

Lithium Battery Passivation and De-Passivation

5 W's

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Lithium Battery Passivation: 5 W's

Who?

Passivation occurs in all lithium thionyl chloride battery cells. There is no escaping passivation...merely dealing with it

Will it affect you and your application? It probably will; but it may not. It depends on some dynamic interactions between your tool's current load pulse profile demands and the most recent condition of your lithium thionyl chloride cell based battery. One application may be fine....another may have an issue. Let's explore further.

What?

Passivation in a lithium thionyl chloride battery cell is a chemical reaction between the solid metallic lithium metal and the liquid catholyte (cathode and electrolyte) in the cell. It is a self-assembled, thin, highly resistant layer of lithium chloride crystals on the surface of the lithium metal. This passivation layer partially blocks the chemical reaction between the solid lithium (anode) and the liquid thionyl chloride (cathode), inhibiting the battery chemical reaction from generating the electrons (electrical current). As the passivation layer grows thicker, the resistance increases, and thus increased prevention of electrical current flow leading to voltage droop on load current pulses.

When?

The passivation layer begins to "grow" as soon as the cell is manufactured. This happens immediately when the liquid catholyte is added into the cell can which already includes the lithium metal anode, carbon, current collector, and insulator "jelly roll" or stack. Then the cell is capped and sealed. The passivation "layer" continues to "grow" thicker with time until reaching equilibrium dependent on the temperature and age of the battery cell. Higher temperature causes a thicker passivation layer, thus storing at cooler (room) temperature helps mitigate passivation layer growth. Consequently, using fresher batteries helps assure a less resistive passivation layer has formed in the battery.

The passivation layer is diminished by appropriate electrical current flow through the cell. This current flow breaks down the passivation layer to reduce the electrical path resistance via a more efficient chemical reaction between the solid lithium anode and liquid thionyl chloride cathode. Thus once a tool is running downhole and pulling sufficient electrical current from the battery to run it's application, it likely will remain sufficiently de-passivated. However, once the application load stops downhole, such as when an alternator turns on, the passivation resumes.

Where?

Since passivation begins to occur as soon as the lithium metal battery cell is manufactured, it occurs anywhere the cell or battery pack using the cell is located. Thus passivation is occurring naturally in the battery while in transit, in storage, at the shop, at the rig, or downhole even while operating, if current loads are very low.

Why?

Passivation is your friend. It is a natural chemical reaction of the lithium thionyl chloride battery chemistry ingredients. Without passivation, the lithium thionyl chloride battery would not be viable. Passivation is a necessary intermediary layer that it inhibits the immediate reaction of the solid lithium anode with the liquid thionyl chloride cathode, thus providing for the stability and very low self-discharge (<3% typical) of the lithium thionyl chloride battery. It also enables the safe use and relatively long shelf life of these batteries, which offer high energy density and high operating temperatures necessary for many MWD/LWD applications.

Passivation can also be your adversary. Passivation can cause electrical performance issues such as voltage droop and current pulse limits for your tool during downhole application. Since passivation will limit the current, and thus slow the electrical voltage ramp responsiveness, in extreme cases severe voltage droop or delay may occur. This is caused by the passivation blocking the access of the liquid cathode to the anode surface area where the chemical reaction occurs to create electrical current sourced from the cell to the tool. It especially prevents sudden, high amplitude pulses of current. Your MWD/LWD tool needs that electrical current to operate, and it often needs sudden, high amplitude current pulses. Thus the proper operation of your tool current-pulse load and proper tool performance not only requires the proper rated cell current (such as high rate versus moderate rate); but, also the proper de-passivation of those cells in the battery. Higher passivation level increases the risk of inadequate tool current pulse load performance by the battery, which sometimes may cause tool performance failure due to under voltage cutoff. This can happen even with the correct cell rate selection in the battery designed for the tool.

To deal with the natural occurrence of passivation, and also account for the need of tool dynamic current-pulse load performance, one needs to mitigate the effects of passivation by properly de-passivating a lithium thionyl chloride battery, or “de-pass”ing as it called in the drilling industry, before and possibly during use. Read on about the 5 W's of De-Passivation.

Lithium Battery De-Passivation: 5 W's

Who?

The tool assembly technician or tool operator should assure that the lithium thionyl chloride battery has been properly de-passivated as a “conditioning” of the battery for proper tool operation. SWE recommends use of a properly sized, automatic de-passivation tool. See Appendix 2: Proper De-passivation.

What?

