Extracting a lithium-ion cell's open circuit voltage and calculating entropy coefficient

Streamlining experimentation and determining reversible heat generation

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Abstract

Finding the Open Circuit Voltage (OCV) of a battery is crucial in estimating its State of Charge (SOC) as well as its State of Health (SOH), which is why determining the battery's OCV in the shortest time possible is vital [1]. The entropy coefficient $\left(\frac{dU}{dT}\right)$ of a battery is used in calculating a battery's reversible heat generation, which makes up over 20% of total heat generation [2]. Finding a battery's heat generation can aid in drawing a picture of the battery's thermal profile, which with further experiments can introduce new and improved thermal management techniques for batteries [3].

A battery setup was designed and manufactured for safely operating the battery, and a Peltier element control unit was assembled for conductive thermal control. The battery was subjected to different temperature profiles and its voltage was recorded using the BaSyTec software. The range of SOC considered was from 100% to 5%. Using results, the battery's OCV can be determined 10 minutes after a temperature change and the $\frac{dU}{dT}$ can be written as a function of SOC using an 8th order Fourier equation, which is useful in estimating the reversible heat generation at any given SOC to a huge accuracy.

Motivation

- Shortening the time needed to obtain a battery's OCV as a function of temperature change.
- Trying a different type of temperature change to observe its effect on calculating the battery's $\frac{dU}{dT}$ for obtaining a battery's reversible heat generation. This helps in defining the battery's thermal behaviour which would aid in research for good thermal management for battery packs [3].
- Manufacturing a battery setup for other researchers to use and improve on as well as making a Peltier element control unit.

Methods

- Product Design Specification was written for a battery setup then it was designed and manufactured.
- An Arduino code was developed to control a Peltier element for conductive heating/cooling and setup a control unit.
- A procedure was written on BaSyTec to discharge battery to change its SOC and pause for changes in temperature.
- A MATLAB code was written to calculate $\frac{dU}{dT}$ and plot it against SOC and to find the best fit for the data.

Battery Testing Setup

- For running the experiments safely and efficiently, a battery setup was designed consisting of an aluminium block to conduct heat from Peltier elements quickly to the battery, a liquid heat exchanger on top of the Peltier element to remove excess heat, a clamp and spring to ensure the Peltier elements and liquid heat exchangers were in place, thermocouple attached to the battery, and a fuse to disconnect the Peltier element from the circuit if it reaches 70°C or above.
- An Arduino code was written to use PID control for controlling the temperature of the Peltier element according to the desired temperature profile and the code was used with the Peltier element control unit.
- The cell used was the Samsung 21700 40T. The cell was subjected under a temperature profile in which the temperature changes from 5 to 40°C in 5°C step changes and different ramp rates to observe if this has an effect when calculating $\frac{dU}{dT}$. The SOC varied from 100% to 5% and the battery would be discharged 10% except from SOC 10% TO SOC 5%. The battery's voltage stabilises after a while from changing the temperature, and that can be taken as the OCV. As for heat generation, it is demonstrated in the following equation [4], with the first term being irreversible and the second term being reversible heat generation: $Q = I(V - U) + IT\left(\frac{dU}{dT}\right)$

