Understanding the passivation effect

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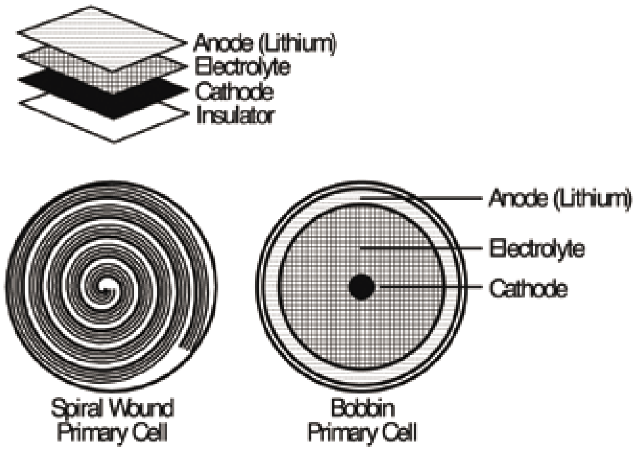
A little known chemical reaction is essential to extended battery life

As remote wireless devices become ubiquitous to the Industrial Internet of Things (IIoT), there is a growing need to extend battery life, especially for applications involving long-term deployments in hard-to-access locations and extreme environments.

Certain low-power devices draw average current measurable in microamps with high pulses measurable in the multi-amp range. These devices are carefully designed to conserve as much energy as possible to operate for decades on their original battery. This requirement limits the choice of primary batteries that can be used to deliver long-term power.

Bobbin-type $LiSOCl_2$ batteries deliver proven 40-years operating life for certain low power applications.

Within the lithium family there are a number of primary (non-rechargeable) chemistries, including iron disulfate ($LiFeS_2$), lithium manganese dioxide ($LiMnO_2$), lithium thionyl chloride ($LiSOCl_2$), and lithium metal-oxide. (*See table on next page*) Of all these choices, lithium thionyl chloride ($LiSOCl_2$) batteries are overwhelmingly chosen for long-term deployments because they deliver the highest capacity and highest energy density of all lithium cells to support product miniaturization. Bobbin-type $LiSOCl_2$ cells also feature an incredibly low self-discharge rate as low as 0.7% per year, largely due to harnessing the passivation effect, enabling certain low-power devices to work up to 40 years on the original battery.



$LiSOCl_2$ batteries can be manufactured two ways, using a spiral wound or bobbin-type construction. Spiral wound cells have a larger surface area for higher rate energy flow, while bobbin-type cells have less surface area to maximize the passivation effect.

Primary Cell	$LiSOCl_2$ Bobbin-type with Hybrid Layer Capacitor	$LiSOCl_2$ Bobbin-type	**Li Metal Oxide** Modified for high capacity	**Li Metal Oxide** Modified for high power	**Alkaline**	$LiFeS_2$ Lithium Iron Disulfate	$LiMnO_2$ CR123A
Energy Density (Wh/1)	1,420	1,420	370	185	600	650	650
Power	Very High	Low	Very High	Very High	Low	High	Moderate
Voltage	3.6 to 3.9 V	3.6 V	4.1 V	4.1 V	1.5 V	1.5 V	3.0 V
Pulse Amplitude	Excellent	Small	High	Very High	Low	Moderate	Moderate
Passivation	None	High	Very Low	None	N/A	Fair	Moderate
Performance at Elevated Temp.	Excellent	Fair	Excellent	Excellent	Low	Moderate	Fair
Performance at Low Temp.	Excellent	Fair	Moderate	Excellent	Low	Moderate	Poor
Operating Life	Excellent	Excellent	Excellent	Excellent	Moderate	Moderate	Fair
Self-Discharge Rate	Very Low	Very Low	Very Low	Very Low	Very High	Moderate	High
Operating Temp.	-55°C to 85°C, can be extended to 105°C for a short time	-80°C to 125°C	-45°C to 85°C	-45°C to 85°C	-0°C to 60°C	-20°C to 60°C	0°C to 60°C

Understanding the importance of passivation

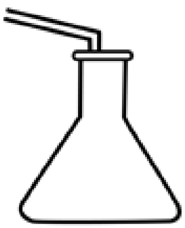
Self-discharge occurs with all batteries, as chemical reactions sap energy even while a battery is inactive or in storage. A battery's self-discharge rate is affected by numerous variables, including the cell's current discharge potential, the purity and quality of the raw materials, but mainly due to the passivation effect.