Battery de-passivation is a process that “conditions” the battery for proper operation. De-passivation serves to break down the passivation layer and “clear” some paths for the liquid thionyl chloride cathode to reach and react with the solid lithium anode, therefore generating sufficient electrons to meet the current load pulse demand for the tool operation.

When?

Battery de-passivation should be conducted prior to use of the battery. As mentioned, the passivation layer will always be attempting to grow. So de-passivating the battery a relatively short time (hours to days) before the battery is used will help avail proper lithium surface area to generate the required current for the tool electrical load.

Sometimes a battery may experience downhole operating conditions of a very low quiescent current to no current load coupled the high downhole temperatures for an extended time before being called upon for dynamic current pulse loads. Use cases such as back-up battery or flow-off surveys are examples. Periodic battery de-passivation conditioning even while operating downhole may become necessary in extreme use cases.

Where?

Battery de-passivation should be conducted just prior to tool assembly at the job shop, rig, or end use application sight. In some rare cases as mentioned above, battery de-passivation may be appropriate while operating downhole and between tool runs.

Why?

It is a simple concept of balancing between continuously changing and competing factors of nature/chemistry. Lithium thionyl chloride batteries will passivate continuously, with more increasing level of passivation both as battery temperatures increase and as time extends longer. Operating tools need current pulses to not be adversely inhibited by this natural passivation layer. De-passivation clears some surface area in this resistive passivation layer on the lithium anode

allowing the battery chemistry to operate and generate the electrons needed for the tool pulse current or other electrical load. Not enough available surface area on the anode due to a heavy passivation layer blocking catholyte access will mean droops in pulse current load currents and voltages. These drops may be severe enough to cause tool run failure due to drooping under low voltage cutoff thresholds in the tool electronics.

Proper de-passivation prior to battery installation (with tools such as the SWE Pow-R Start Depass Box) will allow you the best chance for proper battery de-passivation conditions to meet downhole or other lithium battery current pulse load performance needs.

Appendix 1: Cell Rates and Discharge Profile:

Lithium thionyl chloride battery cell current ratings (nominal and max) directly correlate with the surface area of the lithium anode in the cell. The more lithium surface area available, the more room for chemical reaction to simultaneously occur and release electrons, thus the more electrical current can be provided and the higher the current rating.

There are typically three rates of lithium thionyl chloride cells: low, moderate, and high. However, in MWD/LWD drilling applications, usually only moderate and high rate cells have continuous and peak current ratings adequate to meet the tool current load profile needs.

Moderate rate cells have more lithium surface area than low rate cells of the same size and therefore can serve a higher, or “moderate rate” current load. Correspondingly, high rate cells have more lithium surface area than either low rate or moderate rate cells of the same size, and thus can serve a higher, or “high rate” current load.

Among other operating parameters not mentioned here for simplicity, all lithium thionyl chloride cell current ratings assume that the cells are properly de-passivated prior to use to achieve their rated current performance.

Regardless of the rate of the cell, a lithium thionyl chloride cell discharge profile will simplistically look like this in Figure 1: Simplified Lithium Thionyl Chloride Cell Discharge Curve.

