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6 Charging Sealed Nickel-Metal Hydride Batteries

6.1 General Principles

Recharging is the process of replacing energy that has been discharged from the battery. The subsequent performance of the battery, as well as its overall life, is dependent on effective charging. The main criteria for effective charging are:

- Choosing the appropriate rate
- Limiting the temperature
- Selecting the appropriate termination technique

The recharging characteristics of nickel-metal hydride batteries are generally similar to those of nickel-cadmium batteries. There are some distinct differences, however, particularly on the requirements for charge control because the nickel-metal hydride battery is more sensitive to overcharging. Caution should be exercised before using a nickel-cadmium battery charger interchangeably for both battery types because it may not optimally charge a nickel-metal hydride battery, particularly on high rate chargers.

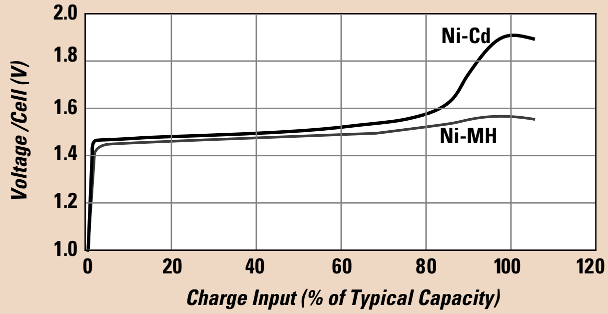
The most common charging method for the nickel-metal hydride battery is a constant current charge with the current limited in order to avoid an excessive rise in temperature. Limiting the charge current also reduces the risk of exceeding the rate of the oxygen recombination reaction to prevent cell venting.

Figure 6.1.1 compares the voltage profiles of nickel-metal hydride and nickel-cadmium batteries during charge at a constant current rate. The voltages of both systems rise as the batteries accept the charge. As the batteries approach 75 to 80 percent charge, the voltages of both battery types rise more sharply due to the generation of oxygen at the positive electrode. However, as the batteries go into overcharge, the voltage profile of the nickel-metal hydride battery does not exhibit as prominent a voltage drop as the nickel-cadmium battery.

In **Figure 6.1.2**, the temperature profiles of the nickel-metal hydride and nickel-cadmium batteries are compared during charge at a constant current charge rate. Throughout the first 80 percent of charge, the temperature of the nickel-cadmium battery rises gradually because its charge reaction is endothermic (absorbs heat). The temperature of the nickel-metal hydride battery, on the other hand, rises quickly because its charge reaction is exothermic (releases heat). After 80 to 85 percent of charge, the temperature of both battery types also rises due to the exothermic oxygen recombination reaction, causing the voltage to drop as the batteries reach full charge and go into overcharge.

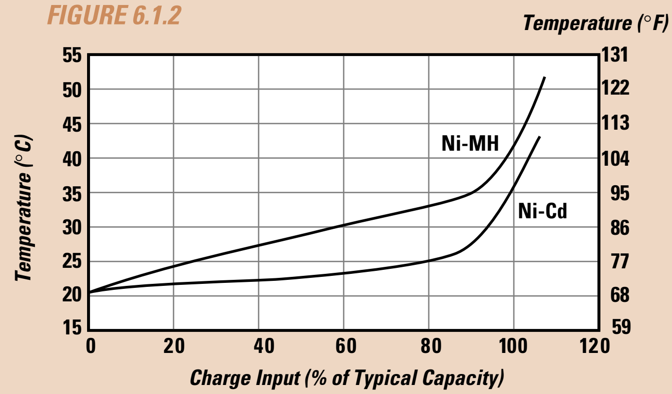
Both the voltage drop after peaking (-ΔV) and the temperature rise are used as methods to terminate the charge. Thus, while similar charge techniques can be used for nickel-metal hydride and nickel-cadmium batteries, the conditions to terminate the charge may differ because of the varying behavior of the two battery systems during charge. To properly terminate charging of DURACELL nickel-metal hydride batteries,

FIGURE 6.1.1



Typical charge voltage characteristics of Ni-MH and Ni-Cd batteries.
[Conditions: Charge: 1C @ 21°C (70°F) to -ΔV = 10mV/cell]

FIGURE 6.1.2



Typical charge temperature characteristics of Ni-MH and Ni-Cd batteries.
[Conditions: Charge: 1C @ 21°C (70°F) to -ΔV = 10mV/cell]

Charging Sealed Nickel-Metal Hydride Batteries (cont.)

