Latest Technology Improvements in Thermal Batteries

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Introduction

This document review legacy technologies for thermal batteries and latest improvement concerning:

- a safer activation with laser igniters,
- a higher thermal stability,
- an increase in operating life.

What is a thermal battery?

A thermal battery is a primary electrical source which needs no maintenance due to a long storage life (>15 years). It is a "plug and play and forget" device. Like any battery, it is based on a voltaic stacking of cells. The main difference with other technologies is that the cells are fully inert and non conductive at room temperature, providing the almost no ageing and thus the long storage life. A heating system, based on heat pellets (made of a redox mixture), is added. Upon activation, the heat pellets "burn" and heat the cells up. The cells become conductive and power is available. The activation time is of the order from 0.1 to 3s depending on load upon activation and thickness of the cells (that is energy of the battery). A thermal battery is, and will remain throughout the discharge, a sealed container, being thus very safe. Moreover, being inactive before activation, it is a technology of choice for high voltage. There is indeed no risk during handling as no power is available.

A thermal battery can deliver from a few to hundreds of volts and from a few milli-amperes to hundreds of amperes. Current densities have been achieved up to 7-8 Amp/sqcm. One further advantage of thermal batteries is that they accept high reinjection current densities, up to 7-8 Amp/sqcm while remaining totally safe. This explains why they are the preferred energy source for actuators.

Finally, thermal batteries show high reliability based on experience. The average reliability (successful completion of the mission after storage) is 0.9995.

Legacy technologies

Anodes

There are two groups of technologies. The first one consists of lithium alloys: lithium aluminium (LiAl) on one side and lithium silicon (LiSi) on the other side. The second group consists of pure lithium "trapped" in a metallic matrix: the so called "LAN" technology and the very recently developed "Super LAN" technology. Most thermal battery manufacturers use only lithium silicon whereas ASB and its subsidiaries (MSB in the UK and ATB in the USA) design batteries using all possible technologies to present to the customer the best design in terms of performance, volume and cost. Figures 1, 2 and 3 give a comparison of cell voltage of LiAl, LiSi and "LAN" at 0.1, 0.5 and 1Amp/sqcm respectively.

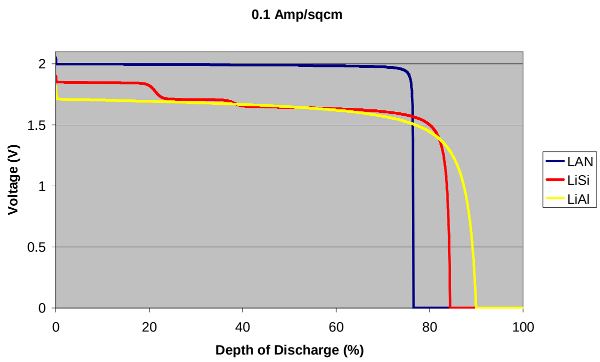

Figure 1: comparison @ 0.1Amp/sqcm

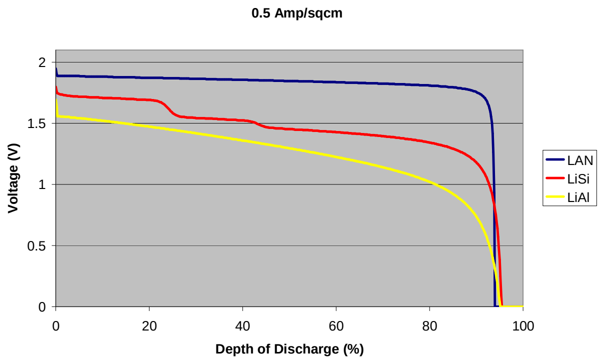

Figure 2: comparison @ 0.5 Amp/sqcm

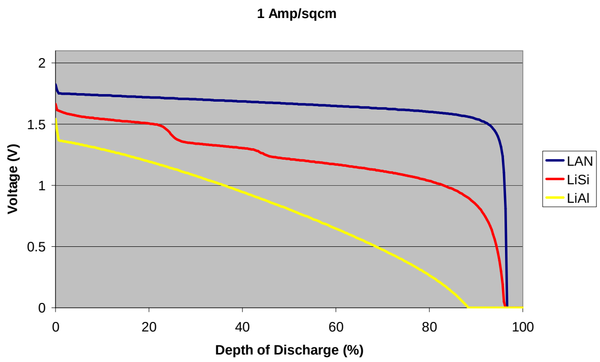

Figure 3: comparison @ 1 Amp/sqcm

It is clear that "LAN" gives the best performances whatever the discharge rate. This is due to its higher cell voltage and its very low polarization, that is voltage decrease on load, even at high depth of discharge (percentage of utilization of the cell capacity). The second best will be LiSi particularly if one can accept a quite wide voltage regulation (range between acceptable minimum and maximum voltage). Nevertheless, in terms of power, LAN is by far the best one with an increase in performance up to 50%, as shown on Figure 4. This is particularly the case at high current densities.

