HEAT TOLERANT NiMH BATTERIES FOR STATIONARY POWER

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ABSTRACT

Exposure to elevated temperatures is a key contributor to premature battery failure. Unfortunately, in some applications, such as outdoor telecom cabinets, heat exposure cannot be avoided. While air conditioning is commonly provided to reduce operating temperatures, this creates significant operating and maintenance expenses for the user.

Advances in the active electrode materials of nickel metal-hydride (NiMH) batteries for consumer electronics and hybrid electric vehicles have resulted in dramatically improved operating life at temperatures in excess of 120°F. These advances are equally applicable to the use of NiMH chemistries for stationary energy storage. When so applied, a NiMH battery solution could significantly increase battery life, and result in fewer battery replacements and reduced operating costs. Ten year battery life might be possible in an outdoor cabinet in Phoenix, AZ without climate control.

As increasing numbers of companies look for ways to reduce operating expenditures and "become green", NiMH batteries may provide an attractive alternative for telecom, UPS, and other energy storage applications. Recognizing that in addition to performance and cost, safety and reliability are key considerations in these applications, NiMH batteries have proven themselves in consumer and hybrid electric vehicle use. Over 2 million hybrid electric vehicles powered by NiMH batteries have been placed into service since 1997 and have demonstrated that NiMH technology performs under a wide variety of abusive conditions with an operating life matching that of the vehicle.

INTRODUCTION

Small rechargeable nickel metal-hydride (NiMH) batteries were introduced to the portable electronics market in 1987. The advent of digital cameras brought the technology to the forefront where it dominated portable consumer electronic devices for many years before giving way to lighter-weight lithium ion technology. However, with significant improvements in charge retention, the consumer market today embraces NiMH as a replacement for disposable alkaline batteries, a market that is growing at a rate of 30-40% annually.

Ten years after its market introduction for consumer electronics, NiMH batteries became the enabling technology for hybrid vehicles. With over 2 million vehicles placed into service since 1997, the NiMH batteries they contain have demonstrated exceptional reliability, safety and performance. Despite the recent high publicity of Li-ion batteries for plug-in hybrid vehicles, the fact remains that commercial hybrid vehicles on the road today use NiMH batteries and major manufacturers have indicated their intentions to continue using these batteries for years to come. Li-ion is technically attractive, but has several hurdles to overcome, not the least of which are cost and widespread consumer acceptance of the plug-in hybrid concept.

With resounding successes in consumer and vehicle applications, it is surprising that NiMH technology has not received more attention for stationary energy storage applications. With proven reliability and safety under demanding conditions, and operating attributes of high power and energy over a wide operating temperature range, NiMH technology offers a rather attractive solution.

TECHNOLOGY

A basic NiMH cell consists of a metal hydride (MH) anode and a nickel hydroxide cathode in a high conductivity aqueous potassium hydroxide electrolyte. This chemistry provides a cell potential of 1.2V with an overall discharge reaction which can be written:

$$MH + NiOOH \rightarrow M + Ni(OH)_2$$

Where nickel oxyhydroxide is reduced to nickel hydroxide and metal hydride (MH) is oxidized to a metal alloy (M). This process is reversed during charging. The electrolyte is not consumed in the overall chemical reaction thereby maintaining a consistent concentration to provide high power and long cycle life.

Adjusting the negative to positive (N/P) ratio to provide excess MH negative electrode capacity enhances the cell's gas recombination mechanism to prevent build-up of gasses during overcharge (oxygen recombination) or over-discharge (hydrogen recombination) situations. This additional capacity also helps to inhibit oxidation or corrosion of the MH alloy.

Cell construction

NiMH batteries are constructed in a variety of shapes and sizes, from small button cells to standard cylindrical sizes to large format prismatic cells up to 250 Ah capacity. Whereas smaller cells routinely use the cell case as an electrical contact, prismatic cells like that shown in figure 1 utilize individual terminals which are electrically insulated from the welded lid/case assembly. The lid also features a re-sealable safety vent.

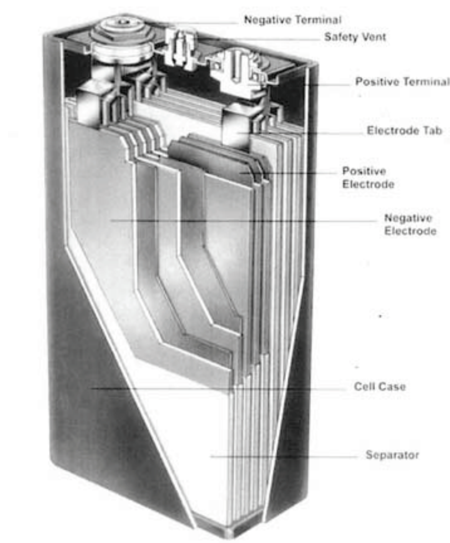

Figure 1: Prismatic NiMH cell construction

Technology improvements

Since its market introduction, NiMH technology has undergone continuous improvement and further development, typically following paths specific to different application requirements such as high power, high energy density, high cycle life, and other characteristics.

