithium Polymer Battery Cell

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ABSTRACT

This article presents an experimental study of battery temperature under constant discharge rate. This study considers several constant discharge rates, constant air velocities, gap between battery cells in the battery module and the placement of thermocouple sensors in order to study the thermal behaviour of the battery cell. The relationship of temperature and discharge rates at different point on battery cell surface is compared. The heat generation on the battery surface as a function of discharge time are captured by RTD thermocouple and linked to the LabVIEW software. An axial fan creates constant air velocities that help in removing heat away from battery module during discharge process. Variables that are considered in this experiment are the discharging rate, air velocities and the thermal behaviour of the Lithium-ion battery cell on various points across the battery cell surface.

1. Introduction

In recent years, many car manufacturers leaning towards producing alternative powertrain vehicle instead of conventional internal combustion vehicle. The production of Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) as alternative powertrain vehicle are growing fast. The main purpose of using these alternative ways is to reduce the usage of petrol and diesel and also to reduce exhaust emission which instigating greenhouse effect [1-4]. Recently, some HEVs and EVs available in the market are using NiMH batteries as their power source, but the usage of Lithium-ion batteries (LiB) are expected to grow fast in HEV and EV markets. The LiB a more preferable power storage medium for HEV and EV since it has high energy density, low self-discharge rate, low maintenance and lightweight [5-8]. Although LiB possess good characteristic for equipping in HEVs and EVs, it has

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a downside of temperature sensitivity [6]. If LiB is used at temperature higher than the allowable operating temperature, it can significantly affect the lifecycle and the capacity of the battery. Operating LiB below the minimum temperature range may result in low efficiency of power delivery, thus lower performance [9-13]. Optimum operating temperature of LiB is within the range of 20°C to 65°C.

In this experimental study focused on the thermal behavior of LiB at different discharge rates and different cell locations through cooling system. The Lithium-ion battery module is placed inside an airflow tunnel while thermocouple sensors are placed on the battery cell surface and anemometer is used to measure the air velocity in determining the distribution of temperature at various points on the battery cell surface during the discharging process with different discharging rates.

2. Experimental Set Up

2.1 Alignment and Installation of the Lithium-Ion Battery Cells

Three battery cells of 40Ah each are packed into a battery module. The cells are link in series connection making a module of 12 Volts, 40Ah. The gap between each battery cell is 3mm. Figure 1 shows the arrangement of gap divider (from acrylic sheet) on the battery surface and with three RTD thermocouples. The placement of the three RTDs is close to positive and negative electrode connector. Previous research shows that this location is expected to have the most significant temperature. The completed battery module is then placed inside an airflow tunnel as shown in Figure 2.

