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Are all Lithium Batteries the Same?

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Very often, lithium technology batteries are all grouped in the same category without any distinction. Yes, a battery is a battery and any battery technology is composed of a grouping of electrochemical cells interconnected in a combination of series and/or parallel configurations to provide the desired voltage and capacity. And yes, lithium technology batteries are in a class apart due to their very high specific and volumetric density as shown in Figure 1. Since its first commercial introduction by Sony in 1991, the lithium ion (Li-ion) battery captured important market shares in electronics applications such as portable phones, camcorders and computers and are now a well known battery technology. Since 2004, a new lithium battery is available on the market: the lithium-metal-polymer (LMP) battery, which should not be confused with the Li-ion polymer technology. The objective of this article is to describe one of the major differences between the LMP batteries and other lithium technology batteries - performance in warm environments.

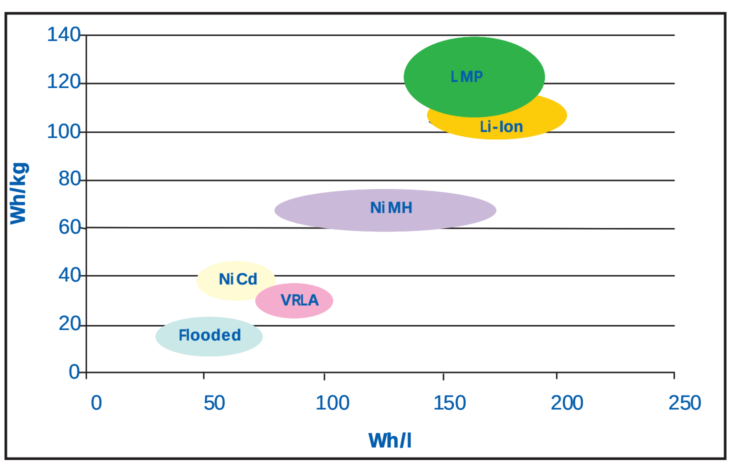

Figure 1 - Specific and volumetric density of different battery technologies

Different Composition and Charge & Discharge Mechanism

To start the differentiation, Figure 2 illustrates different chemistries used in lithium batteries.

Li-ion batteries are composed of cells that employ lithium intercalation compounds as positive and negative materials with a non-aqueous electrolyte. The positive electrode is typically a metal oxide with a layered structure such as lithium cobalt oxide ($LiCoO_2$), on an aluminum current collector. The negative electrode material is typically a layered carbon such as natural graphite, on a copper current collector. Due to the large voltage window of the Li-ion cell, they use electrolyte based lithium salt dissolved in a mixture of organic solvent, like ethylene carbonate with dimethyl carbonate and/or diethyl carbonate that are stable at high oxidation potential. The electrolyte could be in a liquid form or in a gel form to avoid any electrolyte leakage.

	Anode	Electrolyte	Cathode
LMP	Metallic Lithium	Solid Polymer Electrolyte	LiV_3O_8 V_2O_5 V_6O_{13} $LiFePO_4$
Li-ion	Graphite Other Carbon	Liquid Electrolyte Polymer Gel Electrolyte	$Li_{1-x}Co_{1-y}M_yO_2$ (M=Ni, Mg, Al, etc.) $Li_{1-x}Ni_{1-y-z}Co_yM_zO_4$ $LiFePO_4$

Figure 2 - Lithium technology can imply different chemistries

When a Li-ion cell is discharged, the positive material is reduced and the negative material is oxidized. In this process, lithium ions are de-intercalated from the negative materials and intercalated in the positive materials.

The Avestor LMP technology is based on a concept that involves an all solid rechargeable electrochemical generator made from two reversible electrodes physically separated by a dry solid polymer. The anode is an ultra-thin metallic lithium foil that acts as a lithium ion source and current collector. The electrolyte is a lithium-ion conducting membrane that also acts as the separator. The cathode is a composite electrode based on a blend of a reversible intercalation compound of vanadium oxide, carbon black, lithium salt and polymer, backed by a thin aluminum foil acting as a collector.

The result is a totally solid state electrochemical cell, having neither liquid nor gel component, in which near 100 percent of the mass is comprised of electrochemically active materials.

