

TeraStor
Smart. Safe. Secure.

Effect of Temperature on Battery Cell Impedance and Efficiency

C. Michael Hoff

Introduction

Battery cells function through a series of chemical reactions and interactions. In cycling lithium-ion cells, ions move between electrodes via a medium such as a liquid, semi-solid, or solid electrolyte. In any case, temperature makes a significant difference in how well the ions move through the medium. In general, the higher the electrolyte's temperature, the more easily the ions move through it. The ease of mobility translates to a perceived impedance at the terminals of the cell. The more impeded the ions are, the higher the internal resistance of the cell. Internal resistance directly corresponds to energy losses associated with the cell's cycling, and thereby its round-trip efficiency. Electro-reactive battery chemistries are also affected by temperature, except that in addition to the ease of ionic mobility the ease of chemical reactions is also improved with higher temperatures.

Round-trip Efficiency

Round-trip efficiency (η_{RT} , or RTE) is defined as the ratio of the energy discharged from a battery with respect to the energy required to charge that same battery under the same conditions.

$$\eta_{RT} = \frac{E_{discharge}}{E_{charge}}$$

Losses dissipated by the cell(s) during the charging and discharging are mainly due to internal resistive losses, which are due to ionic impedance through electrolyte and the storage medium, and electron impedance through conductors.

$$R_{cell} = R_{ionic} + R_{electronic}$$

Electronic impedance is positively impacted by higher temperatures, and ionic impedance is negatively impacted by higher temperatures.

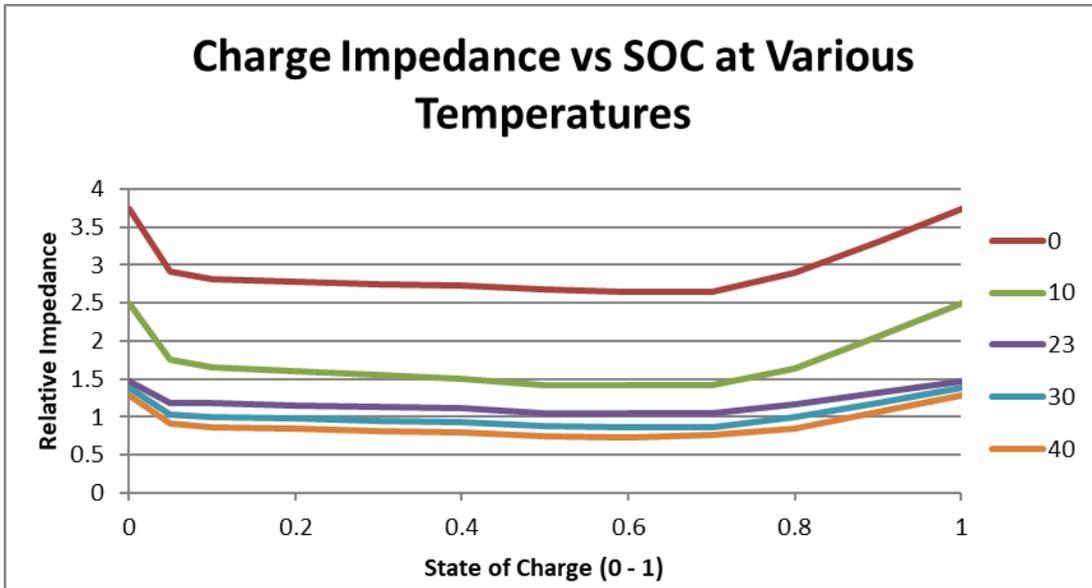
$$R_{ionic} = f(-T)$$

$$R_{electronic} = f(+T)$$

Typically, cells impedance is dominated by ion impedance, thus internal resistances will, in general, go down as temperatures go up.

