Batteries and Heat – A Recipe For Success?

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Abstract

It is well known that prolonged exposure to elevated temperature shortens battery life. Nonetheless, many stationary battery applications must operate under these conditions.

Evaluations of nickel metal hydride (NiMH) batteries have revealed that high temperature performance is strongly influenced by the positive electrode. Development of new cathode material formulations has allowed NiMH batteries to achieve full charge acceptance at temperatures as high as 65^{o}C. Heat tolerance of this level has the potential to significantly reduce cooling concerns and will greatly extend battery life in even the most extreme installations.

An associated benefit of new cathode materials has been observed in cycle life, where more than 2000 cycles have been achieved at full discharge levels. Several orders of magnitude higher cycle life is achievable at lower depths of discharge making NiMH an attractive solution for remote, off-grid applications.

This paper will investigate recent advances in materials technology and the benefits NiMH batteries offer for stationary applications. Case-studies of NiMH batteries installed in harsh environments will be referenced.

Introduction

Heat can be both a blessing and a curse to battery users. As the temperature of the battery decreases, delivered capacity drops quickly compared to that which can be achieved at room temperature. For example, on an 8-hour discharge at -40^{o}C, a VRLA battery will typically achieve only 25-30% of it room temperature capacity, while a Nickel-based battery under similar conditions can be expected to provide 50-60% of its room temperature capacity. At temperatures warmer than room temperature, realized capacity can improve. However, this relationship between temperature and performance can vary significantly from one battery chemistry to the next as illustrated in Figure 1.

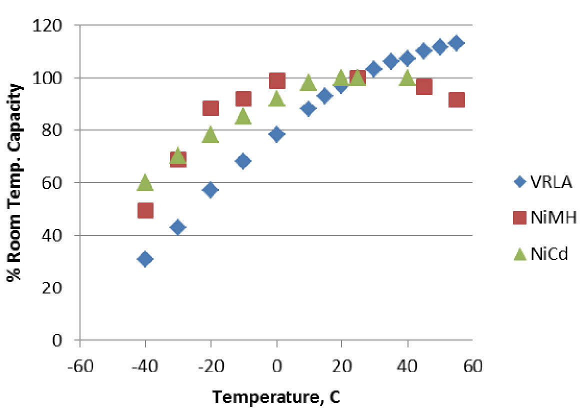

Figure 1 - Effect of temperature on discharge capacity, C/8 discharge

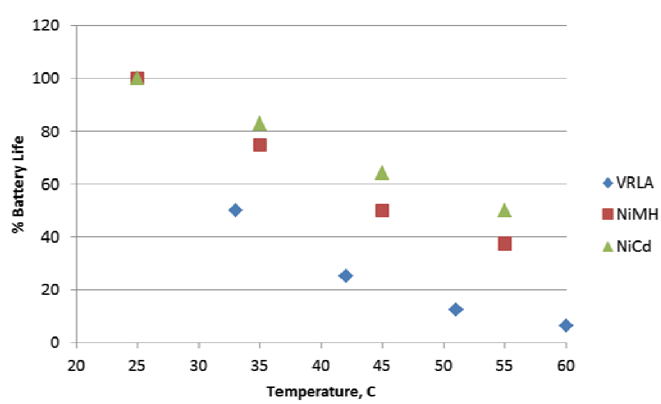

Figure 2 - Effect of temperature on battery life

Another example of the effect of heat on batteries involves keeping a battery at elevated temperature for long periods of time which can significantly shorten its operating life as shown in Figure 2. For example, at 50°C , a 10-year rated VRLA battery can be expected to fail in less than 2 years, while a Nickel-Cadmium (NiCd) or Nickel-Metal Hydride (NiMH) battery will perform years longer at the same temperature.[1] The NiMH data presented in Figures 1 and 2 are representative of commercial products available today. Research has shown that in NiMH batteries, high temperature characteristics can be greatly influenced by the positive electrode.[2] Before discussing cathode material improvements, a brief overview of the Nickel-metal hydride battery chemistry may be helpful.

NIMH 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.

Sealed NiMH batteries are constructed in a variety of shapes and sizes, from small button cells to standard cylindrical sizes to large-format prismatic cells. Cells are typically constructed in a cathode-limited design. Thus, when charging, the positive electrode reaches full charge before the negative electrode and begins to evolve oxygen:

$$4OH^- \rightarrow 2H2O + O2 + 2e^-$$

The oxygen gas diffuses through the separator to the negative electrode where it reacts to produce water:

$$4MH + O2 \rightarrow 4M + 2H2O$$

This oxygen recombination mechanism contributes to the safety of the NiMH battery by stabilizing internal pressure. However, it can also limit charge capacity at higher temperature.