The cell reaction is an intercalation of lithium ions into the vanadium oxide cathode structure during discharge and a de-intercalation of the lithium ions from the charged cathode and deposition on the anode during charge.

$$xLi + Li_yV_3O_8 \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} Li_{y+x}V_3O_8$$

The unique aspect of the LMP technology is that the electrolyte is a solid rubber type film comprised of a dry polymer matrix with an ionic salt complexed into the matrix. This rubber type electrolyte presents key advantages: mechanical separation; a perfect interface with the electrode due to the elastic behavior of the polymer; and elimination of dendrite formation during cycling, which will improve cycle life and safety of the cells.

Main Difference: Performance in Warm Environments

During the initial charge of a Li-ion cell, a decomposition reaction of the electrolyte on the carbon surface of the anode occurs, forming a passivation film, also called a solid electrolyte interface (SEI). This SEI created at the surface of the anode is necessary for the operation of the Li-ion battery; however, when operating or storing the battery at temperatures above 40°C, the SEI film continues to grow on the carbon surface resulting in an irreversible capacity loss mainly due to lithium ions consumption and increase of electrodes' resistance. The electrolyte decomposition is an exothermal reaction that increases the internal temperature of the cell. Depending on the electrolyte composition (salt and solvent nature), at internal temperatures above 80°C this reaction could lead to self heating of the cell.

Due to the accelerated evolution of the SEI, Li-ion batteries operated at ambient temperatures between 40°C and 60°C may experience a capacity fade of 30 percent to 50 percent greater than batteries operated at ambient temperatures between 20ºC and 25°C. When stored at temperatures above 40°C, they also will suffer from significant irreversible capacity loss.

Additionally, this temperature sensitivity is an important limiting factor for designing large format Li-ion batteries. Charging and discharging the battery generates heat that must be dissipated to avoid internal temperature rises. Heat generated internally in a cell usually is transferred by conduction to the external surface of the battery or cell where it is dissipated by conduction or convection. As the battery or cells get larger, the internal heat transfer to the outside is less efficient, leading to higher internal battery or cell temperature, growth of the SEI on electrode's active material surfaces and battery or cell performance degradation.

The Avestor LMP batteries are designed to operate safely at ambient temperatures from -40°C to 65°C and be stored between -40°C to 75°C without affecting their electrochemical performances.

The thermal stability above 40°C of the LMP battery is a major advantage over Li-ion technology that can be explained by the fact that LMP batteries do not contain any organic solvent. The electrolyte is based on a polyether copolymer matrix in which the lithium salt (LiTFSI) is dissolved. This polymer has the reactivity of ether chemical functional group toward the metallic lithium. At the cell assembly a passivation layer, SEI, is formed on the surface of the metallic lithium. Contrary to Li-ion cell in which new solvent molecules and salt could migrate and react at the carbon interface, leading to the growth of the SEI, the solid polymer nature of the electrolyte in an LMP cell will prevent important SEI evolution. The result is a stable interface between the metallic lithium anode and the electrolyte. The very limited evolution of the SEI over time and cycling, confers to the LMP technology a thermal stability. The LMP battery does not present any self heating reaction below 180°C, the melting point of the metallic lithium.

For optimum conductivity of the solid polymer electrolyte, the LMP batteries maintain their internal temperature at 41.5°C (106.7°F) during float and at up to 70°C (158°F) during discharges and recharges. This thermal function is performed by heating elements inserted between battery cells, controlled by an integrated electronic control board and protected against malfunction by a thermal cutoff rated at 98°C.

Applications for LMP Batteries

LMP batteries are being deployed throughout North America by most major telecommunications service providers. Initial deployments of the battery started in outside plant cabinets in which temperatures can easily reach 50ºC during the summer months and where the lead acid batteries were failing quickly and had to be replaced often. Service providers are now taking advantage of several other key characteristics and inherent advantages of lithium-based technologies including the much higher density and lighter weights and longer, more predictable performance. Additional revenue generating equipment is being added to cabinets with the space freed up by using LMP batteries, and some telecommunications providers now are placing LMP batteries outside environmentally controlled cabinets and huts and dedicating this real estate to providing their customers with new, state-of-the-art broadband services.

Lithium-based batteries are not all the same. The intrinsic thermal stability of the lithium-metal-polymer technology makes them best solution of the lithium battery technologies for non-controlled environments, and presents some compelling advantages over traditional lead acid batteries.

Alain Vallée is a highly-qualified expert with a PhD in polymer chemistry. Before moving to Avestor, he was project leader in lithium-metal-polymer battery (LMP) research with Hydro-Québec's research institute (IREQ), where he oversaw a variety of LMP-related research activities and projects. Mr. Vallée holds seventeen patents directly related to LMP technology.

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