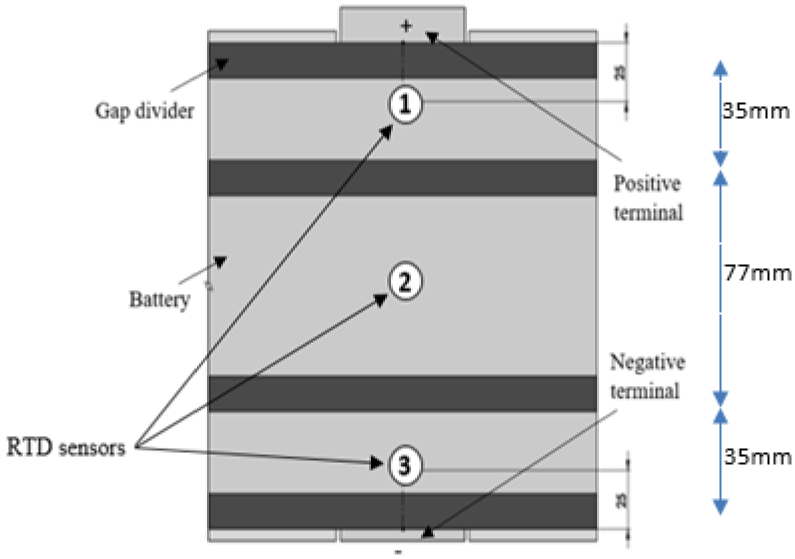
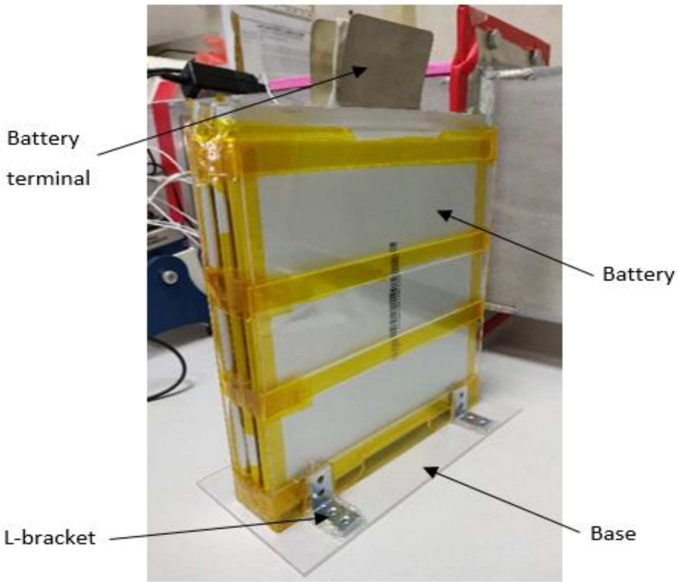


Fig. 1. Gap divider arrangement and placement of RTDs on battery cell surface



(a)

Fig. 2. Completed (a) battery module and (b) air tunnel

2.2 Experimental Procedure

After alignment of battery module is done, the battery module is then connected for discharging process. An electronic load machine is used to discharge the battery. The positive terminal from the battery module is connected to positive terminal on the machine, labeled in red while negative terminal from the battery module is connected to negative terminal on the machine, labeled in black. Figure 3 shows the connection from battery to electronic load.

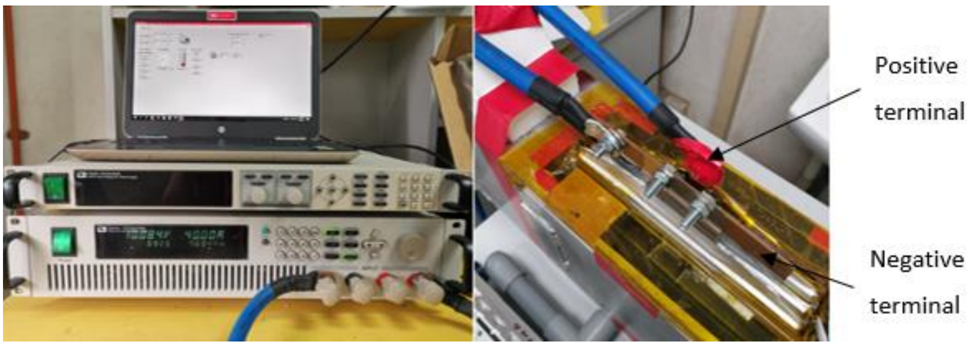


Fig. 3. Connection electronic load machine to battery module

Experiment procedure are as follow

i. The experiment is conducted only when the battery cells are full charge. It is considered that the battery cells are fully charged or 100 % SOC when the battery total voltage is equal to 12 Volts or 4 Volts per cell.
ii. The experiment is started by setting the fan speed in order to obtain the desired constant cooling air velocity, 1.5 m/s.
iii. At this stage the essential information is recorded; air velocity, air temperature, and battery cell voltage.
iv. The battery cells are then discharged at a constant discharge rate, 1C discharge rate (40 Amps).
v. The discharge process is continued until the battery SOC reaches a limit of 20% SOC.
vi. The cooling air velocity is maintained constant at 2 m/s from t=0s until 100 seconds after the end of discharge process, in order to reduce the battery cell temperature rapidly after the end of discharge.
vii. During discharge process, several parameters are monitored to ensure the validity of experiment result and for safety reasons. These include the constant cooling air velocity at 1.5 m/s, cooling air temperature, maximum cell surface temperature which has to stay below 60°C, and the battery voltage above 2.8 Volts.
viii. The experimental results including cell temperatures, battery voltage and current and cooling air velocity and temperature are recorded automatically through Labview software.