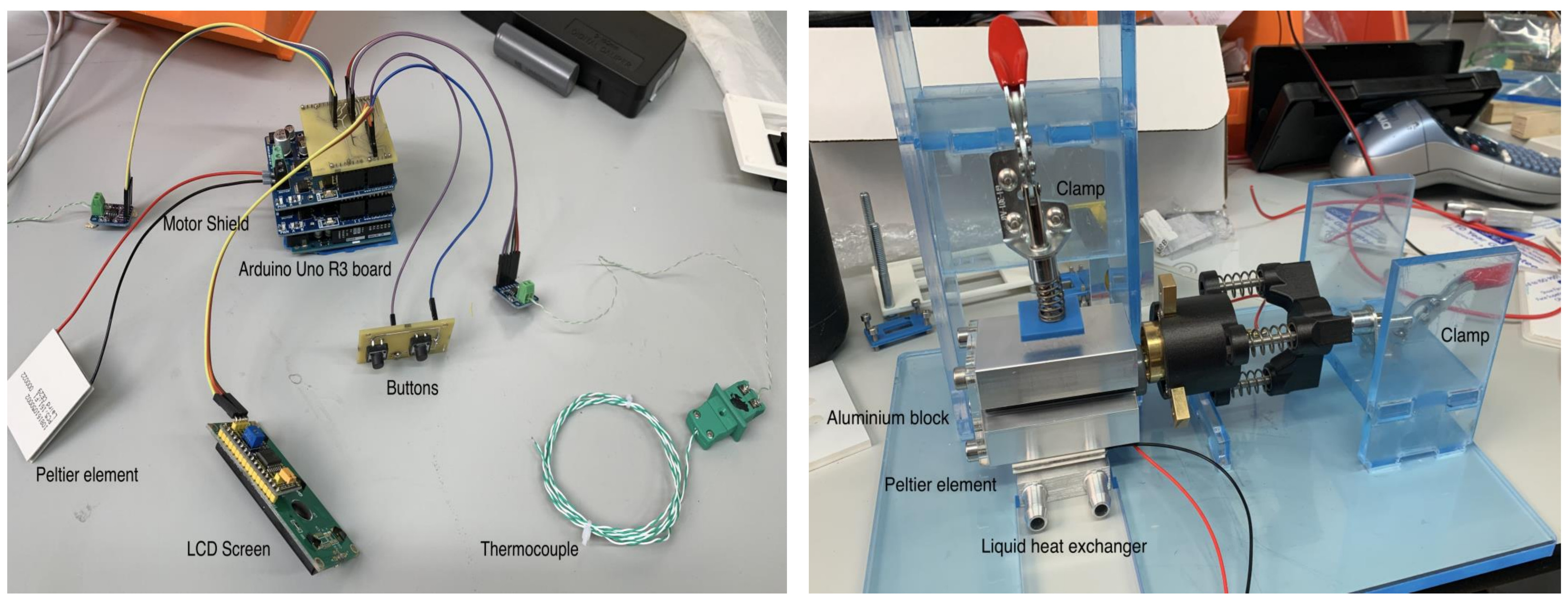

Figure 1. Peltier element control unit and the battery setup

Results and Discussion

- Concerning running the experiment and obtaining data for analysis, there was not enough time for executing the experiment as it would take 32 days to complete; therefore, previous collected data was used to observe when to gather data after each step change and to calculate $\frac{dU}{dT}$.
- The OCV reading can be confidently taken 15 minutes after each temperature change according to the experiment; however, there was too much noise in both the temperature readings as well as the cell voltage to consider these results accurate.
- Using the previous data, plotting the $\frac{dU}{dT}$ against the SOC gives a curve that can be fitted to a Fourier series equation with a goodness of fit r squared value of 99.2% as can be viewed in Figure 2. It was obtained using MATLAB's curve fitting tool. Having the $\frac{dU}{dT}$ as a function of SOC can help in estimating the $\frac{dU}{dT}$ at each SOC which can aid in estimating the reversible heat generation to a reasonable amount of accuracy using the previous equation.
- Climate chambers were used for the previous experiment and from the results, they are inadequate for battery temperature control as the temperature of the battery is not consistent enough as seen in Figure 2. A better temperature control method would be conduction instead (surrounding the battery with temperature conducting element such as aluminium).

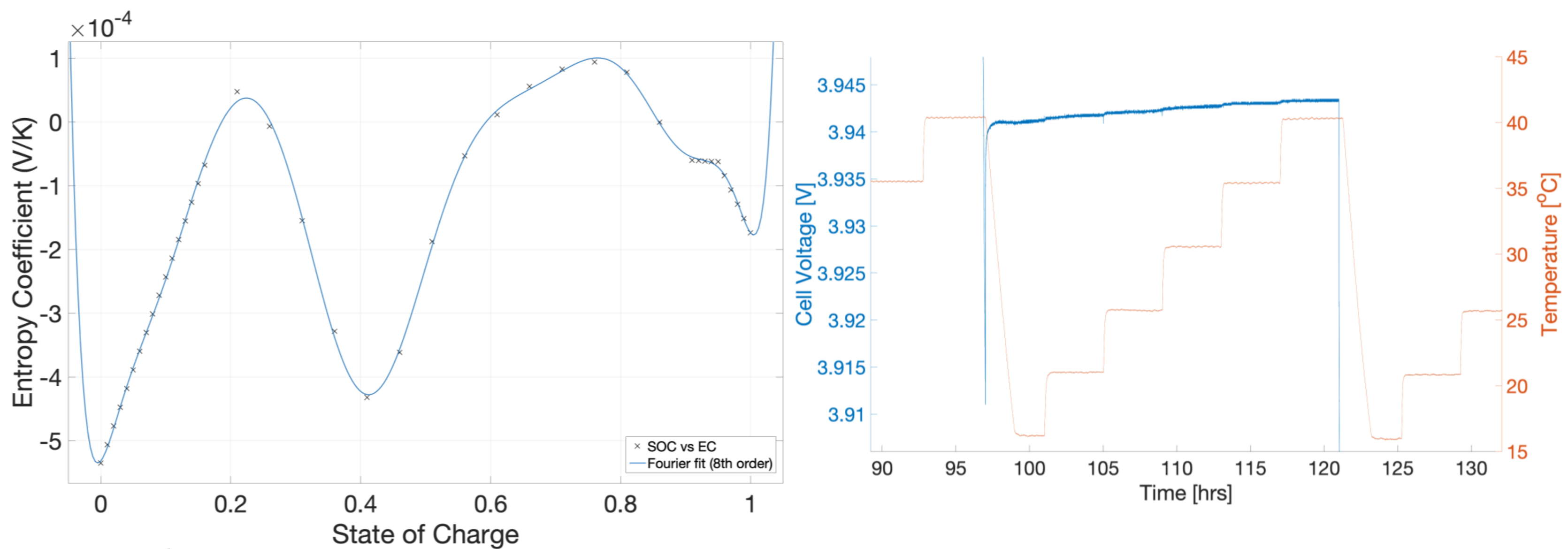

Figure 2. $\frac{dU}{dT}$ as a function of SOC in a Fourier equation and 85% battery SOC with temperature steps

Next steps

- Improve on battery setup to make it even safer and more stable for future uses.
- Run further experiments with conduction temperature control. Compare the results of step change and ramp change in temperature to observe its effect on obtaining the $\frac{dU}{dT}$. After running the experiment, observe if the OCV of the battery can be determined in shorter time.
- Determine irreversible heat generation for calculation of full heat generation of the battery. Executing more experiments can compare different thermal management procedures for lithium-ion battery packs for electric vehicle use.

References

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Intern bio

Aya Rageh is a fourth-year student studying MEng Mechanical Engineering at University of Bristol. She is interested in sustainable engineering and is aspiring to continue studying and researching in the battery field. She is passionate about moving away from non-renewable energy sources as they are finite and harmful to the planet. This field is the future for industries worldwide and any accomplishments in it would have a positive impact on humanity.

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