

Is extended battery life an important consideration? Understanding battery self-discharge.

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A growing number of Industrial Internet of Things (IIoT) applications are dependent on remote power to ensure seamless operation. These wireless networks enable real-time access to big-data analytics to enhance workflow, increase productivity, and maximize profitability.

Remote wireless devices are typically powered by industrial-grade lithium batteries that deliver reliable, long-term power to challenging environments. Battery-powered solutions eliminate the need and expense of hard-wiring devices to the AC power grid, which is highly cost prohibitive, estimated at roughly \$100/ft for any type of hard-wired device, even a basic electrical switch. These costs can rise exponentially in challenging environments and hard-to-access locations.

If the remote wireless device draws an average current in microamps it can achieve extremely long operating life by using an industrial-grade primary (non-rechargeable) lithium battery. Conversely, if the device draws an average current in milliamps, it may quickly deplete a primary battery. Therefore, it may make sense to employ some form of energy harvesting device combined with a lithium-ion (Li-ion) rechargeable battery to store the harvested energy.



Bobbin-type LiSOCl₂ batteries have been proven to last 40 years in certain low power applications.

Lithium thionyl chloride (LiSOCl₂) batteries last the longest

Lithium batteries are preferred for long-term deployments because of their high intrinsic negative potential, which exceeds that of all other metals. As the lightest non-gaseous metal, lithium offers the highest specific energy (energy per unit weight) and energy density (energy per unit volume) of all available battery chemistries. Lithium cells operate within a normal operating current voltage (OCV) range of 2.7 to 3.6 V. The fact they contain no water also allows lithium batteries to endure extreme temperatures without freezing.

Numerous primary lithium chemistries are available including iron disulfate (LiFeS₂), lithium manganese dioxide (LiMnO₂), lithium thionyl chloride (LiSOCl₂), and lithium metal-oxide chemistry. Of all these choices, lithium thionyl chloride (LiSOCl₂) chemistry stands apart in terms of offering various performance features that are uniquely suited for long-term deployments, especially in extreme environments. Typical applications include AMR/AMI metering, M2M, SCADA, tank-level monitoring, asset tracking, and environmental sensors, to name a few.



Bobbin-type LiSOCl₂ batteries allow medical RFID tags to undergo high temperature autoclave sterilization without having to remove the battery.

Bobbin-type LiSOCl₂ batteries feature the highest capacity and highest energy density of any lithium cell, along with an extremely low annual self-discharge (under 1% per year for certain cells), thus permitting up to 40-year battery life. They also deliver the widest possible temperature range (-80 to 125°C) and feature a superior quality glass-to-metal hermetic seal. In addition, specially modified bobbin-type LiSOCl₂ batteries can be adapted for the cold chain, where wireless sensors continuously monitor the transport of frozen foods, pharmaceuticals, tissue samples, and transplant organs at temperatures as low as -80°C.

Bobbin-type LiSOCl₂ batteries are also unique in their ability to handle high temperatures. For example, these batteries are utilized in active RFID tags that track the location and status of medical equipment without having to remove the battery prior to autoclave sterilization, where temperatures can reach 125°C.

Lower self-discharge is crucial

Extended battery life reduces the total cost of ownership. Much attention is being drawn to boosting battery operating life through the use of low-power chipsets and communication protocols. However, the potential energy savings involved do not come close to equaling the energy losses that result from annual battery self-discharge.

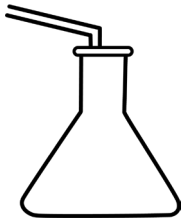
Self-discharge is a natural phenomenon that affects all batteries, as chemical reactions occur even when the battery is in storage and not being used. Self-discharge rates vary due to factors such as the current discharge potential of the cell based on its design, the quality and purity of the raw materials, and the ability of the battery manufacturer to carefully control battery passivation to slow down the chemical reactions that cause self-discharge.

Understanding passivation

Passivation is a thin film of lithium chloride (LiCl) that forms on the surface of the lithium anode, creating a high resistance layer between the electrodes, thereby restricting chemical reactions that cause self-discharge. When a load is placed on the cell, the passivation layer causes higher resistance, which can cause the cell's voltage to dip temporarily until the discharge reaction slowly removes the passivation layer. This process repeats itself each time the load is removed.

Different factors can influence passivation, including: the current capacity of the cell, length of storage, storage temperature, discharge temperature, and prior discharge conditions, as partially discharging a cell and then removing the load increases the amount of passivation relative to when the cell was new.

