



# Li-ion Battery Temperature Trends During Charge and Discharge

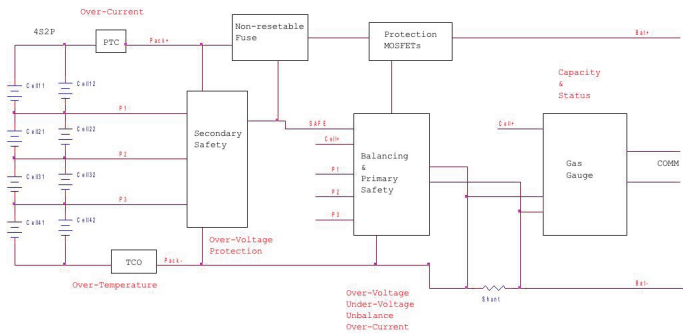
David Gunderson

Lithium chemistry batteries are replacing Sealed Lead Acid (SLA) and Nickel Metal-hydride (NiMH) types in many fixed and portable applications due to their higher energy storage density relative to both weight and volume. As larger Lithium chemistry batteries are designed, managing the waste heat generated by the ever higher high charge and discharge currents becomes an increasing challenge.

Prevention of excessive temperature rise in Lithium chemistry cell packs has always been a major design issue. Most Lithium-Ion (Li-Ion) cells must not be charged above 45°C or discharged above 60°C. These limits can be pushed a bit higher, but at the expense of cycle life. In the worst case, if cell temperatures get too high, venting may occur, resulting in battery failure or even a cell fire. New Lithium battery chemistries, like Lithium Iron Phosphate (LiFePO<sub>4</sub>) promise to increase both charge and discharge max temperatures, but there will always be a fairly low upper limit.

The waste heat energy that causes temperature rise in Lithium chemistry batteries comes from several sources. During both charge and discharge, electronic circuit elements located around the battery may conduct heat into the cells. This is especially true for chargers since they're usually a switching power supply with a controller that implements the CC/CV algorithm required for optimum charge of Lithium chemistry cells. At least 10% of the energy passed through such a charger is lost as waste heat which can be conducted into the battery via terminals and other structures. Some charger architectures can have as low as 70% conversion efficiency.

Other sources of waste heat include protection and gas gauge circuits inside the battery itself. The block diagram below identifies these heat sources. They include the Positive Temperature Coefficient thermistor (PTC) and Thermal Cut-off Fuse (TCO), electronically controlled fuse (usually a Sony Chemical Self Control Protector), the primary protection MOSFETs, and the current measurement shunt for the gas gauge. At high current, resistance of the nickel strips used to interconnect the cells and circuit board traces also become significant.



Example 4S2P Battery Block Diagram

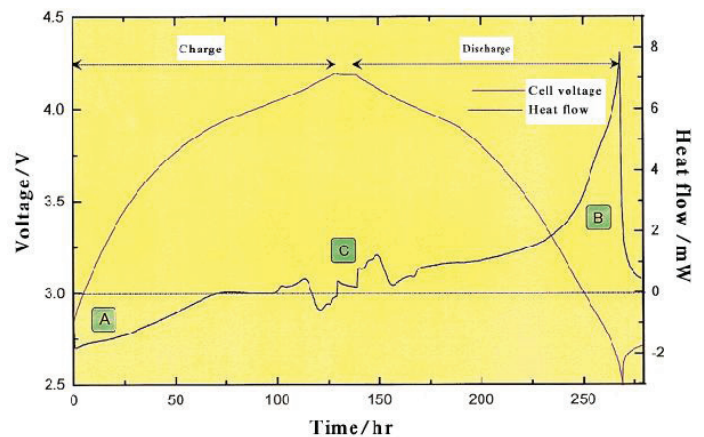
Most electronic elements in the current path are resistive in nature and the heat produced is proportional to the square of the current through the element ( $P = R \cdot I^2$ ). When charge and discharge currents are low (e.g. under 1A), small resistive elements like the R<sub>ds(on)</sub> of protection MOSFETs and current shunt resistance produce little heat. However, these heat sources become critical design challenges as the current increases. It's not unusual for large Lilon batteries to deliver discharge current of 10A or more and have charge current specs in the 5A range. At these current levels, even the smallest resistive element can produce significant heat and contribute to battery temperature rise over a several hour charge or discharge cycle.

