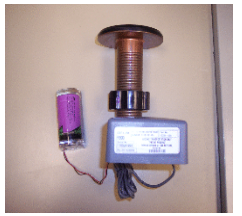
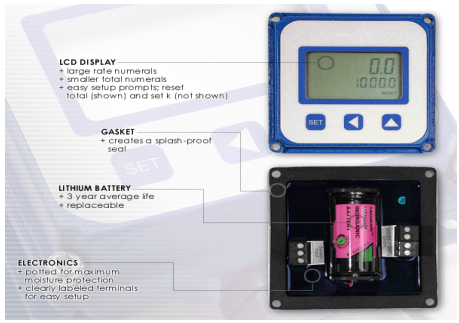
TADIRAN BATTERIES

Understanding Battery operating life





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Batteries are like bottles

The same volume of liquid can be in different types of containers

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The comparison

- 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
- 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 batteries have “small openings”
- LMNO2 and alkalines have “larger openings”

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What effects how long fluids in bottles can last

1. How quickly they are poured out – FLOW RATE
2. How much they evaporate – SELF DISCHARGE
3. How long the fluid stays pure and can still be used (impure liquids will not be used) - PASSIVATION

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Long operating life is all about the bottle opening

- Large openings are good for fast flow/discharge but not for storing fluid for a long time
- For long operating life you need small opening for low evaporation/ self discharge
- Opening size / battery design is a critical issue - too large an opening and more evaporation/self discharge, too small an opening and there is no flow and the opening can be stuffed up (passivation)
- Fluid/chemistry quality is imperative to keep impurities/passivation low

Bottles with larger openings

- Are like higher rate batteries – spiral lithium thionyl chloride, LMNO2, alkalines
- Larger opening allows for higher flow
- Higher evaporation/ capacity loss
- Higher fluid surface area – can lead to contamination/passivation
- Heat causes faster evaporation/ capacity loss and fluid contamination/ passivation
- Cold causes surface to freeze – no flow

- **To gulp**

Bottles with smaller opening

- Can not flow out fast
- Less evaporation/ self discharge
- Less contamination at fluid surface

- **To sip**

Comparative opening sizes

XOL TL-49XX series

iXTRA tl-59XX series and most competition

LMNO2 and alkaline cells

Comparative evaporation / self discharge rates

XOL TL-49XX series

iXTRA tl-59XX series and most competition

LMNO2 and alkaline cells

Comparative flow rates

XOL TL-49XX series

iXTRA tl-59XX series and most competition

LMNO2 and alkaline cells

Volume left after fastest flow rate (bottle with largest opening empty)

