Development of Li/MnO₂ Pouch Cell Batteries for Man-Portable Military Communications-Electronics Equipment

Michael T. Brundage

US Army CECOM RDEC, Ft. Monmouth, NJ, 07703, brundagm@doim6.monmouth.army.mil

ABSTRACT

The Army is continuously striving to improve the effectiveness and capabilities of the soldier in the battlefield. To successfully accomplish these goals an increased emphasis has been placed on the use of lightweight, high power demanding communications and electronics devices. These devices require go-to-war power sources (primary batteries) that provide increased power and energy without substantially affecting weight, volume, and cost. This paper will provide a description of the Army’s current primary battery development efforts in Li/MnO₂ pouch cell batteries, as well as a technology comparison with currently fielded Li/SO₂ batteries.

BACKGROUND

The Army’s reliance on electronics and electronic devices has exploded in the past decade. That reliance is becoming even greater as the information age provides more powerful ways to communicate, in both the consumer and military worlds, than ever before. One of the major considerations for implementing these new, more powerful electronics technologies is the power source. The batteries available to the military today cannot power these devices for sufficient durations to make them viable for battlefield operation. The requirements for power in today’s developing electronic systems and tomorrow’s future information age technologies include a doubling of the energy available from the same volume and a 50% increase in the power delivery capability. It became apparent early on that development of higher power, higher energy power sources (primary and rechargeable batteries in this instance) was necessary.

The Army was developing the Li/SOCl₂ technology in the mid 1980’s through the early 1990’s as the replacement technology for Li/SO₂, the currently fielded battery chemistry. Several programs were carried out and prototypes fabricated, tested and demonstrated. Because of concerns with the safety of this system (thionyl chloride is extremely noxious and corrosive and its safety risks could not be minimized or mitigated), and the prediction that it would never become a cost-effective alternative to Li/SO₂ (there was no evidence of a dual use application in the commercial sector for large high power, high energy cells), this technology was eliminated from further consideration as a primary battery solution.

In the mid 1990’s the military shifted its focus from developing unique technology solutions to exploiting those in the commercial sector whenever possible/practical. This was looked upon as a cost-effective approach to maintaining military effectiveness in the face of shrinking budgets. It was during this time that the Li/MnO₂ electrochemistry started to look like a possible solution. At first the only products available were cylindrical cells in smaller sizes, but the technology has progressed into larger cells that are of interest to the military. The Army currently fields a Li/MnO₂ battery for memory backup applications, and this has served as the impetus to develop larger cells with increased power and energy densities.

APPROACH

Every attempt was made to avoid reinventing the wheel for Li/MnO₂ batteries. The initial steps that were taken involved canvassing the commercial and industrial markets to see what was available and identifying those configurations that showed the most promise for military use. Samples were acquired, tested, and evaluated for performance and safety across the military operational temperature range. As expected, all samples were deficient at the low temperature and high rate ranges of the testing, which was not unexpected since these requirements are unique to the military.
L/MnO$_2$ cells are available in two configurations, cylindrical and pouch. Cylindrical cells are currently more common, and are used in a variety of consumer applications such as fully automated cameras. These cells house the internal components in stainless steel or plated cans, and either crimp sealed or hermetically sealed with a coined safety vent. Pouch cells contain the internal components in a multilaminate heat sealable material that prohibits the introduction of air or water into the cell, and the escape of the electrolyte solvents. These cells can be made in practically any shape imaginable, but the main focus is on a prismatic shape to maximize the volumetric efficiency of the battery form factors currently in use. Other battery configurations are being investigated for a wearable power source to further exploit the design flexibility of the pouch cell. The tradeoffs between the cylindrical and pouch cell configurations are currently under evaluation and some comparison data will be presented and discussed later.

Since the commercially available products could not meet all of the performance requirements advanced development is being conducted to achieve the following:

1) Increase power density by designing higher surface area electrodes and increasing cathode density using higher surface area materials.

2) Increase energy density by designing thinner electrodes and improving cathode densification processes.

3) Achieve a minimum of five years of shelf life by designing hermetic multilaminate materials and heat sealing processes.

4) Enhance safety by developing low flammability electrolyte solvents and designing controlled pressure release seals.

WHY Li/MnO$_2$ POUCH CELLS?