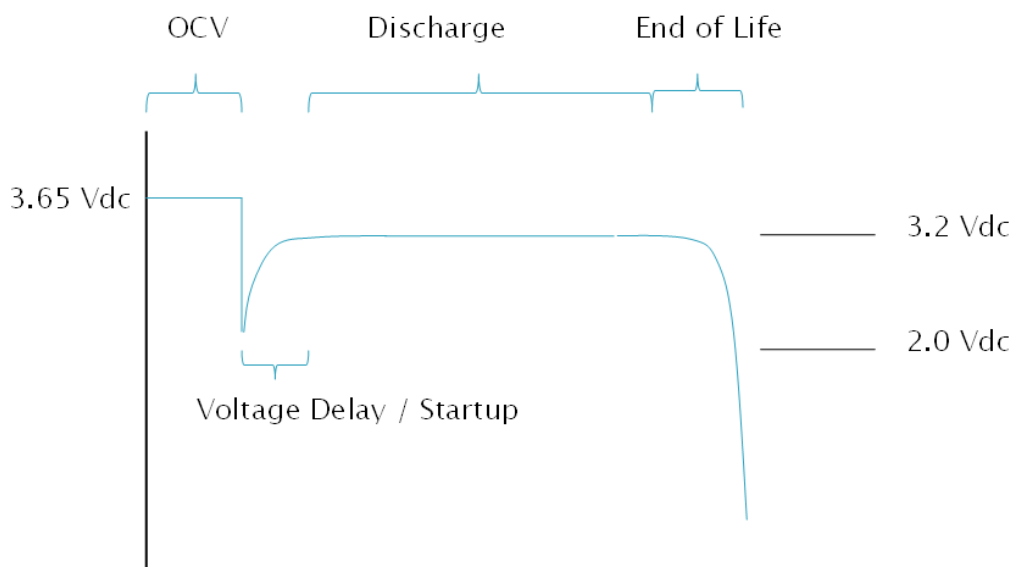


Figure 1: Simplified Lithium Thionyl Chloride Cell Discharge Curve (Courtesy: Engineered Power)

The first portion of OCV (Open Circuit Voltage) is at about 3.65 Volts DC. When initially connected to a load to discharge, such as a MWD tool load, you see the Voltage Delay or droop. This is caused by passivation in the battery cell as discussed prior. The depth of this voltage droop, and the duration of the droop delay, is variable and dependent on the current load relative to the battery continuous current rating, as well as the extent to which the battery has been properly de-passivated.

Ongoing closed circuit operating voltage level should be around 3.2 Volts per cell (in series) of a lithium thionyl chloride battery. It should deliver a relatively flat discharge curve, with the exception of current pulse spikes causing corresponding intermittent small voltage droops (not shown in Figure 1), until reaching near end of capacity, or end of life as called in the industry. The voltage drop off will be fast at battery end of life, with a voltage drop off knee or cliff as can be seen in the End of Life portion of Figure 1. Batteries should not be operated below 2 Volts per cell for safety reasons, and thus should be removed from use prior to reaching end of life.

However, the objective is to get full battery utilization prior to end of life. You want to avoid the situation where this voltage droop causes the tool to encounter the under voltage cutoff threshold for the tool, causing your tool to turn off from low voltage, even though you may have plenty of remaining capacity in your battery. With proper cell sizing in the battery relative to the tool power load profile, and with proper battery de-passivation prior to use, this voltage droop will be mitigated enough for the tool to have adequate electric voltage and sufficient current pulse source to operate reliably until approaching the end of life for the battery.

Appendix 2: Proper De-passivation:

Proper de-passivation is a relative item. The battery needs enough de-passivation such that, assuming it is right sized for the application, it can meet the ongoing background and dynamic pulse current load demand of the tool until the battery is near end of life (the lithium is consumed).

Some de-passivation is achieved by connecting the battery to a resistor to generate continuous current load for a period of time. It leaves a lot of questions to be answered. How much current load should be generated? How long of a period of time? Will this be enough to depass the battery properly? If I lower the resistor and crank up the current, will it damage the battery? How do I know? Since this is a dynamic situation, these questions often go unanswered.

