High Power Reserve Battery for Extremely Low Temperature Applications

Lin-Shu Du[1], Art Driedger[1], William J. Epply[1], Kevin Vriarte[1], Jeffrey A. Swank[2], Giuseppe L. Di Benedetto[3], Richard Dratler[3], Lauren A. Morris[3], Andrew G. Warne[3]***

[1] MaxPower, Inc., 141 Christopher Lane, Harleysville, PA 19438
[2] U.S. Army Combat Capabilities Development Command Army Research Laboratory, Adelphi, MD 20783 (retired)
[3] U.S. Army Combat Capabilities Development Command Armaments Center, Picatinny Arsenal, NJ 07806

*Point of Contact (MaxPower, Inc.): ls.du@maxpowerinc.com / 215-256-4575 ext. 115
**Point of Contact (U.S. Army): andrew.g.warne.civ@army.mil / 973-724-6894

Abstract

Medium caliber fuze power source applications require high power density, extremely fast activation times, low temperature operation, and small form factors. The currently used lithium thionyl chloride system exhibits increased viscosity in cold environments, which results in decreased activation speed as compared to higher temperatures. To investigate alternative systems that can meet rise-time requirements across the temperature range, the U.S. Army and MaxPower, Inc. have renewed ammonia reserve battery technologies. Originally retired based on short run time and relatively low load voltage, liquid ammonia-based batteries are the ideal solution for medium caliber fuze applications where long run time is not required. An ammonia-based electrolyte is capable of meeting both temperature and rise time requirements due to its valuable intrinsic properties: strong solvation (high power), low freezing point (low temperature operation), and low viscosity while maintaining high vapor pressure (fast activation). Historically, the ammonia battery has demonstrated rapid activation (reaching 10 ms) in application temperatures from +160 °F to -65 °F (+71.1 °C to -53.9 °C). Dynamic forces that aid cell wetting during activation are assisted by the high vapor pressure of the system's liquid ammonia electrolyte. MaxPower, Inc.'s research exceeds previous limitations of the ammonia battery. In this presentation, various cathode fabrication processes and key parameters will be discussed. Additionally, MaxPower, Inc. has identified two cathode candidates that provide higher load voltages than the conventional ammonia battery cathode. Lastly, a 3V lithium-containing ammonia battery has been demonstrated for the first time. Strategies to improve the compatibility between ammonia and the lithium-based anode will be discussed.

Keywords

Liquid ammonia battery; lithium ammonia battery; reserve battery; high power battery; extremely low temperature operation

Introduction

There exists an area of improvement with low temperature activation of medium caliber fuze power sources. The typical lithium thionyl chloride system has high viscosity in cold environments which slows the activation process. This creates an opportunity for an alternative solution that can improve rise time across a large temperature range. To address this challenge, MaxPower is proposing the reintroduction of the ammonia reserve battery. This battery has a history in reserve battery applications where it demonstrated rapid activation at temperatures from +160 °F to as low as -65 °F (+71.1 °C to -53.9 °C).[1] Ammonia reserve batteries first made their debut in 1947 and saw continued use through the 1960s until being supplanted by lithium primary systems. Lithium primary batteries became the system of choice due to higher energy densities and lower electrolyte vapor pressures. However, some applications such as medium caliber munitions may have a need for extremely fast activation, high power densities, and low temperature operation; the requirements of which lithium and thermal batteries cannot fully meet. Liquid ammonia-based batteries are the perfect solution for medium caliber and other fuze applications that do not require long operation time but require fast activation time and high power, especially at low operating temperatures. Using ammonia as the electrolyte solvent yields significant benefits due to its valuable intrinsic properties, such as low viscosities with high vapor pressures (fast activation), strong solvation ability (high power) and low freezing point (low temperature operation). Furthermore, reduced dynamic forces that normally aid cell wetting during activation are also driving the need for cells that utilize a high vapor pressure electrolyte, such as ammonia.

High Voltage Cathode Materials

MaxPower has rejuvenated the ammonia battery chemistry that was developed by Honeywell more than 55 years ago. A new cathode chemistry has been further developed to increase load voltages. MaxPower has discovered two new patent pending cathode materials that perform better (higher load voltages; See Figure 1) than the meta-dinitrobenzene (m-DNB) cathode used by Honeywell for mass production.[2] MaxPower developed cathodes that help to provide outstanding rate performance. Figure 2 shows that one of the cathodes can handle current density of 150 mA/cm^2 with load voltages above 2V at ambient temperature. The significant voltage decay is shown when discharged at 150 mA/cm^2. The performance can be further improved by using a high salt concentration electrolyte (HSCE), indicating the decay is due to concentration polarization.