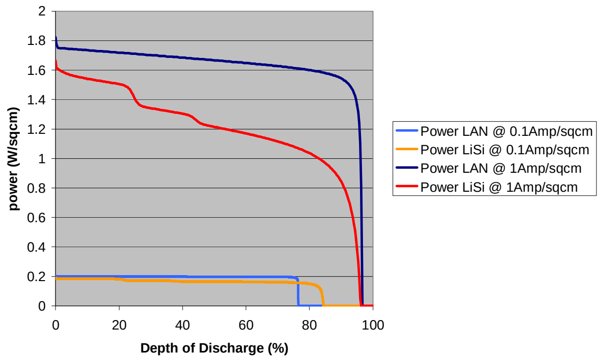

Figure 4 : comparison of power of LAN and LiSi cells @ 2 current densities (0.1 and 1 Amp.s)

To deliver the same power as LAN battery, an LiSi battery will need to be more than 3 times bigger.

LAN thus enables ASB to manufacture high power/high voltage batteries with a much more compact design, compared to other companies.

Cathodes

The standard cathode material is iron disulfide, FeS_2, which is a natural and easily obtainable ore. It has also the advantage of being quite cheap. It has nevertheless limitations in terms of capacity, thermal stability and ability to deliver high constant currents as shown on figure 5.

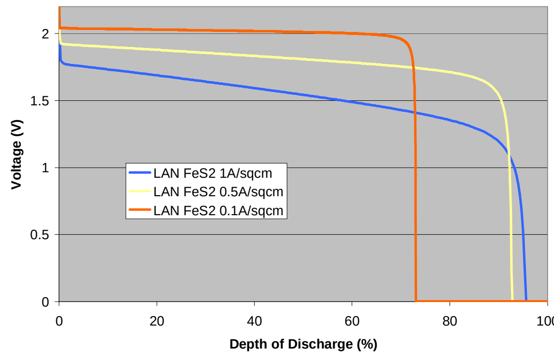

Figure 5: influence of current density on a LAN/FeS_2 cell

Electrolytes

All thermal batteries use lithium salts mixed in a matrix to obtain a good retention, particularly under severe mechanical environments. State of the art electrolyte formulations are full ternary ones (mixture of three different lithium salts) to provide high conductivity and low polarization under heavy loads.

Recent improvements

Improvement in thermal stability

ASB has developed a new cathode technology, a proprietary formulation called **MS_2**. In conjunction with LAN or the improved anode "Super LAN" (described underneath), **it enables to design much safer batteries with an enhanced ability to operate at high temperature**.

Figure 6 shows the weight loss as a temperature is increased, for both FeS_2 and MS_2.

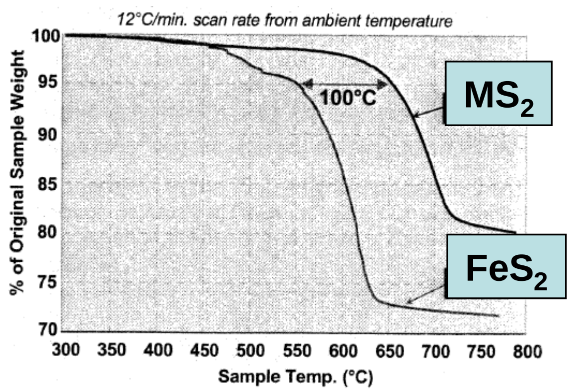

Figure 6 : Weight loss as a function of temperature

Figure 7 shows the increase in thermal stability of MS_2 compared to FeS_2, when tested in a battery environment.

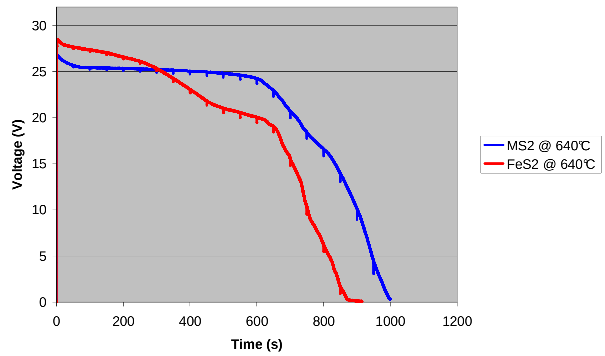

Figure 7: comparison FeS_2/MS_2 @ very high cell temperature (640°C)

The operating life of the battery is almost doubled when using MS_2.

Improvement in safety

Safety can also be improved by replacing the standard hot wire electrical igniters by laser igniters. This improves

- the electromagnetic compatibility of the battery with the system and its electromagnetic environment
- the ability not to ignite at high temperatures (up to 400°C).

An optopyrotechnical igniter was developed by ISL, the French-German Research Institute of Saint-Louis. As shown on figure 8, it was integrated on a standard thermal battery and successfully tested.