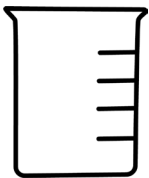
Bottle Examples



*Low flow/
low self-discharge*



*Medium flow/
medium self-discharge*



*High flow/
high self-discharge*

Passivation is the tool that limits the self-discharge of the battery. Unfortunately, it also restricts the potential energy flow rate of the cell for usage.

Balancing passivation and energy discharge is what sets battery designs apart

While passivation is necessary to reduce the self-discharge rate of the battery, too much will restrict the energy from flowing when you need it. Little passivation will allow for a greater flow rate, but also a much higher self-discharge rate and a shorter operating life.

Comparing the effect of passivation on self-discharge and energy flow is like comparing

bottles of fluid 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 lead to plugging the opening which will cause flow stoppage/passivation
- Low liquid/electrolyte quality can cause evaporation/self-discharge
- Lithium Thionyl Chloride (LiSOCl₂) batteries have “small openings”
- LMNO₂ and alkaline cells have “larger openings” that enable higher flow rates but also lead to more evaporation/self-discharge
- Large openings are good for fast flow/discharge but not for storing fluid for a long time
- For long operating life you need a small opening for low evaporation/self-discharge
- Opening size/battery design is a critical issue - too large an opening can cause too much evaporation/self-discharge; too small an opening there is no flow and the opening can be clogged (passivation)
- Fluid/chemistry quality is imperative to keeping impurities/passivation low

Comparative flow rates

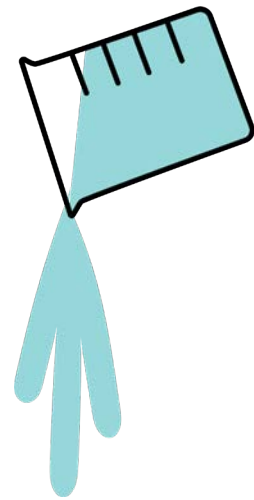
XOL TL-49xx Series



iXTRA TI-59xx series and other manufacturers



LMNO₂ and alkaline cells



Comparative evaporation/self-discharge rates

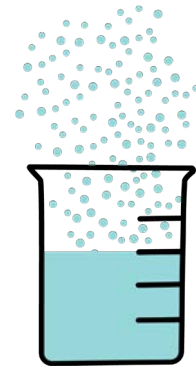
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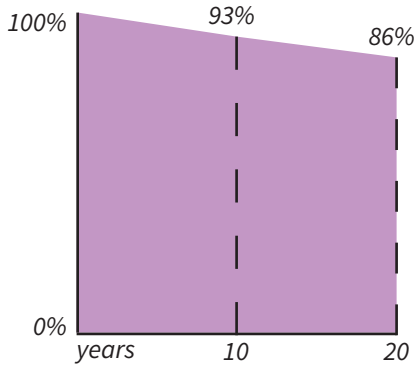
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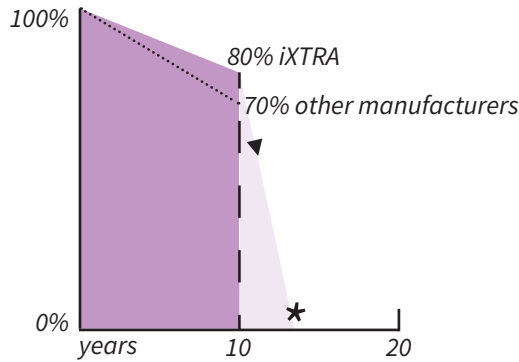
LMNO₂ and alkaline cells



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

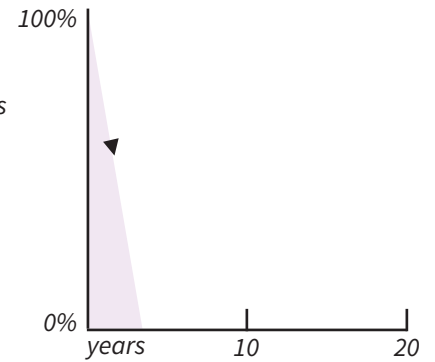


XOL TL-49xx Series



iXTRA TI-59xx series and other manufacturers

**Generally not recommended for applications requiring 10+ year operating life where the average daily current drawn to operate the device plus the annual self-discharge rate will deplete cell capacity to a point so low that compromises long-term reliability.*

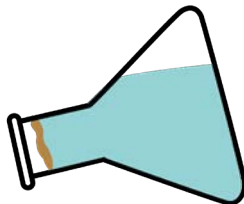


LMNO₂ and alkaline cells

High annual self-discharge rates make 10+ year battery life impossible.