XOL TL-49XX series

99.99%

iXTRA tl-59XX series and most competition

90%

LMNO2 and alkaline cells

N/A

Volume left after 10 years of self discharge only - no load

XOL TL-49XX series

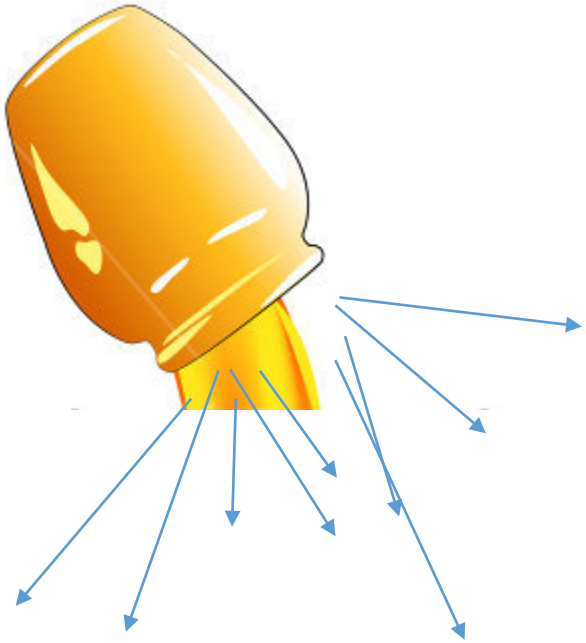
93%

iXTRA tl-59XX series and most competition

80% for IXTRA cells

70% for competition

LMNO2 and alkaline cells



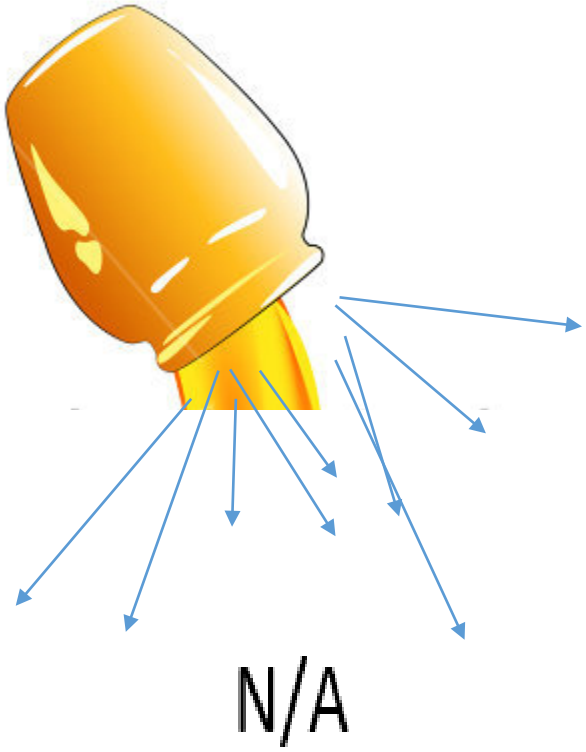
N/A

Volume left after 20 years of self discharge only – no load

XOL TL-49XX series

iXTRA tl-59XX series and most competition

LMNO2 and alkaline cells



Clogged openings – passivation - prevent flow

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

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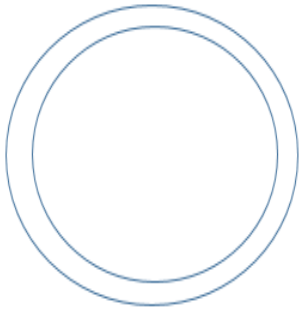
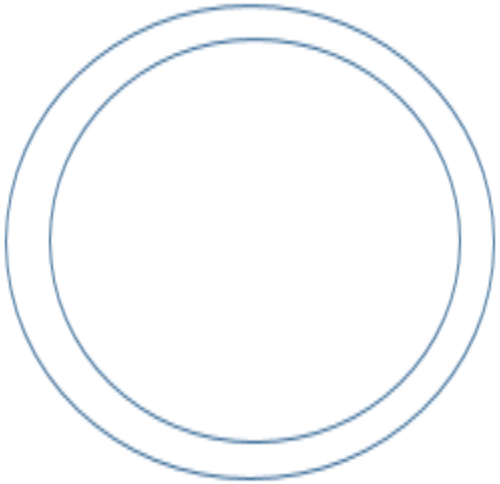
Cross sectional view of container openings

XOL TL-49XX series

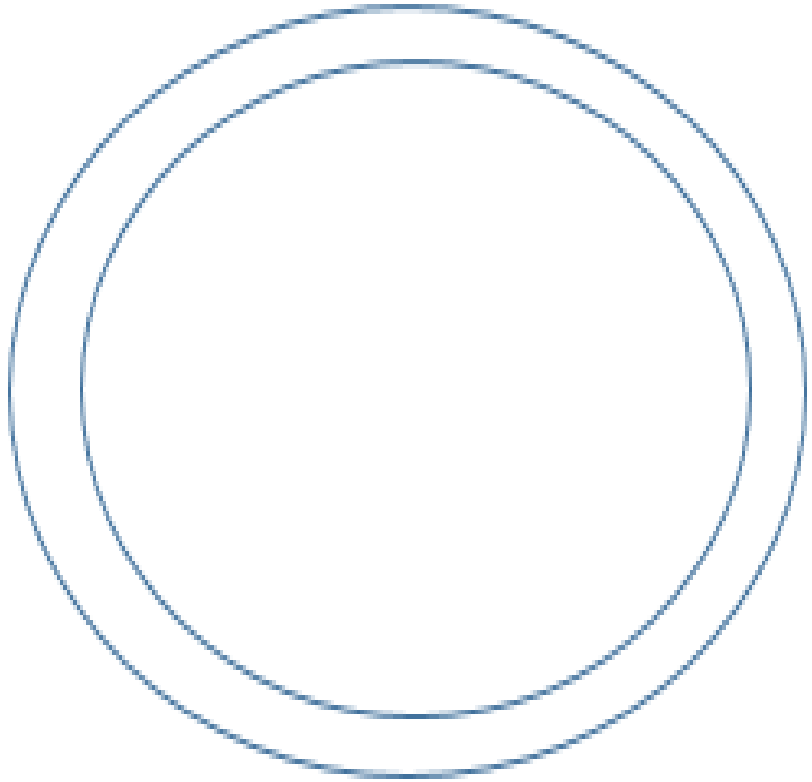


iXTRA tl-59XX series



Low cost competing lithium cell with clogging/passivation

LMNO2 and alkaline cells



Liquid/ electrolyte quality effects self discharge

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Competition

Seal quality effects battery life

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Competition

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When you want long life with occasional big gulps

- You pour from a bottle with a small opening into a glass with a big opening
- You connect a bobbin cell (small opening) to a energy storage device with a big opening (HLC or supercap)
- You must add self discharge of energy storage device to that of bottle

Lithium/supercap hybrid

- Both cheap lithium and supercaps have individual self discharges

The XOL/HLC hybrid – high flow with small opening

- XOL and HLC both have low self discharge
- Closed system – no discharge/leaks

XOL/HLC in action

- Heavy flow upon discharge

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How do you test long life batteries?