Figure 8: ISL laser igniter on header of a thermal battery

It is thus now possible to provide thermal batteries where the ignition signal is brought by optic fibre (thus high distance between battery and command post) and without ignition up to 400°C.

Improvements in design also enable to protect the other pyrotechnic components and thus enabling the battery to remain inert (no activation) for several hours at high temperatures (300 to 400°C).

Improvement in current density

Improvements have been made recently by ASB on anode and cathode designs.

On the anode side, **ASB has developed the "Super LAN" technology which is breakthrough in terms of lithium content** while keeping the same electrochemical properties as "LAN". "Super LAN" enables to go well beyond the current useable lithium content in LAN: **from 15% (current LAN standard) to more than 50% (new "Super LAN" standard)**. For a cell with about 30000Amp.s capacity (100Amp during 300s), the percentage of mass saving will be:

Mass	LiAl	LiSi	LAN
Super LAN	-29%	-11%	-15%

In terms of thickness, the reduction will be:

Thickness	LiAl	LiSi	LAN
Super LAN	-28%	-7%	-8%

This is particularly of interest for high power (high voltage) batteries with many cells.

On the cathode side, **the new formulation MS_2 gives about 25% more capacity** per gram of material than the traditional pyrite (iron disulfide FeS_2). In terms of electrochemical properties, this new cathode material gives a much better ability to sustain high power/current densities although with a slight voltage downward shift compared to FeS_2.

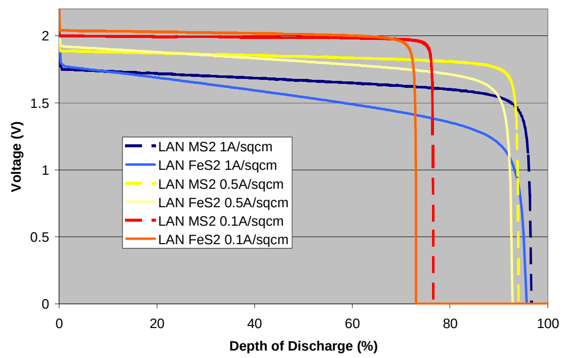

Figure 9: comparison FeS_2/MS_2

Figure 9 illustrates the difference in terms of electrical performance between FeS_2 and MS_2. In all cases, one can observe a better utilization of the cell capacity when one uses MS_2. Besides, there is almost no polarization for MS_2 whatever the current density. This shows that MS_2 will be the cathode material of choice for high power/current applications, with a much more stable voltage and thus a much smaller battery height.

Improvement in operating duration

For many decades, the use of thermal batteries has been restricted to short duration of operation (a few minutes). Major progress has been made recently. **It is now possible to run a battery for one hour and more**. This is achieved by using the new cathode material MS_2 and by improvements in design of the batteries at ASB.

Figures 10 and 11 give examples of discharge of 45 to more than 60 minutes.

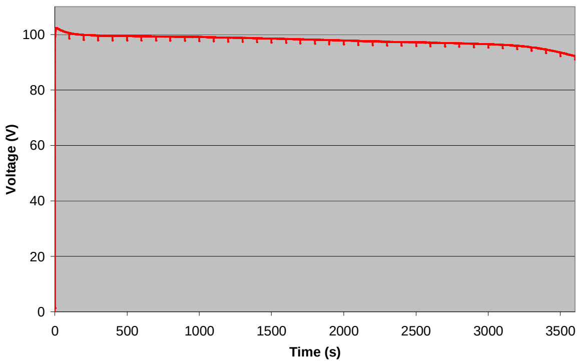

Figure 9: discharge at 1.5kW continuous (60 minutes)

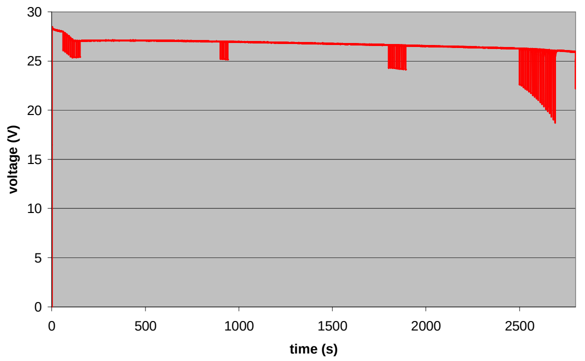

Figure 10: discharge with 500W current pulses (45 minutes)

A new innovative system of thermal management is currently being developed to extend the operating duration from 1 to several hours (target duration is 6 hours).

Conclusion

ASB, MSB and ATB can provide thermal batteries in a wide range of applications, with a fine tuning to customers' requirements. This is possible due to the fact that ASB, MSB and ATB can design with all existing technologies.

The use of LAN or Super LAN in conjunction with a new cathode material and a new laser igniter enables to design thermal batteries with extended operating life in very hot environments. Laser igniter furthermore enables long distance between the battery itself and the command post where the activation is decided.