Duracell recommends the charge termination method described in Section 6.3.1.

The voltage of the nickel-metal hydride battery during charge depends on a number of conditions, including charge current and temperature. **Figures 6.1.3** and **6.1.4** show the voltage profile of the nickel-metal hydride battery at different ambient temperatures and charge rates, respectively. The battery voltage rises with an increase in charge current due to an increase in the "IR" drop and overpotential during the electrode reaction. The battery voltage decreases with increasing temperature as the internal resistance and overpotential during the electrode reaction decrease.

A rise in temperature and pressure at high charge rates occurs and underscores the need for proper charge control and effective charge termination when "fast charging." Excessive pressure and temperature increases can result in activation of cell vents or battery safety electronics, as described in Section 6.4.

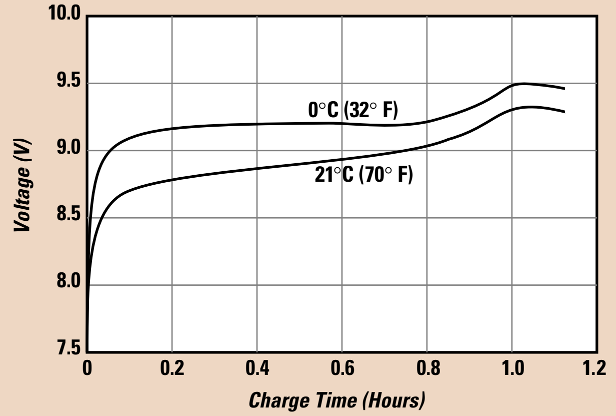
Temperature also affects charge efficiency. Charge efficiency decreases at higher temperatures due to the increasing evolution of oxygen at the positive electrode. Thus, charging at high temperatures results in lower capacity. At lower temperatures, charge efficiency is high due to decreasing oxygen evolution. However, oxygen recombination is slower at lower temperatures and a rise in internal cell pressure may occur depending on the charge rate.

Proper charging is critical not only to obtain maximum capacity on subsequent discharges but also to avoid high internal temperatures, excessive overcharge and other conditions which could adversely affect battery life.

6.2 Techniques for Charge Control

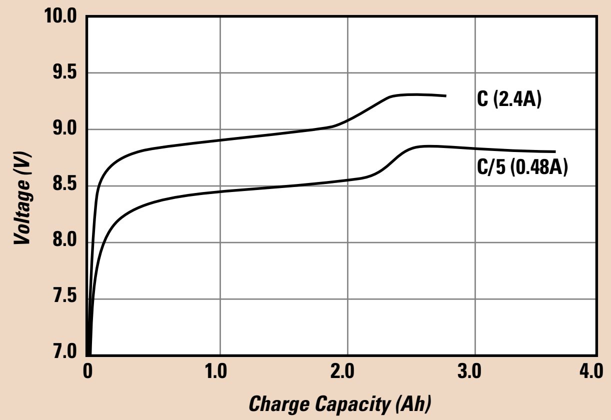
The characteristics of the nickel-metal hydride battery define the need for proper charge control in order to terminate the charge and prevent overcharging or exposure to high temperatures. Each charge control technique has its advantages and disadvantages. For example, higher capacity levels are achieved with a 150 percent charge input, but at the expense of cycle life; long cycle life is attained with a 105 to 110 percent charge input, albeit with slightly lower capacity due to less charge input. Thermal cutoff charge control may reduce cycle life because higher temperatures are reached during the charge; however, it is useful as a backup control in the event that the primary termination method is not effective during charge.