The experimental procedure is than repeated for 3C and 5C discharge rate.

3. Results and Discussion

Graph 4-6 show the battery cell surface temperature for discharge rate of 1C, 3C and 5C respectively. T1, T2 and T3 are the notations for location 1, 2 and 3 respectively on the battery surface as shown in Figure 1. In general, for all 3 discharges rate point 1 (near to positive electrode terminal) is the hottest point followed by point 3 (near to negative electrode terminal) and the lowest is point 2. During discharge process, all the current flows to the positive and negative terminal from the entire electrode plate [14]. Thus, the current densities and consequently the temperature of positive and negative terminal are higher than the other parts of the battery cell [14]. Furthermore, the temperature at the positive terminal is higher than the negative terminal due to lower electrical conductivity of the positive electrode, despite the fact that the current flow in both terminal are similarly high [15]. Figure 4 shows the battery cell surface temperature at 1C discharge rate for 3 different locations with constant air velocities of 1.5m/s.

At the end of discharge process, the highest temperature is at T1 with 33˚C followed by T2 with 31°C. The lowest temperature is at T2 with 29.0˚C. In general, the temperature increase is relatively small. This is because only small amount of current is discharged from the battery. Heat generation inside the battery is proportional to the amount of discharge current [16, 17]. The higher the amount of current discharged, produced more heat thus resulting in higher temperature increase. Figure 5 shows the battery cell surface temperature at 3C discharge rate for 3 different locations with constant air velocities of 1.5m/s.

Result shows same trend as in Figure 4, highest temperature T1, followed by T3, and T2. T1 recorded the end of discharge temperature of 47˚C, 44°C for T3 and 36°C for T2. The temperature increase is quite significant as the end of discharge temperature approaching 50°C. It shows that for this type of battery a significant cooling system is needed if the battery is used under higher discharge rate. This condition should be put in consideration as allowable operating temperature is normally 60°C to avoid damaging the battery.