Early consumer NiMH AA cells demonstrated a specific energy of 54 Wh/kg. Improvements in electrode materials and manufacturing methods have more than doubled this value as shown in Figure 2.

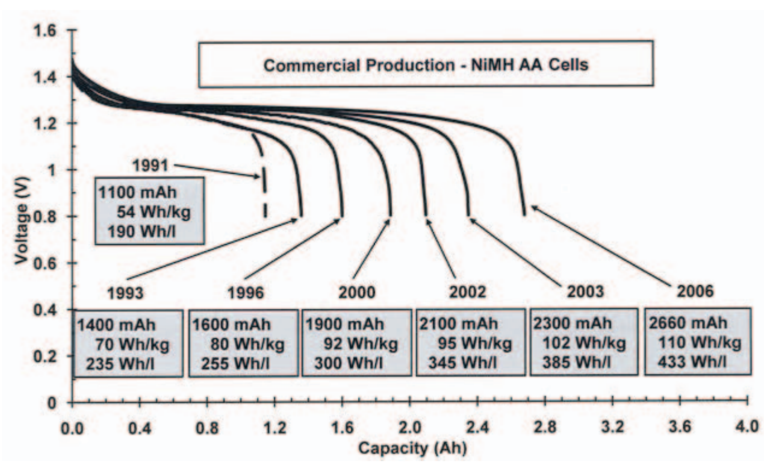

Figure 2: NiMH AA cell evolution

Specific energy is reduced somewhat in batteries with enhanced current collectors and other features designed for high power applications. 45-60 Wh/kg specific energy is normal for hybrid vehicle batteries whose specific power can exceed 1300 W/kg under both charge and discharge conditions. Traditionally, NiMH was considered a low power technology, but some manufacturers have demonstrated specific power as high as 2000 W/kg. Figure 3 shows that improved C cells can easily discharge at 10-C rates.

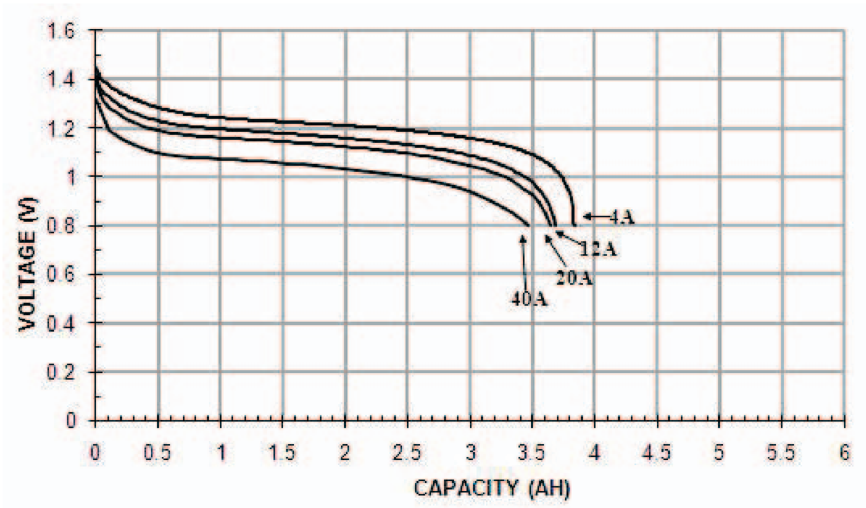

Figure 3: NiMH C cells discharge performance

Improvements in charge retention are primarily responsible for today's increased use of consumer NiMH batteries as replacements for disposable alkaline cells. Early NiMH products exhibited self discharge rates as high as 70% in one month at room temperature. Improvements in MH alloys, $Ni(OH)_2$, and separator materials have reduced self discharge in certain applications to less than 15% per year making it possible to market "ready to use" NiMH batteries. With widespread availability and comparable purchase price to alkaline cells, consumers are switching to rechargeable NiMH in increasing numbers.

Consumer NiMH batteries vary by manufacturer, but typically provide 500 to 1000 full discharge cycles making their lifecycle costs a tremendous value compared to disposable alkaline batteries. Many factors can influence cycle life in larger format NiMH cells; substrates, active material formulations, material processing (structure), electrode construction, etc. Cell balance and depth of discharge can influence cycle life of most battery chemistries. Figure 4 shows that NiMH batteries demonstrate exceptional cycle life at all discharge depths.