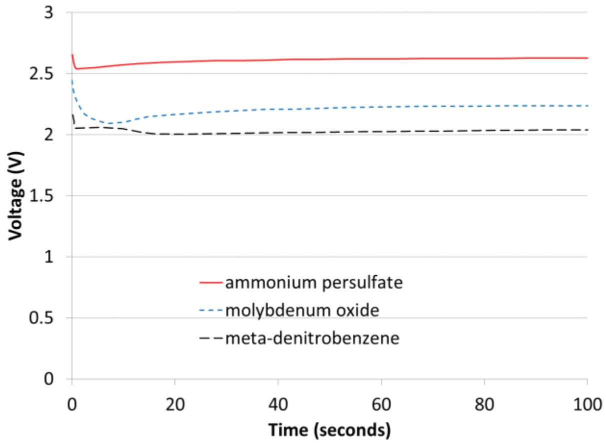

Figure 1: Discharge time vs. voltage for Mg ammonium batteries with MaxPower developed cathode materials and the baseline cathode material discharged at 10 mA/cm^2 at -49 F (-45 °C).

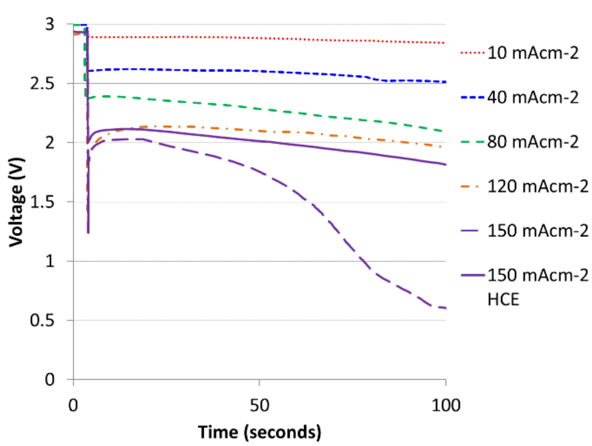

Figure 2: Discharge time (first 100 seconds) vs. voltage for MaxPower's Mg ammonia battery discharged at 10 to 150 mA/cm^2 at ambient temperature.

Electrolyte enabling Lithium Ammonia Batteries

MaxPower has also successfully demonstrated for the first time that lithium metal can be used as the anode in the ammonia battery to further increase the load voltage. Magnesium is known to be the only metal among alkali and alkali earth metals that is stable in ammonia and is therefore the choice of anode in the ammonia battery. When in contact with ammonia, lithium metal forms lithium ion and solvated electron (so-called lithium blue; see Figure 3a) which is very reactive and can immediately react with cathodes and sometimes could lead to explosion. MaxPower has successfully developed a patent pending high concentration electrolyte (HCE) that can inhibit the formation of lithium blue (see Figure 3b) and successfully demonstrate the lithium-based ammonia cell with much improved load voltages.[3]

Figure 4 shows the discharge profile of a Li-based ammonia cell at 40 mA/cm^2 at ambient temperature. The load voltage reaches 3V with the lithium-based cells having 30 ms of rise time.

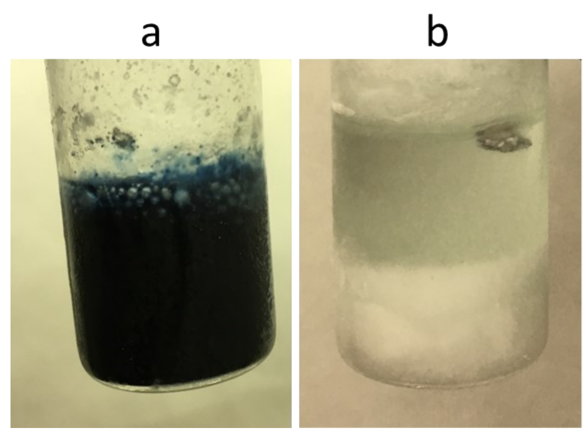

Figure 3: Images of (a) Li reacts in ammonia at -108 °F (-78 °C), forming Li blue and (b) Li is stabilized in a saturated ammonia electrolyte.

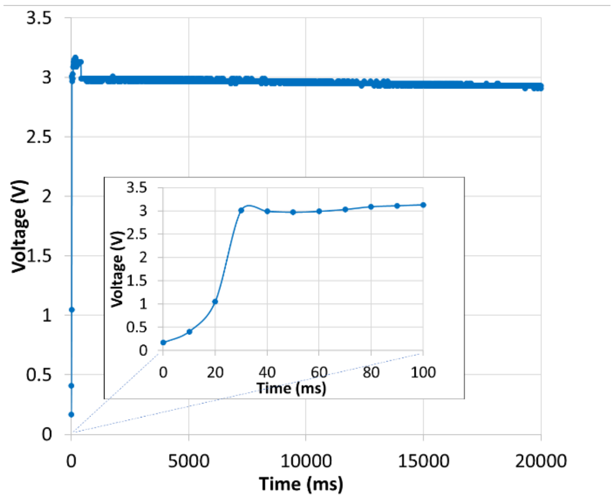

Figure 4: Discharge profile at room temperature at 40 mA/cm^2 of a Li based liquid ammonia cell. The inserted plot is the discharge profile during the first 100 ms.