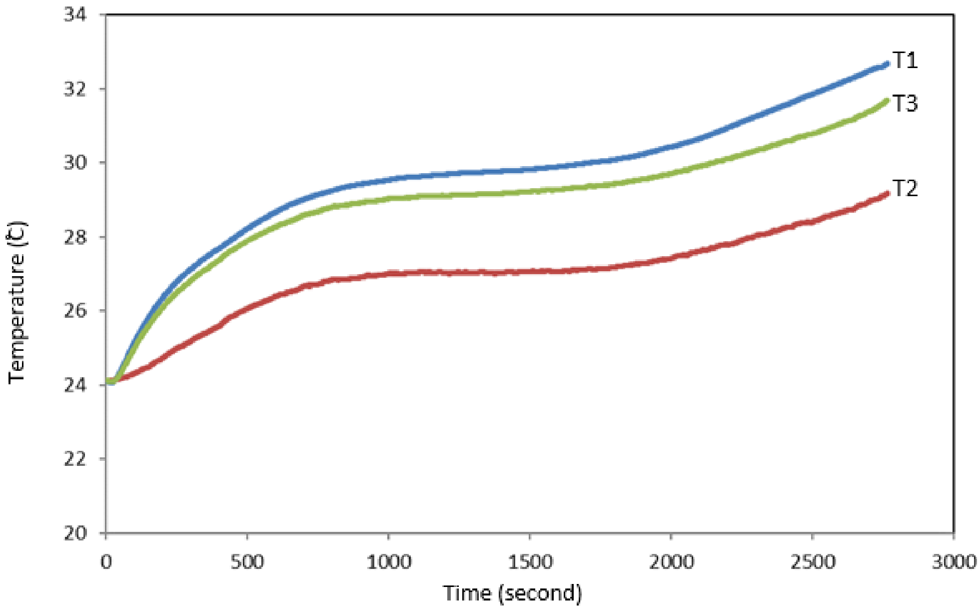


Fig. 4. Battery cell surface temperature for 1C discharge rate

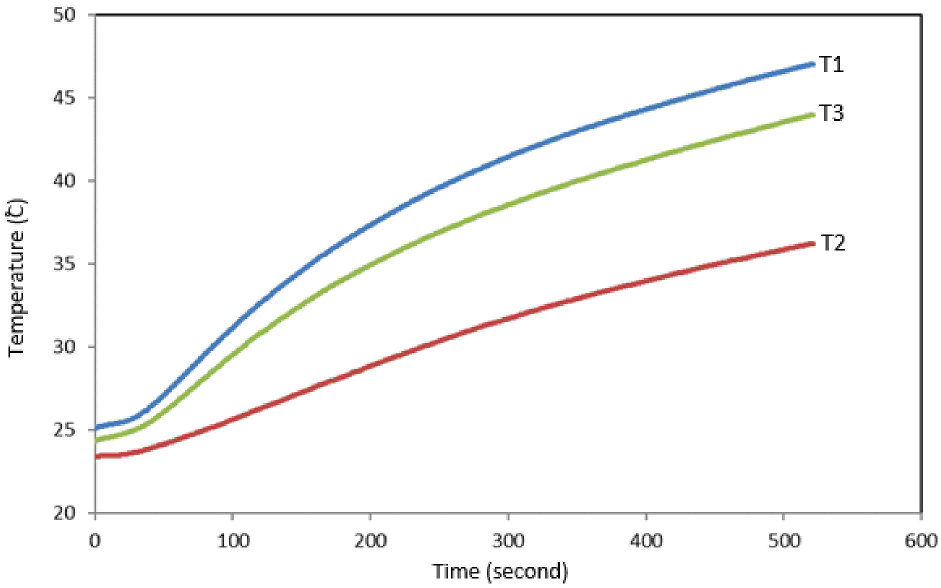


Fig. 5. Battery cell surface temperature for 3C discharge rate

Figure 6 shows the battery cell surface temperature at 5C discharge rate for 3 different locations with constant air velocities of 1.5m/s. Experiment stop at 205 seconds when the battery reach the cut-off voltage of 8.4V. This is far from theoretical discharge duration which should last until 570 second. Experimental time is only about one-third of theoretical time. Figure 6 shows that temperature at T1 52˚C, 45°C at T3and 34°C at T2. Even though the temperature still not reaching 60°C, but discharge time is too short caused by the rapid decreased of voltage. From this result, it can be concluded that this battery do not support deep discharge (more than 3C).

Figure 7 shows the cell surface temperature behaviour at T1 with different discharge rates of 1C, 3C and 5C under 1.5 m/s cooling air velocities. This result is to compare the effect of amount of discharge current on the cell temperature. Results confirm the theory that higher discharge rate produced more heat, thus more temperature increase.