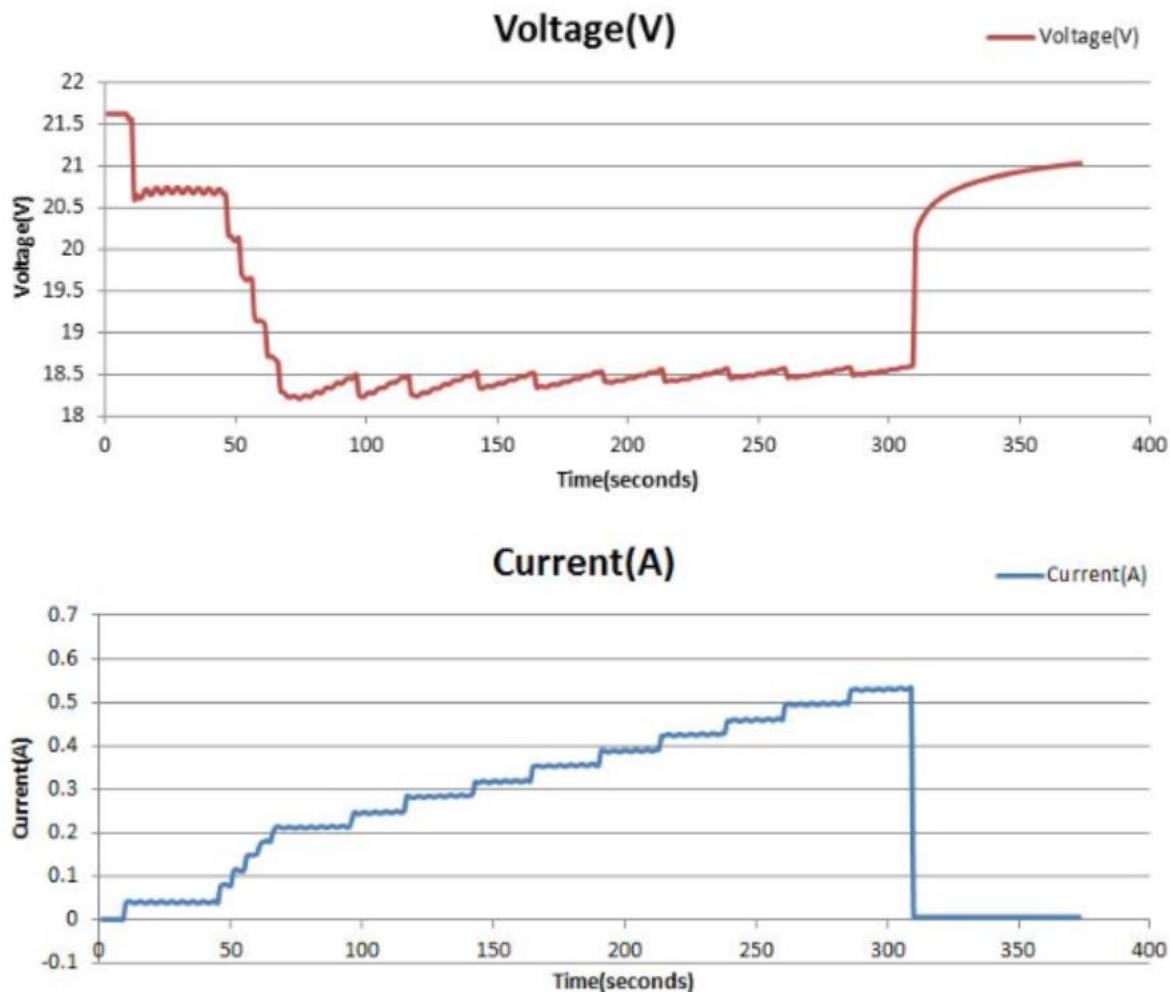


Figure 2: Voltage and Current: Suggested Incremental Load De-passivation

A logical and empirical supported systematic approach is to ensure that a battery cell is de-passivated enough to meet 75% of it's at temperature rated continuous current performance when de-passivated at room temperature. But knowing that lithium batteries perform better at higher temperatures, how do we safely and properly de-passivate the battery at room or job site temperatures without damaging the battery?

The clearest way is to initially create a battery load at high resistance that is a very low current load for the battery, as illustrated in Figure 2 Voltage and Current: suggested Incremental Load De-passivation. This will allow it to start de-passivating gradually without causing too much voltage droop. Note that this 6 series cell battery pack example starts with an open circuit voltage of about 21.6 Volts. ($6 \times 3.6 \text{ V} = 21.6 \text{ V}$) (Lithium cell manufacturers indicate you do not want to droop battery voltage much below 3.0 V per cell in series for longer than a few seconds or you may begin to damage the cathode of the battery cells). Also note that the first current load of about 33 mA is applied, the battery voltage droops to about 20.6 V. As the cell "warms up" at this light load and begins to clear a very slight de-passivation path, you can move the cell to the next lower level resistance to increase the current load.

The Figure 2 example increments the current at 33 mA per step and maintains the 6 series battery voltage above 18V, which is above the important 3 volts per cell threshold. This increased load begins to clear a slightly larger area of de-passivation. Be sure to not droop below the 3V per cell when you increase that load. Continue this process on and on until you reach a current level of 75% of the rated continuous current of the lithium cell, all the while not drooping below 3 volts per cell in the stair step current increasing process. This assures that you get the final answer you want....continuous current capable of 75% of the rated current of the cell. In the Figure 2 example, the 6 cell battery reaches and maintains 525 mA current on it's 15th increment step. That is 75% of the 700 mA rated continuous current of the Lithium cell in the 6 series battery. Proper de-passivation mission accomplished. It also assures that you did not damage the cathode of the battery cells on the way to the final answer of the properly de-passivated battery.

Those many steps of changing resistance progressively to increase battery current steps while not allowing the battery to droop below 3 volts per cell seems like a lot of work for the technician to do to get to a properly de-passivated battery 75% final answer. It is. SWE offers an automated solution to simplify and achieve this de-pass process. See Appendix 3.

Appendix 3:

POW-R START™

De-passivation Box User's Manual

PRODUCT DESCRIPTION

The POW-R START™ De-passivation Box is designed to automatically, safely, and reliably de-passivate a Lithium Primary battery.