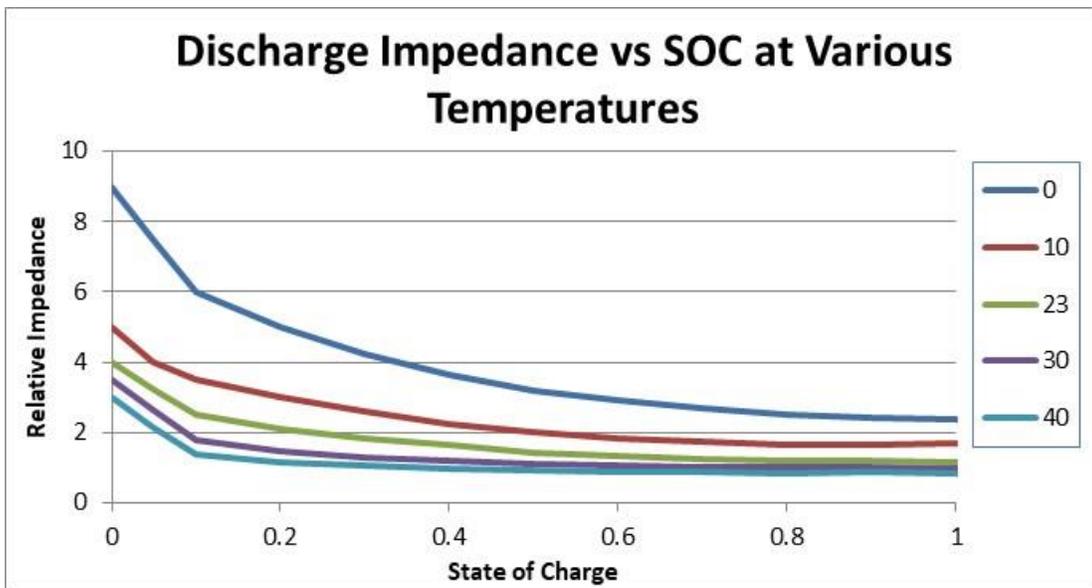
Different chemistries and different formulations of electrolytes with various additives will change the effect of temperature on a cell's impedance. The examples shown in these paragraphs are for specific lithium-ion cells and represent only the general characteristic of all lithium-ion cells.

Another factor that affects impedance is state-of-charge (SOC). Quite often a chart of impedance will show a family of curves at different SOC's with respect to temperature or vice versa. Below is a chart of charging cell dc impedance for various temperatures with respect to SOC.

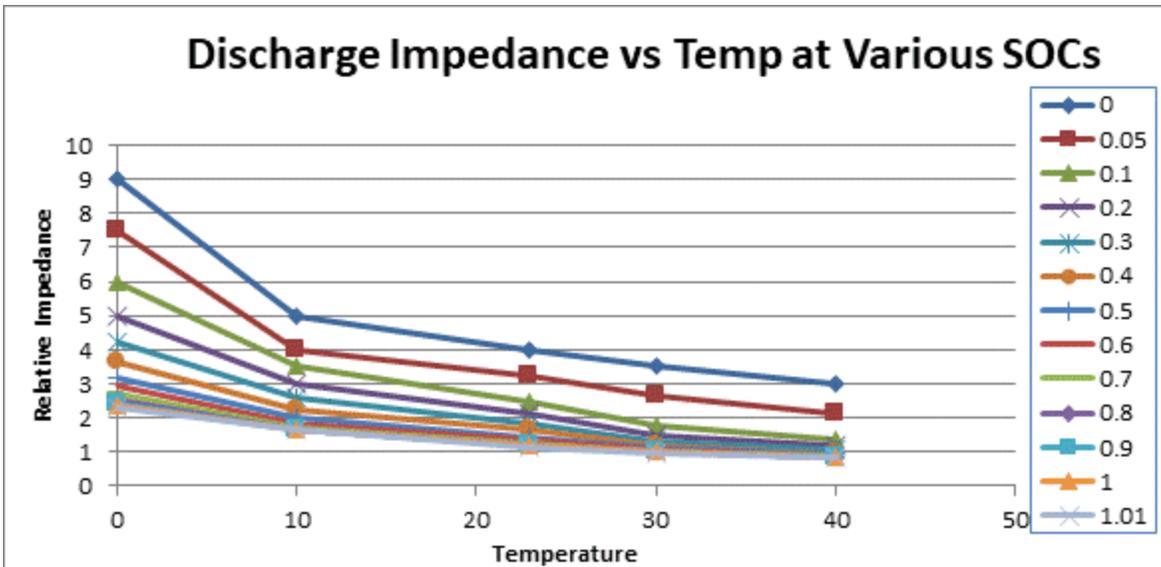


It is evident that as the temperature increases from 0 to 10 °C, the impedance values at any given SOC are roughly half in amplitude. But a further decrease from 10 to 23 °C reduces the impedance by 33%. As the temperature approaches 40 °C, the reductions in impedance are even more reduced.

In addition, impedances vary depending on the direction of charge. The chart below shows a cell's relative discharge dc impedance verses SOC for various temperatures.