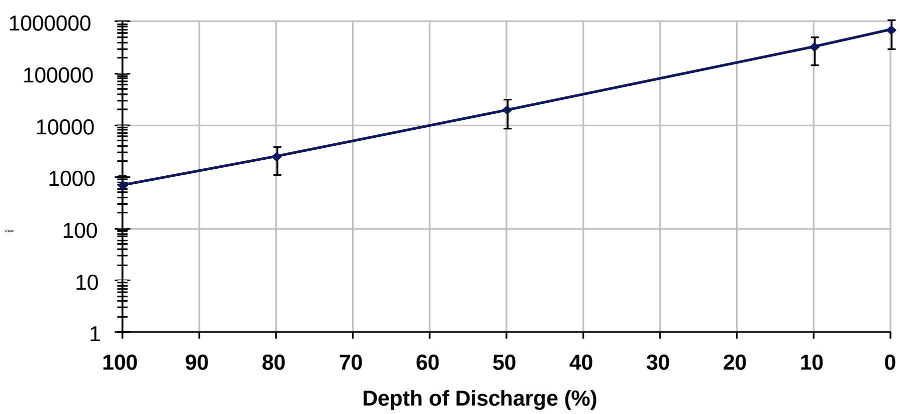

Figure 4: NiMH cycle life vs. discharge depth

Operation over a wide temperature range is a problem for all batteries and prolonged exposure to elevated temperatures can be particularly troublesome. Early NiMH batteries intended for electric vehicle use would lose almost 50% of their room temperature capacity when charged at 60°C. Advancements in nickel hydroxide active materials have overcome this problem and have pushed the temperature limit even further as shown in Figure 5.

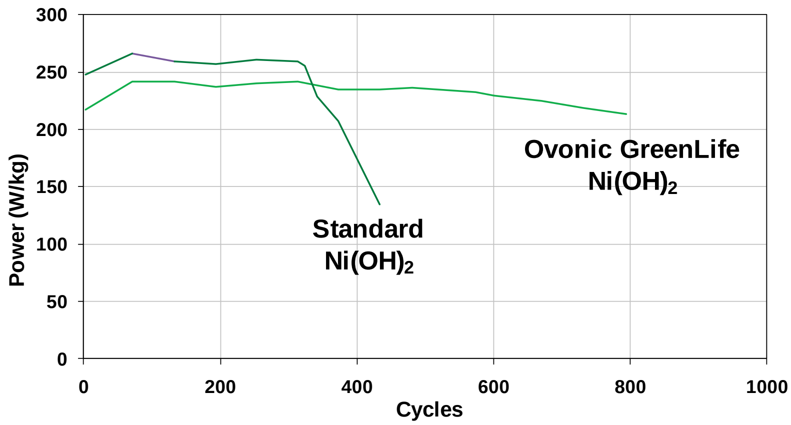

Figure 5: 70°C EV battery improvement

If all of these improvements (energy, power, charge retention, cycle life, and high temperature resistance) could be taken collectively into a single design, the resulting battery would represent an extremely attractive solution for current and emerging stationary power applications.

STATIONARY APPLICATIONS

The concept of utilizing NiMH batteries for stationary applications was introduced at Battcon 2005. At that time, a value proposition of reduced weight and size compared to lead acid was proposed. A case study of a 560kW UPS battery replacement showed an incredible 68% floor space reduction achieved by replacing a room full of flooded lead acid batteries with stacks of NiMH modules.[1] While this is one important benefit of NiMH, the technology brings a host of persuasively beneficial attributes for stationary customers.

Consider the telecommunications market. As power systems have become further distributed, more and more equipment is installed in outdoor enclosures. These enclosures are typically exposed to wide temperature fluctuations where prolonged exposure to elevated temperature which can severely shorten the life of VRLA batteries. Some users have installed air conditioning systems to maintain appropriate temperatures to extend battery life, but this practice can subject the customer to substantial operating and maintenance expenses. Some battery manufacturers have begun marketing advanced NiCd and Li-ion batteries as higher temperature solutions allowing for warmer operating conditions while preserving battery life.[2] However, as shown in the graph in Figure 6, these “advanced solutions” pale in comparison to the inherent temperature capability of NiMH technology. With the ability to operate at temperatures as high as 70°C (158°F), NiMH batteries can eliminate the need for expensive temperature controlling systems. We see the existing telecom outside plant application as an immediate, ideal fit for NiMH technology. Similarly, the high temperature capability of NiMH batteries could allow central office, data center, and server room operators to reduce their operating costs by slashing climate control expenses.