The POW-R START™ intelligently applies an appropriate, automatically adjusted load to the battery to safely eliminate the passivation layer and progresses until the battery is either passed or failed. A passed battery is pre-conditioned for proper use and operation in the MWD/LWD tool (subject to adequate remaining battery capacity).

SPECIFICATION

Voltage:

- Custom manufactured to your specific pack voltage, and number of cells
- Supports any single pack voltage between 5 V to 65 V
 - 3 to 17 cells arranged in series
 - Parallel-connected cells are not supported
- De-passivation is limited to battery packs containing between **N-1** and **N+1** cells, where:
 - **N** denotes the number of cells in your pack
 - $3 \leq N \leq 17$
 - Series-connected packs of 2-cells or less, and 18-cell or greater, are not currently supported
 - **Example:** An 8-cell, 29.6 V POW-R START™ box will be able to depassivate a 7-cell, 25.9 V and a 9-cell, 33.3 V pack, as well

Current:

- 1.4 mA quiescent

Temperature:

- 0 °C – 50 °C operation

Dimensions:

- 4.25" x 5.83" x 2.56"

Connector:

- Field-proven, ruggedized Amphenol 3-pin connector

Cable:

- Connection from Pow-R Start to your specific battery
 - Pow-R Start connector on one end
 - Your battery connector mate on other end
- When ordering Pow-R Start as Line Item #1, please also order a mating cable as a separate Line Item #2:
 - Std SWE# 9999812 –flying leads for you to add your battery connector mate later; OR
 - Custom to your battery connector mate



Lithium Battery Passivation

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FEATURES AND OPERATION

The POW-R START™ De-passivation Box works by applying a progressively stepped load (from lightest to heaviest) based on the type (High Rate or Moderate Rate) and number of cells in your pack. This is the safest and most reliable method of de-passivating your lithium primary battery.

Starting with the lightest load, the POW-R START™ monitors the pack voltage and watches as it first dips, and then returns back to its rated closed-circuit voltage (CCV). It applies each load for a minimum duration of 30 seconds, and continues to apply the load and test the results for up to 30 minutes. If at the end of the 30 minutes, the pack voltage has still not risen back to its rated voltage, the pack is assumed to be too passivated and is failed, as evidenced by the **RED** Fail LED illuminating.

However, if the POW-R START™ sees the voltage return back to its rated CCV after application of the light load, it then switches to a heavier load. If the voltage drops below a certain threshold, then the load will be decreased. This sequence of increasing and decreasing the load in order to keep the voltage between two set levels continues until the 30-minute time period has fully elapsed. The de-passivation is successful if all loads have been turned on. This result is reflected by the **GREEN** Pass LED illuminating. The de-passivation is unsuccessful if the test takes longer than the allowed 30 minutes, or the pack voltage drops below minimum.

USAGE

Per the directions printed on the top face of the De-passivation Box:

1. Connect your battery to the appropriate terminals on the depass box
2. Press the **Start** button until the **YELLOW** LED begins flashing.
3. A flashing **YELLOW** LED will indicate that the de-passivation test is currently in progress
4. Upon completion of the testing, you will see the following:
 - a. **GREEN** LED = Depass Test Has **PASSED**
 - b. **RED** LED = Depass Test Has **FAILED**

If at the end of the 30 minutes your pack has failed to be depassivated, you may elect to try to depassivate the battery again by repeating Steps 1 – 4 above up to three more times. If you cannot successfully depassivate your battery after four attempts, it is likely that your battery is unable to be depassivated and should be disposed of in accordance with local rules and regulations.

NOTE: The LED pass/fail status will remain illuminated for 8 hours after a de-passivation attempt.

USAGE WARNINGS

In order to ensure that this tool operates effectively and safely, SWE recommends that users of this product strictly follow these instructions and pay specific attention to the following cautionary practices:

- Under no circumstances should you tape down or construct a method of holding the **Start** button down other than using your finger to press it until the **YELLOW** LED begins flashing.
- **WARNING:** This box will become HOT as it goes through the full de-passivation process. Caution should be taken not to expose skin directly to the box while testing is in progress.

SUPPORT

Support inquiries or questions should be directed to outsales@swe.com.

POW-R START™ Coupon



GET 50% OFF*
FIRST POW-R START ORDER
(ANY QTY)

*Qty 1 price

Call us on +1 (281) 240-4000 & quote 'POWRSTART50'