The electronics aside, an often neglected source of waste heat is the cells themselves. Li-Ion cells contain over-current protection devices that are resistive and a source of heat when current is flowing. The anode and cathode of the cells conduct the current from the chemical reaction sites to the cell's external contacts and have resistance that depends on their materials.

Most Li-Ion cells have impedance specs in the 80mohm to 100mohm range and can be a significant heat source when the charge or discharge current is near the maximum for the cell. Cells are coming on the market with 10C to 20C current ratings (1C is the capacity rating of the cell in Amp-hrs divided by 1 hr, so a 2400mAh cell has a 1C rating of 2.4A). Of course, the cell can't sustain a 20C current for very long, but it's going to be fairly hot in the short time that it can unless it's cooled in some way.

Almost completely ignored is the chemical reaction in the cell. The chemical reaction that takes place during charging of Lithium chemistry cell is endothermic (the

reaction absorbs heat). Since there is no free lunch in thermodynamics, the discharge reaction is exothermic and produces heat. The Central Research Institute of Electric Power Industry (CRIEPI) did a classic study in 1995 that characterized this in a calorimeter. The plot below was taken from a report on that research (see [http://criepi.denken.or.jp/en/e\\_publication/a1996/96seika29.html](http://criepi.denken.or.jp/en/e_publication/a1996/96seika29.html))



This plot shows a charge cycle followed by a discharge cycle of a single Li-Ion cell and details the heat flow into and out of the cell during this process. Note that the initial section of the plot, labeled "A", shows the endothermic nature of the charge chemical reaction. The discharge section labeled "B" is obviously exothermic, but the surprise is that near the end of discharge, the heat produced increases rapidly, indicating a rapid increase in cell impedance near the end of cell capacity (note that constant current charge and discharge was used).

Note that the endothermic nature of the charge chemical reaction is weak in comparison to other heat sources. In every case we've studied here at Micro Power, battery temperature increased during charge because the other heat sources overwhelm the weak endothermic chemical reaction inside the cell.

The strong exothermic nature of the discharge chemical reaction may cause a large increase in temperature rise near the end of discharge. This is compounded by the fact that many times, the load on a battery is constant-power in nature. As the battery voltage decreases near the end of its capacity, the current must increase to maintain constant-power. This causes all

the resistive elements in the battery circuit to produce more heat and can result in large battery temperature increase.

A properly protected Lithium chemistry battery should have over-temperature protection built-in. Most primary and secondary Lithium chemistry safety circuits contain some provision to open the primary safety MOSFETs when the temperature is too high (too low as well). As shown in the example battery block diagram above, some primary and secondary safety circuits can open an electronically controlled fuse as a last resort (because those fuses are usually not resettable and disable the pack when open).

There are many factors to consider when designing high current Lithium chemistry batteries. One must design a method for removing waste heat from resistive circuit elements around the cells and heat produced inside the cells themselves must be handled. At the high current levels found in transportation applications, active cooling with forced air or even circulating liquid must be used.

To avoid heating in the cells themselves, battery designers use several parallel columns of cells to reduce the current into and out of individual cells. However, this presents a challenge itself because a weak cell in one row can load the other cells in the same row, causing internal current flow in the cell array strapping. This can be prevented by proper placement of PTC devices, but adds cost and complexity.

As Lithium chemistry batteries get larger and are used in more high-current applications where SLA and Nickel chemistry batteries have been dominate, battery designers must pay much more attention to heat sources and removal. The consequences of not designing for the heat that will be produced are at best a battery that doesn't perform well and at worst a safety or reliability issues.

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