One of the major goals of this development program is to come up with an alternative technology that can be packaged into the same battery volumes currently being used. Thousands of pieces of communications-electronics equipment are in the field and to recall them all for a battery box retrofit is expensive and impractical. It is obvious that the best way to fill a prismatic battery box is with prismatic cells. Another goal is to maximize the power and energy contained in the battery box (volumetric energy and power density) without a significant increase in weight. The theoretical energy density of the Li/MnO$_2$ system is 1005 Wh/kg, and that reduces to 270 Wh/kg and 600 Wh/l in a practical cell. The last value (600 Wh/l) is the second highest volumetric energy density among lithium systems except for Li/SCl$_2$, which as described earlier is not a viable alternative. These energy density values in practical cells were for the cylindrical type, so it is expected that the further reduction in energy density due to the inefficiency of filling rectangular boxes with cylinders will not be as drastic when prismatic pouch cells are used instead.

Pouch cells also decrease the amount of inert weight in the cell. The weight savings from using the multilaminate pouch material are offset by adding active materials, which provides more performance. Safety is enhanced because the vent mechanism for the pouch cell is the heat seal, which opens at a much lower pressure and temperature than the coined vent in cylindrical cells. The pouch cell technology also has potential commercial applications for use in RF tagging devices and high capacity laptop computer batteries from which the military battery production can be leveraged. Another example of leveraging commercial technology is the pouch cell material itself, which is a spinoff from the food packaging industry.

CURRENT POUCH CELL DESIGNS

There are currently two cell sizes under development for use in two specific battery types. The first cell size is used in the BA-5590/U box, and the second size fits into the BA-5847/U box. These two batteries were chosen for two different reasons. The BA-5590/U size was chosen because it is the most widely used lithium primary battery in the Army. The improvements achieved in this battery size would have the most significant impact across the widest portion of military battery users. The BA-5847/U was chosen because it is the battery shape of choice for the Thermal Weapon Sight and Land Warrior developmental systems. Both of these systems have high power and energy demands which are not being satisfied by the current Li/SCl$_2$ battery. Development of pouch cell batteries for these systems is the only viable solution to meet their increased power and energy demands.

All pouch cells, regardless of size, are comprised of the same basic components. A Lithium metal anode with Copper current collector and Nickel tab is layered between two sheets of fusible multilayered separator (Polypropylene/Polyethylene/Polypropylene), followed by
the cathode. The cathode is comprised of chemically or electrolytically synthesized Manganese Dioxide, Shawinigan Acetylene Black or other high surface area carbon and/or graphite, and Teflon emulsion as binder, all laminated onto an Aluminum or Stainless Steel current collector with tab. The electrolyte varies in composition, but the major ingredients are typically a ternary combination of Propylene Carbonate (PC) with either DiMethoxyEthane (DME), Tetrahydrofuran (THF), or Dioxalane (DOL) in which either Lithium Perchlorate, Lithium Imide, or Lithium Triflate salt is dissolved. These components are all contained in pouches that consist of a multilaminate of Polyester, Polyethylene, Aluminum, and Surlyn. The pouches are then heat/pressure sealed.

TEST DESCRIPTION

Two separate data sets will be presented. The first set of tests were designed to emulate a training device called the Simulated Area Warfare Effects/Modular Individual Laser Engagement System - II (SAWE/MILES-II). This device does not have stringent power demands (1 A peaks, 240 mA background, average power 7.8 W) for a BA-5590/U application, but has a long duration (energy) requirement (48 h continuous operation). The existing BA-5590/U in 12 V mode delivers 26 hours of operation in the SAWE/MILES-II at ambient temperature. The pouch cell version of the SAWE/MILES-II battery (5 cells in series in the BA-5590/U battery box) delivers 49 hours of operation at ambient temperature, an 80% increase in energy in the same volume. At -30°C the Li/SO₂ battery delivers 19 hours of operation, while the pouch cell battery delivers 28 hours of operation, a 47% increase in capacity (Ah). It is important to note that the pouch cell battery did not experience any voltage delay at the start of this test, primarily due to the low power demand. The energy delivered (Wh) is higher for the Li/SO₂ due to its higher operating voltage and despite its lower capacity.

The second set of tests were designed to emulate the Thermal Weapon Sight (TWS) profile. The duty cycle is a two step discharge at different power levels:

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>Duty Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>-30</td>
<td>8 W constant for 2 minutes then 5 W</td>
</tr>
<tr>
<td>+23</td>
<td>9 W constant for 2 minutes then 6.5 W</td>
</tr>
<tr>
<td>+55</td>
<td>12 W constant for 2 minutes then 9 W</td>
</tr>
</tbody>
</table>

These profiles were run on Li/MnO₂ cylindrical cell and pouch cell batteries. The cylindrical cell batteries contained D cells from Friwo Silberkraft (Germany) utilizing their low temperature electrolyte. The pouch cell batteries contained prototype cells from Power Conversion Inc. (Elmwood Park, NJ) with electrolyte designed to operate at low temperature as well. For comparison, capacities for the BA-5847B/U and BA-5847C/U Li/SO₂ batteries were extrapolated from existing discharge data. The BA-5847B/U utilizes two D cells while the BA-5847C/U uses two short F cells to increase the power capability via higher surface area electrodes.