Elevated Temperature Charging

Figure 3 shows typical charge profiles for a commercial NiMH cell at three different temperatures. Notice the rise in voltage in the 25° and 45°C curves as the positive electrode becomes fully charged and the oxygen evolution process described above takes over. This step is not seen in the 65°C curve where oxygen evolution begins sooner, competing with the charge reaction and keeping voltage depressed.

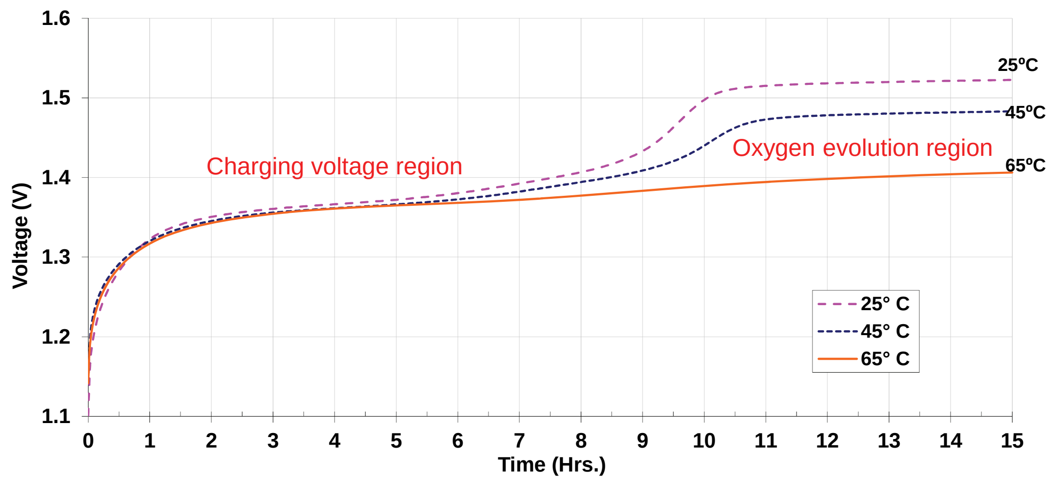

Figure 3 - Typical Charge Profiles of a Commercial NiMH Cell

Ongoing R&D in the BASF-Ovonic laboratories has yielded advanced cathode materials which enable high heat tolerance. Figure 4 shows charging profiles for NiMH cells constructed with an advanced cathode material, AP87, developed for high temperature operation. Notice the shift to higher voltage and the emergence of a step in the 65ºC curve indicating a delay in the onset of oxygen evolution.