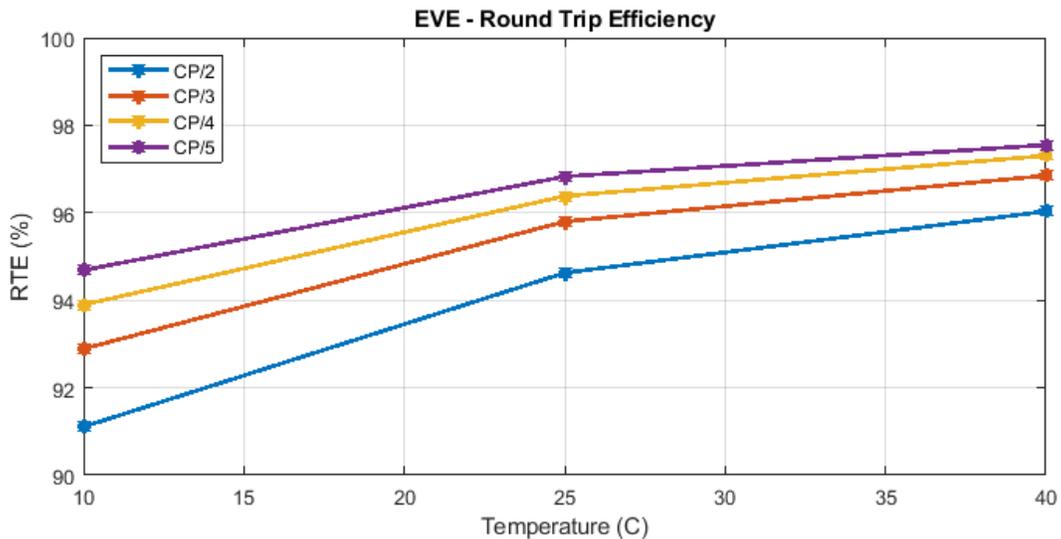


Instead of the "bath tub" shaped charge impedance, the discharge impedances increase monotonically as the cell is further discharged. A similar relation between temperatures exists as in the charge impedance. As the temperature approaches 40 °C, the reduction in impedance is reduced. The data above is reproduced below showing the impedances vs temperature for various SOC:

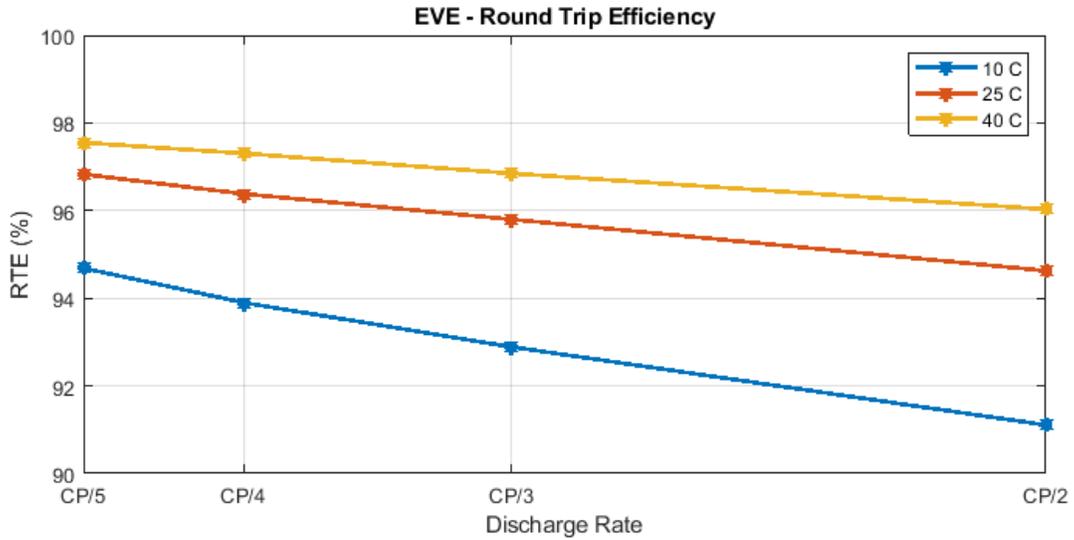


Round-trip efficiency curves

In addition to temperature, cycling losses are also affected by the rate of charge and discharge. The plot below shows the impact of both temperature and rate on the round-trip efficiency of a specific 280 Ah cell.