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



When you need both low self-discharge and high flow/pulses



PulsesPlus™ batteries combine a standard bobbin-type LiSOCl_2 battery with a patented hybrid layer capacitor (HLC) to deliver periodic high pulses.

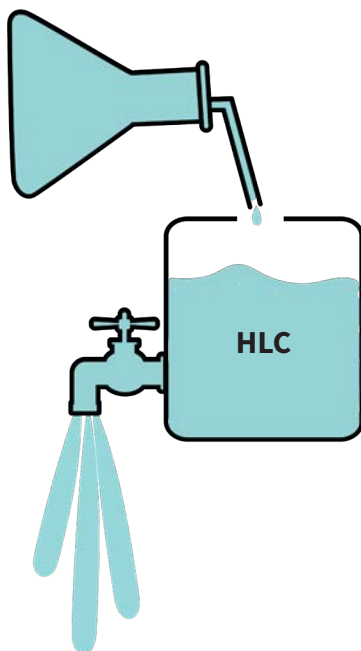
A standard bobbin-type LiSOCl_2 battery cannot deliver high pulses due to its low rate design. However, this can be easily overcome by incorporating a patented hybrid layer capacitor (HLC). The standard bobbin-type LiSOCl_2 cell delivers low daily background current while the HLC handles periodic high pulses. The patented HLC also features a special end-of-life voltage plateau that can be interpreted to deliver low-battery status alerts.

Supercapacitors can also deliver high pulses electrostatically rather than chemically. However, supercapacitors are generally unsuited for industrial applications due to inherent drawbacks such as 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, which add to their cost and bulkiness and consumes energy, which further raises their self-discharge rate.

High pulse requirements invariably draw more average daily current, so various techniques are often used to reduce daily energy consumption. These techniques include the use of low-power communications protocols (ZigBee, WirelessHART, LoRa, etc.), low-power microprocessors, and being speedy and efficient when sampling and transmitting data.

XOL/HLC in action

- Heavy flow upon discharge



Testing for self-discharge can be misleading

The impact of a higher self-discharge rate may not become apparent for years, and theoretical test data generally under-represents the true effect of passivation and long-term exposure to extreme temperatures. If your application demands long-life power, then you must be thorough in conducting your due diligence when evaluating potential battery suppliers. Ask for fully documented long-term test results and in-field performance data from similar applications, along with customer references.



AMR/AMI meter transmitter units (MTU) are often buried underground, exposed to extreme temperatures and difficult to access for replacement.

For example, access to accurate long-term test data is essential when specifying a long-life bobbin-type LiSOCl_2 battery for meter transmitter units (MTUs) used in AMR/AMI utility metering applications it pays to choose wisely, as a large-scale battery failure can disrupt customer billing systems and disable remote service start-up and shut-off capabilities. The possibility of such wide-scale chaos could force a utility to prematurely invest millions of dollars to replace batteries early so as not to jeopardize data integrity.

How to choose an industrial-grade battery

When specifying an industrial-grade lithium battery, you must take into account various technical requirements, including: the amount of current consumed in active mode (along with the size, duration, and frequency of pulses); energy consumed in stand-by or sleep mode (the base current); storage time (as normal self-discharge during storage diminishes capacity); expected temperatures (including during storage and in-field operation); equipment cut-off voltage (as battery capacity is exhausted, or in extreme temperatures, voltage can drop to a point too low for the sensor to operate); the annual self-discharge rate of the battery (which can approach the amount of current drawn from average daily use).

High temperature applications can be especially problematic to certain chemistries due to the Arrhenius Equation:

Arrhenius equation shows how the rate constant of a chemical reaction is affected by the absolute temperature, a pre-exponential factor, and other constants of the reaction, where:

k is the rate constant,

T is the absolute temperature (in kelvins),

A is the pre-exponential factor, a constant for each chemical reaction,

E_a is the activation energy for the reaction (in the same units as RT),

R is the universal gas constant.

$$k = Ae^{\frac{-E_a}{RT}}$$

According to this equation, a temperature rise of +10°C will cause the self-discharge rate to double. Fortunately, specialized bobbin-type LiSOCl₂ batteries are available that can handle extreme temperatures without experiencing a major drop in performance and/or accelerated self-discharge.

Where extended battery life is essential, you must be extra careful to perform added due diligence, as battery manufacturer claims may be highly misleading, failing to take into account the true impact of passivation and elevated temperatures.

A superior quality bobbin-type LiSOCl₂ battery can achieve the lowest possible annual self-discharge rate to lower your cost of ownership over the life of the device. But remember, when calculating your true cost of ownership, make sure to include all anticipated expenses related to future battery replacements, along with the risks and expenses associated with premature battery failure.