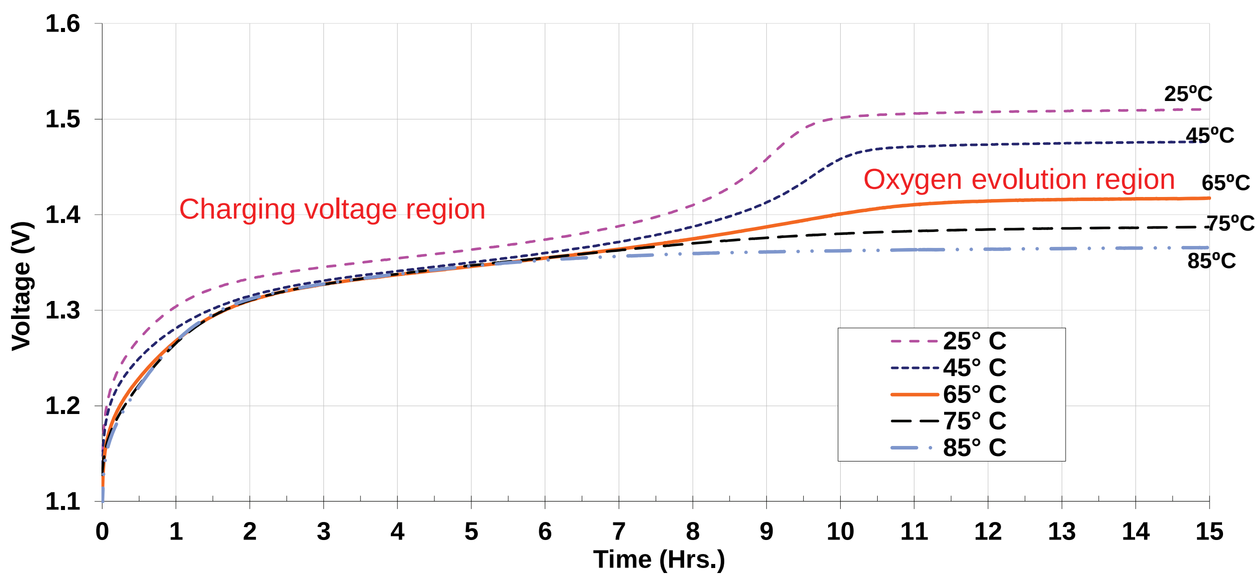

Figure 4 - Charge Profiles of a NiMH Cell Using Advanced Cathode Materials

The impact of this shift can be seen in significantly improved charge acceptance. The bar graph in Figure 5 shows multiple charge cycles at 65ºC compared to initial characterization at room temperature for NiMH cells with Ovonic AP87 nickel hydroxide cathodes. The results show that full charging can be achieved at 65ºC compared to only 20-25% for standard commercially available NiMH product. Testing at higher temperatures suggests greater than 60% charge acceptance is possible with this material at temperatures as high as 85ºC.

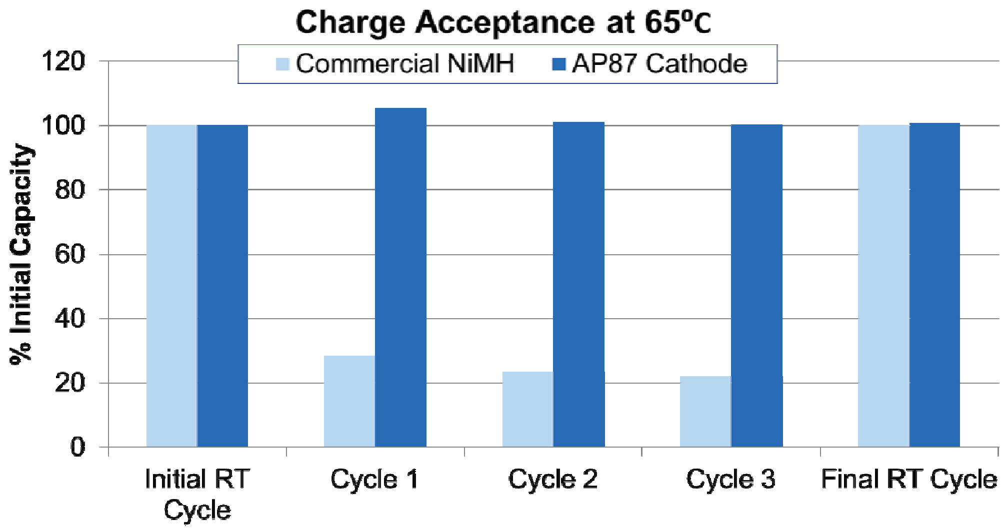

Figure 5 - 65°C Charge Acceptance of NiMH Cells Using Ovonic AP87 Cathode Material Compared to Standard Commercial Product

Significance to Stationary Applications

The significance of this improvement to stationary battery users is easy to demonstrate. In harsh environments, users can expect longer operating life with fewer battery replacements potentially resulting in lower overall lifecycle cost. Revisiting Figure 2, a VRLA battery may fail in as little as 6 months at 60°C, while an advanced NiMH battery could be expected to provide 3 years of service before needing replacement. Although the initial purchase price of the NiMH battery may be 3 - 4 times higher than VRLA, the user's total cost of ownership becomes favorable for NiMH after a few VRLA battery replacements.

These newly developed cathode materials contribute to improved cycle life as well. In general, battery cycle life suffers with increasing discharge depth; the deeper the discharge, the fewer cycles that can be delivered over the life of the battery. The typical solution for high-cycle applications is to oversize the battery to minimize discharge depth.

Figure 6 compares the number of cycles achievable at different depths of discharge for traditional and deep-cycle VRLA[3] as well as commercially available and advanced NiMH batteries with AP87 cathodes.