Passivation occurs when a thin film of lithium chloride (LiCl) forms on the surface of the lithium anode to limit chemical reactions. Whenever a load is placed on the cell, the passivation layer also creates initial high resistance, causing voltage to dip temporarily until the discharge reaction removes the passivation layer: a process that keeps repeating each time the load is removed.

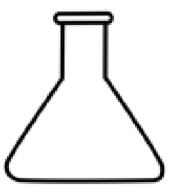
The level of passivation is influenced by factors such as the current capacity of the cell, length of storage, storage temperature, discharge temperature, and prior discharge conditions, as removing the load from a partially discharged cell can impact passivation more relatively to when the cell was new.

Passivation is key to reducing self-discharge, however too much of it can be problematic by overly restricts energy flow when its needed most. Conversely, cells with lower passivation are ideal if higher energy flow is required, but there is a major trade-off in terms of a higher self-discharge rate that shortens operating life.

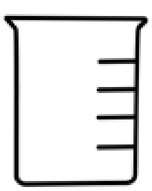
Bottle Examples



Low flow/ low self-discharge



Medium flow/ medium self-discharge



High flow/ high self-discharge

Using the bottle analogy to explain passivation

The effects of passivation on battery self-discharge and energy flow are similar to comparing bottles with different size openings:

- The volume of the glass/bottle is equivalent to battery capacity
- Evaporation/self-discharge is equivalent to capacity loss
- Flow volume is equal to discharge/energy flow
- Low liquid/electrolyte quality can clog the bottle opening, causing a stoppage to flow/passivation
- Low liquid/electrolyte quality can cause evaporation/self-discharge
- Large openings are good for fast flow/discharge but not for storing fluids for a long time
- Long-life demands a smaller opening for low evaporation/self-discharge

Bobbin-type $LiSOCl_2$ batteries have very “small openings” (low flow rate with slower evaporation/self-discharge), whereas a $LiSOCl_2$ cell with spiral wound construction has far greater surface area for chemical reactions to occur, akin to a bottle with a wider opening. As a result spiral wound $LiSOCl_2$ cells permit greater energy flow with the trade-off being a significantly higher self-discharge rate that shortens battery life. Other available battery chemistries such as LiMnO and Alkaline also feature “larger openings” to enable higher flow rates with faster evaporation (self-discharge).

Generally, the bottle with a smaller opening is ideal for sipping small amounts of energy. However, too small an opening can cause the bottle to get clogged (excess passivation), a problem that can be exacerbated by chemical impurities. Therefore, it is essential to know how the battery was manufactured and the quality of the raw materials.

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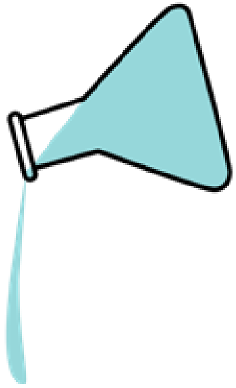
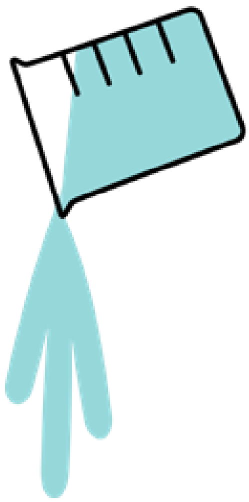
Comparative flow rates

XOL TL-49xx Series

iXTRA TI-59xx series and other manufacturers



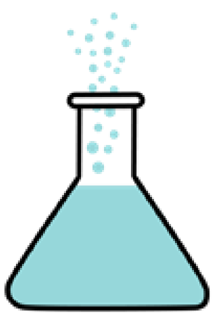
LMNO$_2$ and alkaline cells



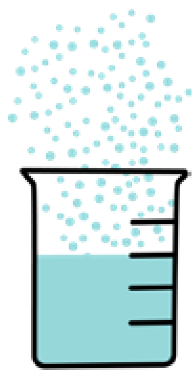
Comparative evaporation/self-discharge rates

XOL TL-49xx Series

iXTRA TI-59xx series and other manufacturers



LMNO$_2$ and alkaline cells



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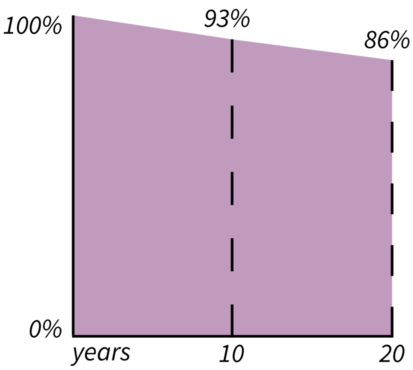
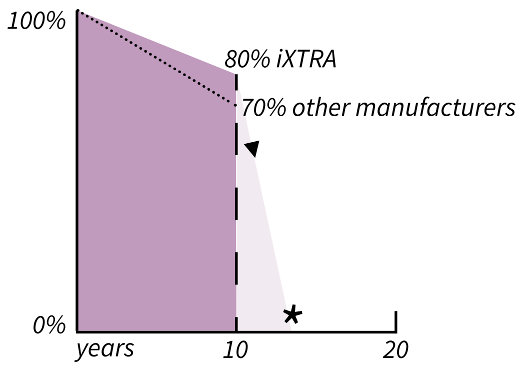
Volume left after 10 and 20 years of self-discharge only (no load)