RESULTS AND DISCUSSION

For consistency the data will be presented in the same order for each different battery: low temperature (-30°C) capacity in hours, ambient temperature (+23°C) capacity in hours, and high temperature (+55°C) capacity in hours. Capacity is expressed in hours of operation because this was the parameter most critical to the user. The values presented are the average for at least three batteries discharged at each test condition, or extrapolations of capacity data from thousands of production tests.

As expected, the Li/SO₂ batteries delivered the lowest capacity, and the D cell version was slightly lower than the F cell version. The D cell version (BA-5847/U) is estimated to deliver 2.8 hours, 4.4 hours, and 3.6 hours, respectively, at the duty cycles described above. Some improvement is estimated in the F cell version (BA-5847C/U) with capacities of 3.5 hours, 5.5 hours and 4.4 hours, respectively. The data for the cylindrical Li/MnO₂ batteries is markedly better than either of the Li/SO₂ versions. Capacities of 4.6 hours, 7.5 hours, and 5.6 hours, respectively, were achieved and exceed the better of the two Li/SO₂ versions by 27-36%. The data for the pouch cell batteries is better still, and is expected to improve since these were developmental (non-optimized) prototype cells. Prototype pouch cell batteries routinely deliver 12 Ah of capacity over a wide range of current drains at ambient temperature, and recent cell level testing has achieved as high as 16 Ah at 2 A at ambient temperature. Over 60% improvement in capacity was observed at all temperatures compared to the best Li/SO₂ data, and 18-26% improvement was shown when compared to the cylindrical Li/MnO₂ data. This latter improvement is a function of improved materials and processing and the increased volumetric efficiency of the pouch cells. Data
for the pouch cells is 5.5 hours, 8.8 hours, and 7.1 hours, and is expected to improve. This data clearly shows the promise of Li/MnO₂ pouch cell technology satisfying rigorous military power and energy requirements.

CONCLUSIONS/FUTURE PLANS/EXIT CRITERIA

Li/MnO₂ pouch cell batteries to date have demonstrated significant increases in power and energy capability compared to existing cylindrical cell Li/SO₂ batteries and modest increases compared to cylindrical cell Li/MnO₂ batteries under the same exact test conditions. However, not all of the questions have been answered concerning this technology. There are still concerns regarding the ability of a heat sealed multilaminate material providing a minimum of five years of shelf life. Safety, the number one priority for any military system, is still an open issue. Exhaustive safety testing will take place in the coming months to accurately characterize the behavior of pouch cell batteries in two cell (BA-X847/U) and ten cell (BA-X590/U) configurations. Safety Assessment Reports will be submitted to CECOM for review and evaluation. These reports, and the test data that accompanies them, will serve as the basis for providing safety releases to allow testing these batteries in field training exercises scheduled throughout the next two years.

The Army plans to continue to develop the Li/MnO₂ pouch cell technology, focusing primarily on optimization of the cell and battery designs for safety, power and energy, and shelf life. Cost-effectiveness analyses will be conducted once final designs are established. At that point tradeoffs will be made within the user community to help fine tune the next generation of primary batteries for the Army.

The exit criteria for this program are to develop Li/MnO₂ pouch cell batteries that:

1) Deliver double the energy of existing Li/SO₂ batteries (Wh/l).
2) Provide 1.5 times the power of Li/SO₂ (3 A + in the BA-X590/U configuration).
3) Enhance safety during use and abuse (eliminate shrapnel and fire).
4) Maximize power and energy without substantially increasing weight (3 lbs max for BA-X590/U, 0.8 lbs max for BA-X847/U).
5) Are cost-effective throughout their life cycle.

It has been and always will be the Army’s mission to provide the soldier with the best available tools and technology to maintain superiority on the battlefield. Continued development of improved power sources plays an integral role in the successful execution of that mission.

ACKNOWLEDGMENTS

The author would like to extend his sincere thanks to Mr. Anthony Pellegrino, Ms. Diane Bennington, and Mr. Daniel Berka for their exceptional assistance and insights in conducting the battery testing and analyzing the data. The author is also grateful to the developers of the Li/MnO₂ technology for their continuous innovation and dedication to this program.