FIGURE 6.1.3



Charge voltage of DURACELL DR30 Ni-MH batteries at various temperatures.
[Conditions: Discharge: C/5 to 6.0V @ 21°C (70°F); Charge: 1C to -ΔV = 60mV]

FIGURE 6.1.4



Charge voltage of DURACELL DR30 Ni-MH batteries at various rates.
[Conditions: Discharge: C/5 to 6.0V; Charge: 1C to -ΔV = 60mV, C/5 to 7.5 hrs.; Temperature: 21°C (70°F)]

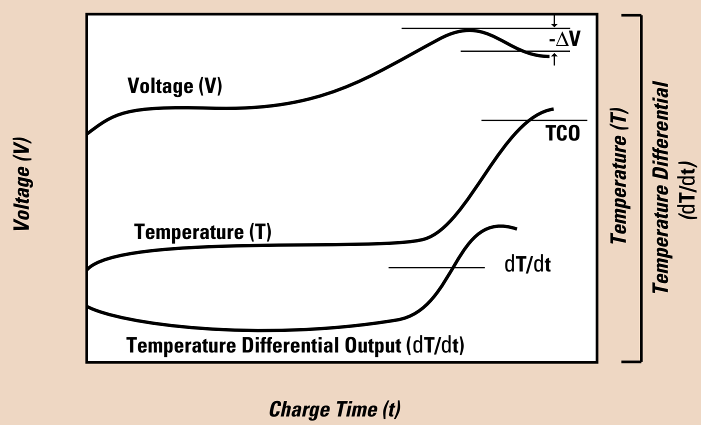
Charging Sealed Nickel-Metal Hydride Batteries (cont.)

The following summary explains some of the recommended methods for charge control. The characteristics of each of these methods are illustrated in **Figure 6.2.1**. In many cases, several methods are employed, particularly for high rate charging.

6.2.1 Timed Charge

Under the timed charge control method, the charge is terminated after the battery is charged for a predetermined length of time. This method should be used only for charging at low rates (less than C/3) to avoid excessive overcharge because the state-of-charge of the battery, prior to charging, cannot always be determined. If a timed charge termination is used, a time of 120 percent charge input is recommended with a backup temperature cutoff of 60°C (140°F).

FIGURE 6.2.1



Charge characteristics of Ni-MH batteries using various charge termination methods.

Voltage drop is widely used with nickel-cadmium batteries. With this technique, the voltage during charge is monitored and the charge is terminated when the voltage begins to decrease. This approach can be used with nickel-metal hydride batteries, but as noted in Section 6.1, the voltage drop of the nickel-metal hydride battery is not as prominent as that of the nickel-cadmium battery and may be absent in charge currents below the C/3 rate, particularly at elevated temperatures. The voltage sensing circuitry must be sensitive enough to terminate the charge when the voltage drops, but not so sensitive that it will terminate prematurely due to noise or other normal voltage fluctuations. A charge rate of 1C and a 5 to 10 millivolt per cell drop is recommended for the nickel-metal hydride battery with a backup temperature cutoff of 60°C (140°F). A top-up charge is not necessary with this charge termination method.

6.2.3 Voltage Plateau (Zero ΔV)

Since the nickel-metal hydride battery does not always show an adequate voltage drop, an alternate method used is to terminate the charge when the voltage peaks and the slope is zero, rather than waiting for the voltage to drop. The risk of overcharge is reduced as compared to the -ΔV method. If this method is employed, a charge rate of 1C and a backup temperature cutoff of 60°C (140°F) is recommended. A top-up charge can follow to ensure a full charge. *Duracell does not recommend this termination method because of the risk of premature cutoff.*

6.2.4 Temperature Cutoff

Another technique for charge control is to monitor the temperature rise of the battery and terminate the charge when the battery has reached a temperature which indicates the beginning of overcharge. It is difficult, however, to precisely determine this point because it is influenced by ambient temperature, cell and battery design, charge rate, and other factors. A cold battery, for instance, may be overcharged before reaching the cutoff temperature, while a warm battery may be undercharged.

Charging Sealed Nickel-Metal Hydride Batteries (cont.)

6.2.4 Temperature Cutoff (cont.)

Usually this method is used in conjunction with other charge control techniques primarily to terminate the charge in the event that the battery reaches excessive temperatures before the other charge controls activate. A charge rate of 1C and a temperature cutoff at 60°C (140°F) is recommended. A top-up charge is not recommended if this termination method is used.