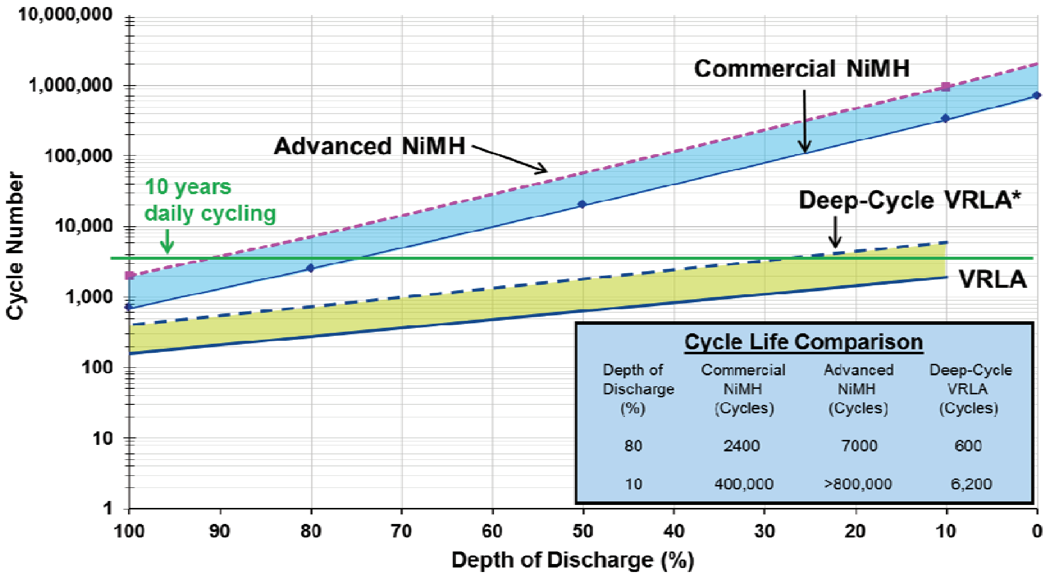

Figure 6 - Cycle Life as a Function of Discharge Depth

Consider a remote, off-grid installation. To achieve the 3650 cycles needed for daily PV charging over 10 years, an advanced NiMH battery could be sized based on a 90% discharge depth compared to only 25-30% for VRLA. As a result, the NiMH battery could be roughly 1/3 the size of the VRLA battery. The smaller NiMH battery size would nearly overcome any cost differential before the added temperature benefits discussed earlier are even considered.

The benefits of advanced cathode materials promise to make NiMH batteries a very attractive alternative to incumbent stationary batteries for both standby power and high cycle applications.

Commercialization Status

The advanced cathode materials described in this paper are not yet available in the commercial marketplace. However, while material development has progressed in the laboratory, several battery manufacturers have introduced stationary NiMH products to the marketplace based on current technology. A 2.5kWh UPS system using NiMH battery back-up is available to customers in Japan while larger systems utilizing a similar battery architecture are undergoing field trials for major Japanese wireless carriers. Similarly, 12V NiMH battery modules up to 60Ah capacity are now available to customers in China and North America with additional products in development. Customer evaluations and field trials are underway at numerous locations.

To date, the results of ongoing field tests have been impressive. For example, in April 2012, a 7.2kWh NiMH battery successfully passed a series of tests at China Telecom's Dabanshan Base Station (Qinghai Province, China) at an altitude of 4500 meters and an average temperature range of -20 to +4^{o}C. Field trials are ongoing in this frigid plateau region of China. At the other extreme, a 3.9kWh NiMH battery was installed in a telecom enclosure in Needles, CA in July 2011. Like Death Valley to the Northwest, Needles is known for extreme heat; temperatures exceed 90^{o}F/32^{o}C over 168 days of the year and routinely reach 120^{o}F /50^{o}C in summer. After nearly 2 years of service, these batteries continue to perform to expectations.

Going forward, we expect to see Ovonic AP87 cathode material incorporated into these commercial products to further enhance temperature range and performance. UL and NEBS approval is anticipated on NiMH batteries from a number of suppliers within the next year. Finally, qualification of several batteries to the new Telcordia GR-3168 NiMH telecom battery guidelines published in July 2012 is expected to be underway by year's end.

Conclusion

Nickel metal hydride battery technology offers numerous benefits as an advanced alternative to VRLA in stationary applications.

- Proven safety and reliability in 4 million hybrid electric vehicles
- High energy density
- Wide operating temperature range
  - Superior low-temp performance
  - High temperature operation to 85^{o}C
- Substantially more cycles at greater depths of discharge

Recent developments in positive electrode materials have significantly improved high temperature performance; allowing full charge up to 65^{o}C and partial charge acceptance (better than 60%) as high as 85^{o}C. These new materials have also benefited cycle life, further extending the orders of magnitude more cycles that can be achieved at substantially greater discharge depths than traditional VRLA batteries. These advancements promise longer operating life and fewer battery replacements in harsh environments with both stable and non-stable grid installations.

References

1. Telcordia GR-3168-CORE, Issue 1, 2012
2. D. Linden, Thomas B. Reddy, Handbook of Batteries, Fourth Edition, McGraw-Hill, New York, 2011
3. Product literature; Concorde Battery (SunXtender), East Penn (EPM), C&D Technologies (DCS)