- 1. **ACTUAL LONG TERM TESTING -** Cells are tested for extended periods of time.
- Tadiran has batteries that are still in test for over 24 years and still running. Tests are run under different loads and test profiles. Many cells of different ages are running concurrently in the lab.
- 2. **ACCELERATED TESTING** - using a method called Arrhenius test (two-fold increase of reaction rate for every 10 degree C) we can lower the amount of time needed to run tests on very long term applications. In this situation tests are run at 72C which is the equivalent of about 32 times the lifetime of operations at 22C. It is important to understand how to run this test and read results as an inferior cell that suffers from passivation would show false positive results. For this reason it is important to not just store a cell at 72C and then test, but to actually test the cells during the 72C storage. The following is one example of this type of testing:
- Cells are tested at 72C for one month at the one month rate (using the cells up), others at 2 months at the 2 month rate, others for 3,4,5,6 month rates and some at the 1 year rate. At the one and two month rates our XOL cells show very low capacities because they are not meant to be used quickly (see an earlier paper I sent you explaining how a lithium battery can have a high usage rate or low self discharge rate but NOT both). Our IXTRA cells and some of our competitors might show higher capacities at these fast rates but their self discharge rate will be higher in other tests.
- Starting with the 3 month test at the 3 month rate at 72C (which is the equivalent of 8 YEARS at 22C) the higher self discharge of competing cells starts to show and we can see how Tadiran's cells start to have higher operating life capacity. The longer the test and the lower the usage rate the more the Tadiran cells start to outlive the competition since less capacity is lost to self discharge.
- Tadiran also has tests running on cells for 90 months at 72C (the equivalent of HUNDREDS OF YEARS).
- 3 **CALORIMETER TESTING**. Calorimeters test self discharge of a battery by seeing any rise in temperature of water around a battery due to its self discharge. This is run after a battery has completely stabilized for a period of a year before it is placed in the device.

Testing cont.

- 4. **FIELD RESULTS** - our calculations continue to be proven correct by actual results from the field. Tadiran closely follows each application for accuracy and will often check random samples of batteries in long term use in a device to see if the amount of lithium left in the battery coincides with the results from the lab. Another way to determine the results of actual field usage compared to design is with the number of FITs (Failures In Time, in BILLIONS of device operating hours) of our cells in the field. Our overall average is between 5 and 20 which is very low, meaning our design criteria is very accurate.
- 5.**LITHIUM TITRATION** – for special cases with unusual requirements where we might not have data points available (temperature extremes, prolonged high current pulses, short life time applications etc.) we check the remaining content of the lithium anode in the battery after specific test conditions (e.g. partial discharge, temperature soaking and so on).
- For example, after a battery has been tested for several months under elevated temperature and various discharge currents, it is cut open to dissolve its remaining lithium to calculate from the titration results its self discharge as a function of the applied currents and/or temperature. The higher the self discharge the lower amount of lithium remaining in the cell.
- 6. **COMPETITIVE TESTING** - Tadiran runs similar lab tests on batteries made by other manufacturers as a comparison. When running tests on other batteries the battery should have been used for about a year before testing. This will show the influence of any impurities in the electrolyte during the test. Tadiran probably knows more about other manufacturers' batteries that they know themselves.

- **When you consider that Tadiran has covered over 100000 application points, has tested the equivalent of over 10 THOUSAND operating years in the lab and has double checked its results with decades of data from the field you can see why we are so confident that our products will last as long as you need them to.**

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Conclusions I

- We all know that this is just an analogy, but it explains why Tadiran's technology and quality are the best
- Bottle opening (flow rate and self discharge rate), liquid quality and technology (passivation and self discharge) and seal quality (self discharge) are all important factors in bottle/battery design
- When clients run a fast test between Tadiran's XOL and cheaper competition they only tend to look at the "liquid" poured and not what is left in the bottle.
- Battery self discharge is in heat dissipation and not evaporation except for low quality high rate cells which use crimped seals (Tadiran uses laser welding and glass to metal seals)

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Conclusions II

- In short term tests self discharge is not much of a consideration but in real life long term applications self discharge is the major concern.
- In order to really test for self discharge you need to run the test for YEARS.