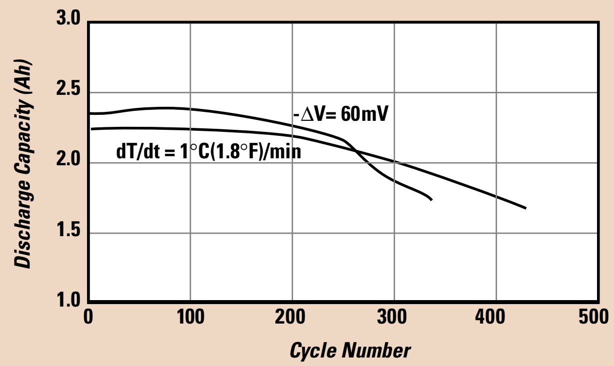
6.2.5 Delta Temperature Cutoff (ΔTCO)

This technique measures the battery temperature rise above the starting temperature during charging and terminates the charge when this rise exceeds a predetermined value. In this way, the influence of ambient temperature is minimized. The cutoff value is dependent on several factors, including cell size, configuration and number of cells in the battery, and the heat capacity of the battery. Therefore, the cutoff value should be determined for each type of battery. This value will be greater for nickel-metal hydride batteries than for nickel-cadmium batteries. A charge rate of 1C and a temperature change of 15°C (27°F) with a backup temperature cutoff of 60°C (140°F) is recommended for ΔTCO charge termination. A top-up charge is not necessary with this termination method.

6.2.6 Rate of Temperature Increase (dT/dt)

In this method, the change in temperature with time is monitored and the charge is terminated when a predetermined rate of temperature rise is reached. The influence of ambient temperature is reduced. A dT/dt cut-off is a preferred charge control method for nickel-metal hydride batteries because it provides long cycle life. **Figure 6.2.2** shows the advantage of using a dT/dt method compared to -ΔV in terminating a fast charge. The dT/dt method senses the start of the overcharge earlier than the -ΔV method. The battery is exposed to less overcharge and overheating, resulting in less loss of cycle life. A charge rate of 1C and a temperature increase of 1°C (1.8°F) per minute with a back-up temperature cut-off of 60°C (140°F) is recommended for dT/dt. A top-up charge of C/10 for 1/2 hour is also recommended.

FIGURE 6.2.2



Cycle life and capacity of DURACELL DR30 Ni-MH batteries as a function of charge termination.
[Conditions: Charge: 1C; Discharge: C/5 to 6.0V; Cycled to 70% of initial capacity; Temperature: 21°C (70°F)]

6.3 Charging Methods

Nickel-metal hydride batteries can be charged employing the same methods used for charging nickel-cadmium batteries. However, the charge termination technique may differ because of the varying behavior of the two battery systems. For proper charging of nickel-metal hydride batteries, the charge termination technique used should be appropriate for the particular charge rate. The charge rate and appropriate termination technique is summarized in **Table 6.3.1**.

Some of the various methods used to properly charge nickel-metal hydride batteries are explained in Sections 6.3.1 to 6.3.5. In order to optimize performance, Duracell recommends a three-step charge procedure.

Charge Rate	Termination Technique
1C to C/2	Voltage or temperature based
C/2 to C/3	Voltage based
C/3 to C/10	Not recommended
C/10 and below	Time limited

Table 6.3.1 Recommended charge termination techniques for particular charge rates.

Charging Sealed Nickel-Metal Hydride Batteries (cont.)

6.3.1 Duracell's Recommendation: Three-Step Charge Procedure

For fast charging and optimum performance, Duracell recommends a three-step procedure that provides a means of rapidly charging a nickel-metal hydride battery to full charge without excessive overcharging or exposure to high temperatures. The steps in sequential order are:

1) Charge at the 1C rate, terminated by using dT/dt = 1°C (1.8°F) /minute.
2) Apply a C/10 top-up charge, terminated by a timer after 1/2 hour of charge.
3) Apply a maintenance charge of indefinite duration at C/300 rate.

The three-step charging method should be used with a backup temperature cutoff of 60°C (140°F).

6.3.2 Low-Rate Charge (≈12 hours)

Charging at a constant current at the C/10 rate with time-limited charge termination is a convenient method to fully charge nickel-metal hydride batteries. At this current level, the generation of gas will not exceed the oxygen recombination rate. The charge should be terminated after 120 percent charge input, or approximately 12 hours for a fully discharged battery. Excessive overcharging should be avoided, as it can damage the battery.