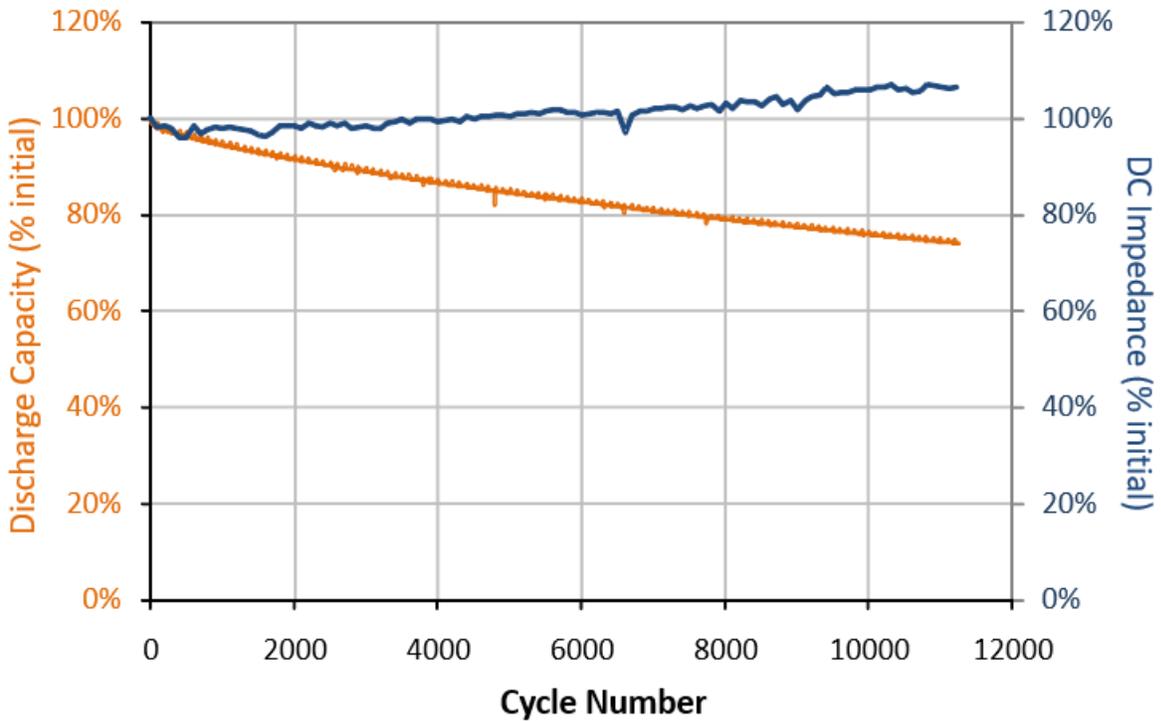
It shows that the RTE rises in general, with rising temperature. Also evident is that the increase in temperatures beyond 40 °C results in smaller increases in efficiency. Also, remarkable is that the efficiency gets no better than 98%. That is because of the hysteresis of LFP chemistry. No matter how low the discharge and charge rates, the cell does not achieve an RTE better than 98%. Below is another view at the same data with respect to discharge and charge rates:



RTE vs Service Years

As capacity decreases over the service life, the cell's resistance grows. Some chemistries experience higher impedance growth than others. In addition, the type of duty profiles and associated aging mechanisms will affect the rate of impedance growth. Below is an example of an LFP-type cell that shows only 8% impedance growth after 10,000 cycles:

1C-1C, 100% depth of discharge (DOD) cycling



Other chemistries and cell models may have much higher impedance growth, sometimes, doubling their internal impedance after losing 30% of their beginning-of-life capacity. Naturally, the RTE will be proportionately affected by the growth of impedance over the service life.

Battery System RTE vs Temperature

The discussion above describes how RTE is affected by the actual cell temperature. In a battery system, cooling equipment maintains the cell temperatures as close to 20 to 25 °C as possible, or wherever the manufacturer specifies the optimum temperature to be. Therefore, external environmental temperatures will have little effect on the cells' RTE.

However, environmental conditions do have an impact on the balance-of-plant RTE. For one, the cooling equipment uses energy to keep the cells cool by powering pumps, chillers, fans and other apparatus. This energy contributes to the overall system losses and its corresponding RTE. Typically, most cooling equipment will use more energy to remove heat from a battery as the external ambient temperature increases. The exact relationship between this increased energy and ambient temperature will vary based on equipment design, range of ambient temperature, and the cell's operating temperature.

In addition, environmental temperatures will increase transformers temperatures, reducing their efficiency, and will also increase the heat-load on the battery enclosures, which will require more cooling energy to remove.

Summary

Battery cells' RTE is improved by a higher operating temperature because higher electrolyte temperatures decrease internal impedance, which is a substantial contributor to cycle losses. However, battery temperatures should be constrained to a limited range, per manufacturers' specifications, if a long service life is an operating priority. Battery systems equipped with cooling apparatus will help to maintain the cell temperatures but will experience additional energy losses associated with powering this apparatus. This energy increases with increasing ambient temperature, thus reducing RTE of the whole system. Cell impedance also varies with SOC and DoD. Because cell impedance is higher at lower SOC levels, larger swings of SOC during a cycle will result in increased losses while operating at higher average SOC levels will result in lower losses. Thus, battery energy storage system's RTE is dependent on environmental conditions, internal temperature control and the type of duty profiles they perform.