Aging Factors Explained

The Lithionics Battery BMS includes advanced data telemetry features available via a Bluetooth connection on any mobile device. It is a "world's first." Most telemetry values are self-explanatory and easy to understand, but there are 2 values which require additional explanation – **Aging Factor SOC** and **Aging Factor Temp**.

QUICK SUMMARY

- **Aging Factor Temp** is a weighted number representing the time spent at higher than room temperature, increasing the rate as the temperature rises. Smaller numbers are better.
- **Aging Factor SOC** is a weighted number that tracks the number of hours the battery is stored in an over- or under- charged state. Smaller numbers are better.
- These values are recorded over the life of the battery. They are used as reference values to offer an explanation as to why a particular battery may have experienced a shorter versus a longer life.
- Therefore, these values are only relevant if a battery is returned for a measurement of battery amp hours for purposes of a warranty claim. A battery is considered healthy so long as the battery is at or above 80% of its original capacity or amp hours. (This is called SOIC or State of Initial Capacity.)

TECHNICAL SUMMARY

It is well known that all batteries age with time, a process called calendar aging. Batteries are electro-chemical devices with chemical reactions inside the battery that eventually cause material degradation, thus reducing a battery's **usable capacity**. The rate of such reactions, or the rate of aging, depends on multiple factors, such as temperature, state of charge (SOC), and the number and depth of charge/discharge cycles. These dependencies are complex, are non-linear, and are cumulative over the lifetime of a battery. In a wide range of operating conditions, a battery can last more or less time, depending on the cumulative effect of aging conditions. It can be helpful to measure and record these cumulative effects, so battery aging can be modeled and predicted with better accuracy in the future. The Aging Factors from Lithionics Battery are modeled by calculating and reporting these aging factors in the BMS telemetry.

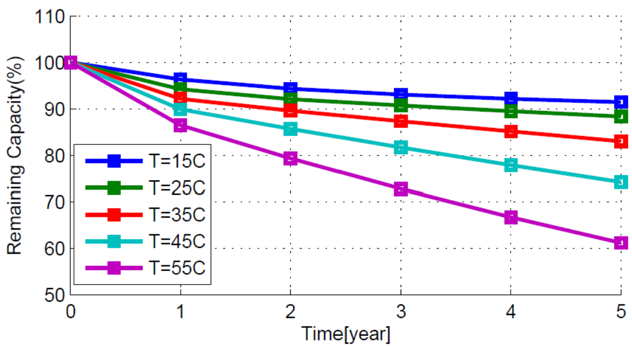
Note that aging doesn't necessarily mean the battery will be dead after a certain amount of time. Battery aging is expressed in % of remaining capacity, which is measured at a 1C discharge rate, much higher than normal use rate of a typical battery. So, even an aged battery will still be useful, but would need more frequent recharge cycles and its voltage would sag deeper under heavy loads due to an increase in internal resistance, which is a function of material degradation.

Lithium Iron Phosphate (LFP) batteries exhibit very long calendar aging. A battery can last 7 to 10 years or even longer, depending on specific operating conditions. As conditions change, such as seasonal temperature swings from cold to hot, the battery aging is affected. Some batteries are operated in hotter climate zones, some batteries are stored for months at a time without use, all of which affects rates of aging. Aging factors can be compared between batteries used in different conditions to see how well prediction models **correspond to the real life of a battery**.

"Aging Factor Temp"

Ideal temperature for any battery is room temperature, around 25C/77F. Manufacturer datasheets specifies cycle life at room temperature. When operated at a higher temperature, especially closer to maximum allowed limit, the rate of aging is increased. Aging factor value represents time in hours spent at higher than room temperature, increasing the rate as the temperature rises. Formula for calculation is $\mathbf{Ft = h*(0.002t^2 + 0.03t)}$, where "t" is the temperature rise above 25C and "h" is battery calendar life in hours. This formula was modeled from IEEE research project "Modeling of Lithium-Ion Battery Degradation" linked here https://www.researchgate.net/publication/303890624

The graph below shows that battery is aging exponentially faster when it spends its life at higher temperatures.



Calendar aging with varying temperature

-Aging factor is a relative value, meant to compare with other batteries or lab models: it does not specifically predict how much battery life would be shortened. Aging processes are too complex and involves too many variables to make specific predictions.

-For example, a battery sitting at 35C for one year, will produce value Ft = 4380, while battery sitting at 45C for one year will produce value Ft = 12264. A difference in 10C speeds up aging by factor of 2.8, but no battery in real use would spend entire year at 45C.

"Aging Factor SOC"

The "ideal" or optimal state of charge for a lithium-ion battery is 50%, where electro-chemical processes inside the battery are the most stable. The further the state of charge (SoC) is from this middle point, the faster the battery is aging, with all other parameters being equal. However, this process is highly non-linear, with real effects only notable at the very top and bottom of SOC range, accumulated over long time periods. So, in practical terms, the battery spending most of its life in an SOC range of 5%-95% is almost the same as being at 50%. The highest impact on SOC aging is from holding a fully charged battery voltage above its natural resting voltage after the charge is completed. Therefore, proper charge termination is important for lithium batteries. Charge voltage is held higher during charging, to facilitate flow of current into the battery, to overcome its internal resistance. However, when the charge is finished the charger must remove or reduce the voltage to what is commonly called Float level, where a fully charged battery can be safely maintained. If the battery is not used for long periods, it should be partially discharged, to further reduce its voltage. (See Lithionics Battery STORAGE PROCEDURE for these voltage values and storage methods.)

Therefore, Lithionics' BMS calculates the "Aging Factor SOC" as cumulative time in hours spent or held above Float voltage after the charge is completed. There will be some natural accumulation of this value during time when voltage is resting from fully charged to Float, but the number will stay low enough if charge process is well regulated. Some systems could have poorly regulated or incorrectly programmed chargers, which would result in much higher value in this aging factor. If such behavior continues for months or years, the battery will age faster than normal, and it will be reflected in high value of this aging factor. (For these reasons, using approved charging sources that are capable of following our recommended multi-stage charging algorithm becomes important to achieving maximum battery life. Examples of Concern: solar charge controllers with long absorb times or very high float values, or, "converters" that hold batteries at high voltage or "constant voltage" will reduce the battery life.)

Similar degradation occurs if a fully depleted battery spends a lot of time without being recharged, at a very low SOC. Therefore, the Lithionics BMS algorithm also increments an aging factor during such time.

The Formula for Aging Factor SOC is **Fc =** $\sum_h(\boldsymbol{V} > \mathbf{13.8}) + \sum_h(\boldsymbol{V} > \mathbf{14.2}) + \sum_h(\boldsymbol{V} < \mathbf{10.8})$

It means that "time in hours" is counted while battery is above 13.8V but counted at a double rate when above 14.2V and counted at a normal rate when below 10.8V. The formula is applied only when battery is not charging, the time counter is paused during charging, as voltage is expected to be higher during charging.

-For example, if battery is fully charged, but continuously held at 14.4V after charge is finished, then Fc will increment by 2 for every hour until voltage is allowed to rest down.

NOTE: Voltages shown above are for 12V nominal battery. For 24V and 51V batteries, multiply values by 2x or 4x.