The temperature range for this charge method is 0°C to 45°C (32°F to 113°F), with optimum performance being obtained between 15°C to 30°C (59°F to 86°F).

6.3.3 Quick Charge (≈4 hours)

Nickel-metal hydride batteries can be efficiently and safely charged at higher rates than described in Section 6.3.2. Charge control is required in order to terminate the charge when the rate of oxygen recombination is exceeded or the battery temperature rises excessively. A fully discharged battery can be charged at the C/3 rate terminated with a $-\Delta V$ = 10 mV/cell. In addition, a timer control set to a 120 percent charge input (3.6 hours) and a temperature cutoff of 60°C (140°F) should be used as a backup termination to avoid exposing the battery to excessively high temperatures. This charging method may be used in an ambient temperature range of 10°C to 45°C (50°F to 113°F). A top-up charge is not necessary if this termination method is used.

At the C/3 rate, a dT/dt termination method should not be used because the rate of temperature increase may not be sufficient to terminate the charge.

6.3.4 Fast Charge (≈1 hour)

Another method of charging nickel-metal hydride batteries in even less time is to charge at the C/2 to 1C constant current rates. At these high charge rates, it is essential that the charge be terminated early during overcharge. However, timer control is inadequate, as the time needed for charge can not be predicted — a partially charged battery could easily be overcharged while a fully discharged one could be undercharged, depending on how the timer control is set.

With fast charging, the decrease in voltage ($-\Delta V$) and the increase in temperature (ΔT) can be used to terminate the charge. For better results, termination of fast charge can be controlled by sensing the rate of temperature increase (dT/dt). A temperature increase of 1°C (1.8°F) per minute with a backup temperature cutoff of 60°C (140°F) is recommended. A top-up charge of C/10 for 30 minutes should follow to ensure a full charge.

Charging Sealed Nickel-Metal Hydride Batteries (cont.)

6.3.5 Trickle Charge

A number of applications require the use of batteries which are maintained in a fully-charged state. This is accomplished by trickle charging at a rate that will replace the loss in capacity due to self-discharge. In these applications, a trickle charge at a C/300 rate is recommended. The preferred temperature range for trickle charging is between 10°C to 35°C (50°F to 95°F). Trickle charge may be used following any of the previously discussed charging methods.

6.4 Thermal Devices

DURACELL nickel-metal hydride batteries contain a temperature sensing device and thermal protective devices. Thermal protective devices terminate charge/discharge in the event high temperatures are reached. This protection is particularly important when fast charging methods are used. The types of devices used are:

1) Negative Temperature Coefficient (NTC) Thermistor: This device senses internal battery temperature and provides this information by means of a calibrated resistance value to an external control circuit. The thermistor is attractive because the control can be set, external to the battery, to meet the particular conditions of the charge. This device is used in dT/dt charge control.
2) Thermostat: This bimetal thermal protective device operates at a fixed temperature and is used to cut off the charge (or discharge) when a pre-established internal battery temperature or current is reached. These temperature cutoff (TCO) devices reset automatically after the overtemperature or overcurrent condition has decreased below a reset threshold.
3) Thermal Fuse: This device is wired in series with the cell stack and will open the circuit when a predetermined temperature is reached. Thermal fuses are included as a protection against thermal runaway and are normally set to open at approximately 91°C (196°F). This device cannot be reset once opened.
4) Positive Temperature Coefficient (PTC) Device: This is a resettable device whose resistance rapidly increases at a predetermined current, thereby reducing the current in the battery to a low and acceptable level. The PTC device will respond to high current beyond design limits (e.g. a short circuit) and acts like a fuse. Unlike a one-time fuse, the PTC device will reset to its low resistance state when the latching current is removed. It will also respond to high temperatures around the PTC device, in which case it operates like a temperature cut-off (TCO) device.

The location of thermal devices in the battery assembly is critical to ensure that they will respond properly as the temperature may not be uniform throughout the battery. Thermal devices in DURACELL nickel-metal hydride batteries are set so the cells are not exposed to temperatures above 91°C (196°F). The inclusion of thermal protective devices in DURACELL nickel-metal hydride batteries helps ensure safe battery operation.