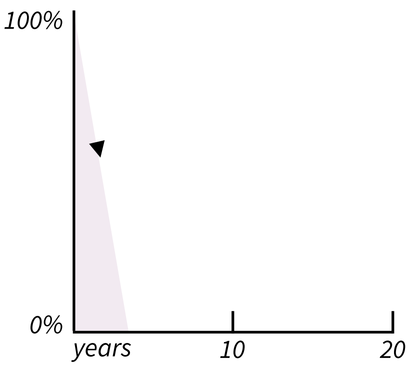


XOL TL-49xx Series



iXTRA TL-59xx series and other manufacturers

**Generally not recommended for applications requiring 10+ year operating life as the average current drawn plus the annual self-discharge rate will cause cell capacity to be quickly depleted, thereby reducing the operating life of the device.*

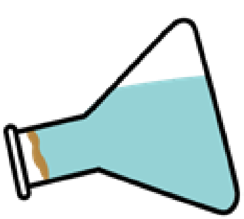


$LiMnO_2$ and alkaline cells

High annual self-discharge rates cut maximum battery life to well under 10 years.

Clogged openings - passivation - prevent flow

- *Low quality fluid / electrolyte can freeze in the opening in cold*
- *Low quality fluid / electrolyte can plug up the opening in the heat*



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Combining low self-discharge with high pulses

PulsesPlus™ batteries combine a standard bobbin-type $LiSOCl_2$ cell with a patented hybrid layer capacitor (HLC) to generate the high pulses required to power two-way wireless communications.

A growing number of remote wireless devices require high pulses of short duration to power data queries and two-way wireless communications. Standard bobbin-type $LiSOCl_2$ batteries can sip small amounts of energy to deliver the low-level background current required during 'stand-by' mode. However, these cells are not designed to generate high pulses due to their low rate design. This challenge can be addressed with the addition of a patented hybrid layer capacitor (HLC) that stores energy to deliver the high pulses required to power two-way wireless communications. The patented HLC also features a unique end-of-life voltage plateau that can be interpreted to generate low-battery status alerts.

Supercapacitors perform a similar function for consumer electronics but are ill suited to most industrial applications due to inherent drawbacks, including: short-duration power, linear discharge qualities that prevent use of all the available energy, low capacity, low energy density, and high annual self-discharge rates (up to 60% per year). Supercapacitors linked in series also require the use of cell-balancing circuits that add expense, bulkiness, and consume additional energy to further accelerate self-discharge.

XOL/HLC in action

- *Heavy flow upon discharge*

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High passivation is difficult to detect

Unfortunately, the cumulative effects of passivation as well as long-term exposure to extreme temperatures typically do not become apparent for years, and predictive models generally underestimate their impact on actual battery operating life.

When an ultra-long-life power source is essential it is important to conduct thorough diligence when comparing competing battery brands. This evaluation process includes the need for all prospective battery manufacturers to provide fully documented test results, along with in-field performance data under similar loads and environmental conditions along with multiple customer references.

AMR/AMI meter transmitter units (MTU) are often buried underground, exposed to extreme temperatures and difficult to access for replacement. Bobbin-type $LiSOCl_2$ cells with passivation minimize the need for future battery replacement, which increases ROI.

Whenever extended battery life is critical it is important to do your homework as a superior quality bobbin-type $LiSOCl_2$ battery can harness the passivation effect to deliver a self-discharge rate as low as 0.7% per year, permitting up to 40-year battery life. By contrast, a lower quality $LiSOCl_2$ cell with higher passivation can exhaust up to 3% of its total capacity each year due to self-discharge, losing up to 30% of its total capacity in 10 years, making 40-year battery life impossible.

Specifying a battery that can last for the lifetime of your device can eliminate the need for future battery replacements, which reduces the cost of ownership while improving product reliability.

Don't be fooled by competing $LiSOCl_2$ batteries that have an annual self-discharge rate of up to 3% .

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