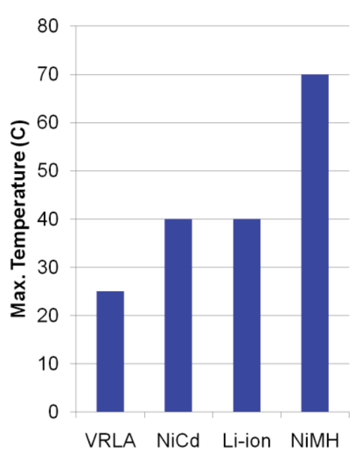

Figure 6: Maximum temperature by battery chemistry

Looking forward, significant attention is being focused on the emerging “smart grid” where utility-scale storage will be required to balance supply of power generated from intermittent renewable sources along with fluctuating demand created by large numbers of customers potentially charging plug-in hybrid vehicles. According to GTM Research, storing electricity on the grid could become a $2.5B market by 2015. Utilities see energy storage as a means to utilize the existing infrastructure more efficiently through balancing supply and demand peaks. In order to operate in a cost effective manner, such grid storage systems will require extensive cycle life with very high round-trip efficiency. NiMH battery solutions have demonstrated efficiencies greater than 95% with exceptional cycle life as illustrated previously in Figure 4.

Competitive position

Table 1 summarizes the advantages and disadvantages of NiMH batteries compared to other stationary battery chemistries.

Table 1: Advantages and disadvantages of NiMH battery technology

Advantages of NiMH	Disadvantages of NiMH
-Higher energy density than VRLA and NiCd -Higher temperature capability than VRLA, NiCd and Li-ion -Excellent charge retention Good high rate capability -Longer cycle life at higher DOD than VRLA -Proven safety and reliability in demanding HEV application	-Higher initial cost than VRLA -Lower gravimetric energy density and specific power compared to Li-ion -No available product for stationary applications -Certifications will delay market introduction

Cost Challenge

The advantages outlined in Table 1 attest to the attractiveness of NiMH technology, but cost represents the most significant factor in determining market success. Large prismatic NiMH cells for hybrid vehicles are commercially available for $800-1000 / kWh. However, many features of the high power HEV battery are not required for use in stationary applications. The removal of unnecessary features provides an opportunity to reduce cost by 50% or more, in volume. While this would still translate to about double the cost of incumbent VRLA batteries, the performance attributes of NiMH technology suggests a rather impressive lifecycle cost savings to the user.

Consider a typical air conditioned outdoor telecom enclosure with 2 strings of 12V, 100Ah VRLA batteries. Given initial purchase price, maintenance and replacement after approximately 7 years, the effective battery cost to the customer over 10 years is approximately $14,600 plus the cost of electricity to maintain temperature below 77ºF. NiCd batteries are reported to last 10 years at 35ºC (95ºF) eliminating replacement and reducing climate control cost.[3] If battery purchase price is reduced by these operating cost savings, the effective cost to the customer of such NiCd batteries over 10 years is reduced by more than half. A similar model can be applied to Li-ion batteries, although initial cost will be higher and operating life remains to be proven. In contrast, a NiMH battery solution could further reduce operating expenses by allowing the customer to maintain a temperature as high as 45ºC (113ºF), the operating temperature of the electronic equipment.[4] Over the 10 year life of the battery[5], the savings in operating expenses would significantly offset the projected $400/kWh purchase price creating an effective 10-year cost to the customer less than one-fifth that of VRLA. This 10-year lifecycle cost comparison is illustrated in Figure 7 below.

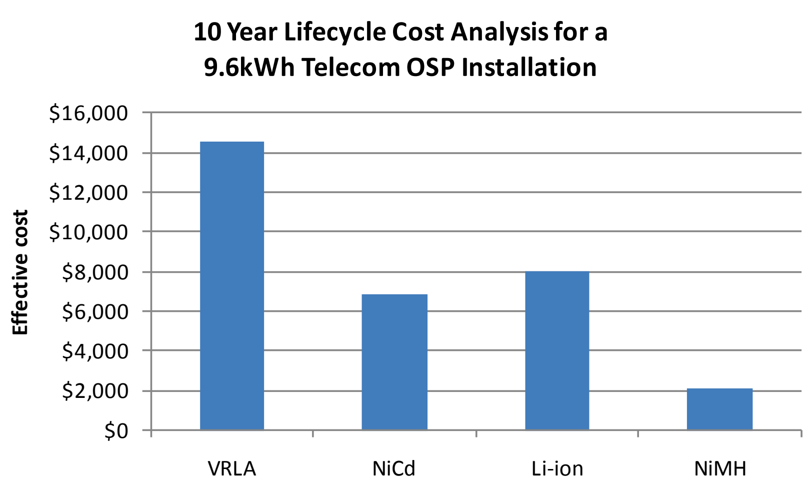

Figure 7: 10-year battery cost comparison

CONCLUSION

Although nickel metal hydride batteries were introduced to the market more than 20 years ago, the technology is far from mature as evidenced by the wide range of performance improvements that have been achieved and further advancements being made through ongoing R&D. High energy density, exceptional high temperature capability, long cycle life, excellent charge retention and high efficiency, combined with proven safety and reliability in demanding consumer and hybrid vehicle applications make NiMH technology an excellent candidate for stationary power applications.

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