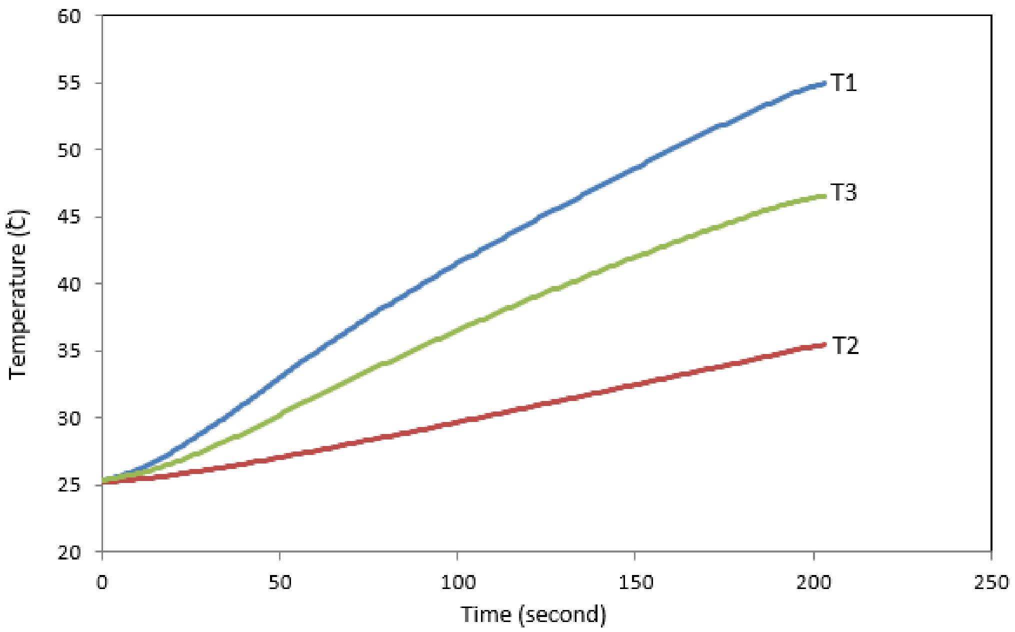


Fig. 6. Battery cell surface temperature for 5C discharge rate

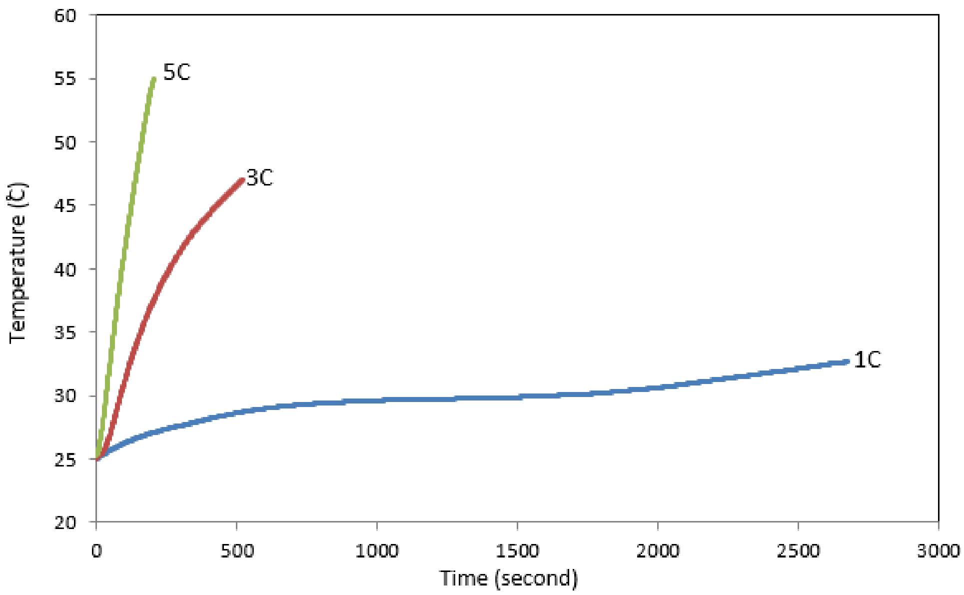


Fig. 7. Cell temperature at T1 for 3 different discharge rates

4. Conclusions

Throughout this experimental study, it is clear that the distribution of temperature across the surface of battery cell is not uniform. Temperature near positive and negative terminal is higher than other location because current is flowing through these small electrodes during discharge process. Current densities and consequently the temperature of positive and negative terminal are higher than the other parts of the battery cell. Furthermore, the temperature at the positive terminal is higher than the negative terminal due to lower electrical conductivity of the positive electrode, despite the fact that the current flow in both terminals is similarly high. The temperature increases with the increasing of discharge rate. The higher the discharge rate, the higher the heat produced by the battery. This is observed for from 1C to 3C and 5C discharged rate. Results from experiment show that this battery does only support up to 3C discharge rate. So, the battery is not suitable for deep discharging for discharge rate of 5C or above. Under 1C discharge rate, temperature increase is relatively small. However, for 3C discharge rate a more significant temperature increase is recorded thus need more attention for cooling system.

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