Anode Stabilization

Besides using HCE to stabilize the lithium anode and to enable the high voltage lithium-based ammonia battery, MaxPower has additionally developed patent pending lithium alloying based anode materials that can be used along with the electrolyte having lower salt concentration.[4] The cell voltage when using Li alloy is comparable to that when using lithium metal. Strategically, enabling the use of lower salt concentrations can provide faster rise time due to the relatively lower electrolyte viscosity especially at extremely low temperatures.

Battery Design

A 3-cell battery with a cell diameter of 18mm and length of 35mm. The battery design is shown in Figure 5 where the cell holder design concept has been proposed to provide easy cell assembly and minimize intercell leakage. The 3-cell Mg-based ammonia battery shows good performance at room temperature as well as at -40 ºF (-40 ºC) (Figure 6). The rise time at -40 ºF (-40 ºC) is 20 ms (see inserted figure in Figure 6).

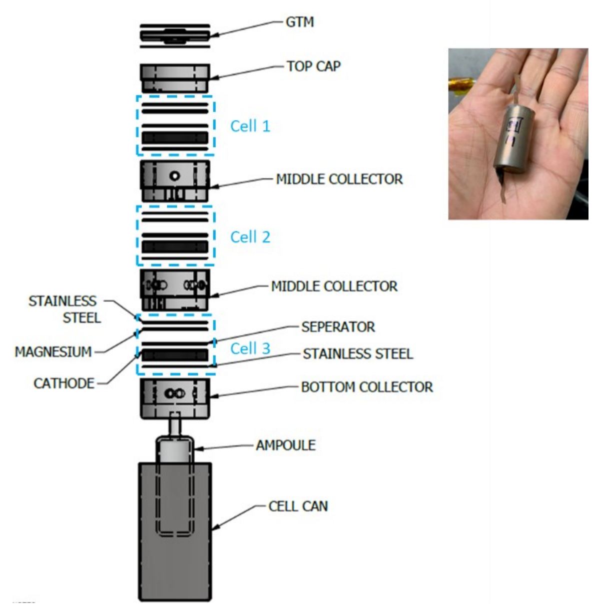

Figure 5: MaxPower developed 3-cell Mg ammonia battery with the cell holder design.

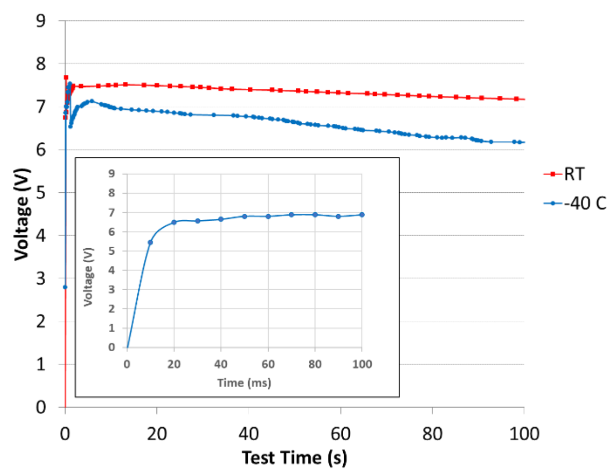

Figure 6: Discharge time (first 100 seconds) vs. voltage for MaxPower developed Mg-based 3-cell battery, discharged at 40 mA at room temperature (RT) and -40 °F (-40 °C). Inserted figure shows the voltage response at -40 °F (-40 °C).

.

Conclusion

The liquid ammonia battery provides high power and fast response time (rise time) at low temperatures and therefore can meet the needs for the medium caliber reserve battery applications. MaxPower has developed high voltage cathodes that are ~0.5 V higher than the baseline m-DNB cathode. The cathode can operate at exceedingly high current densities (150 mA/cm^2). In addition, MaxPower has demonstrated, for the first time, a stable 3V lithium-based ammonia battery via the use of high salt concentration electrolyte and alloy anodes to improve the electrolyte and anode compatibility.

Acknowledgements

This research was funded and supported by U.S. Army DEVCOM Armaments Center and under the NJIT index (997039 2018-2019) and Army SBIR (W911QX-18-P-0158, 2018-2019; W911QX-20-C-0018, 2020-2022).

Reference

1. W.C. Spindler "Ammonia Batteries", U.S. Naval Ordnance Laboratory, 1965.
2. L.-S. Du, N. Aulicino, A. Driedger, J. Pastore, G.L. Di Benedetto and J. Swank, "High Voltage Cathode Materials for Non-aqueous Ammonia Based Primary and Reserve Batteries", US Patent US 20220328848A1.
3. L.-S. Du, J. Pastore, N. Aulicino, A. Driedger, G.L. Di Benedetto and J. Swank, "Non-aqueous Ammonia Electrolytes for Lithium Anode Based Primary and Reserve Batteries", US Patent Application # 17/300,843.
4. L.-S. Du, A. Driedger, C. Shen, K. Vriarte, W. J. Eppley, B. Hayes-Oberst, G.L. Di Benedetto and J. Swank, "Lithium Alloy Based Anode for Non-aqueous Ammonia Primary and Reserve Batteries", US Patent Application # 17/803,259.