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Chapter: 5

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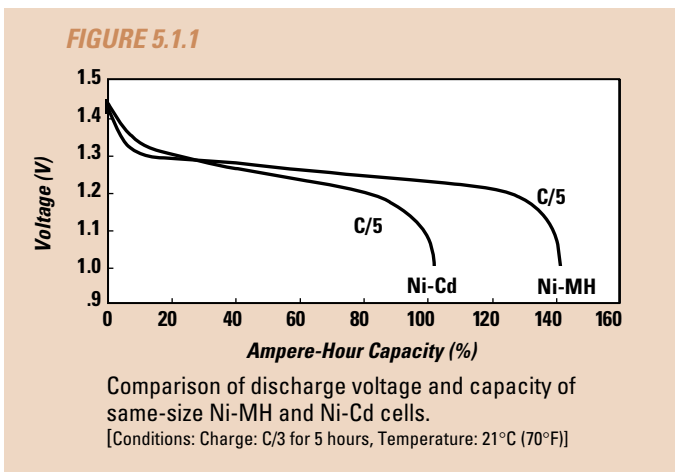
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5 Performance Characteristics

5.1 General Characteristics

The discharge characteristics of the nickel-metal hydride cell are very similar to those of the nickel-cadmium cell. The charged **open circuit voltage** of both systems ranges from 1.25 to 1.35 volts per cell. On discharge, the **nominal voltage** is 1.2 volts per cell and the typical **end voltage** is 1.0 volt per cell.

Figure 5.1.1 illustrates the discharge characteristics of nickel-metal hydride and nickel-cadmium rechargeable cells of the same size. As shown, the voltage profile of both types of cells is flat throughout most of the discharge. The **midpoint voltage** can range from 1.25 to 1.1 volts per cell, depending on the discharge load. **Figure 5.1.1** can also be used to compare the capacity of the two rechargeable types. Note that the capacity of the nickel-metal hydride cell is typically up to 40 percent higher than that of a nickel-cadmium cell of equivalent size.



5.2 Discharge Characteristics: Effect of Discharge Rate and Temperature

Typical discharge curves for DURACELL nickel-metal hydride batteries under constant current loads at various temperatures are shown in **Figures 5.2.1** to **5.2.3**. Discharge voltage is dependent on discharge current and discharge temperature.

FIGURE 5.2.1

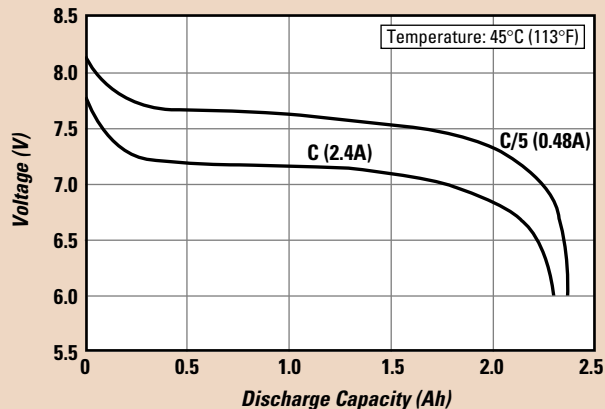


FIGURE 5.2.2

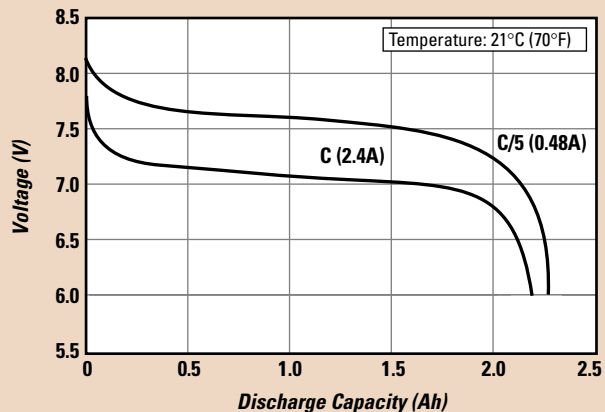
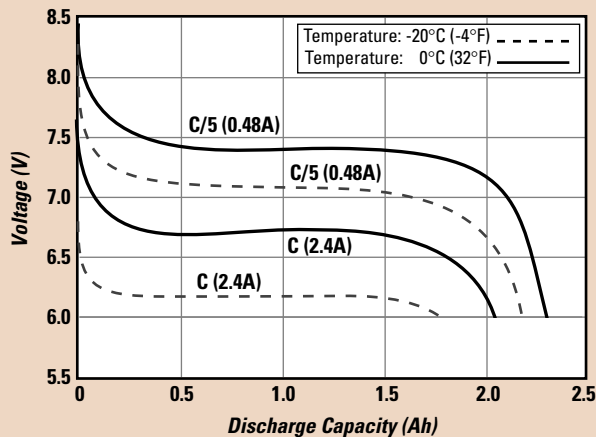


FIGURE 5.2.3



Voltage and capacity of DURACELL DR30 Ni-MH batteries at various discharge temperatures and rates.

[Conditions: Charge: 1C to $-\Delta V = 60\text{mV}$ @ 21°C (70°F)]

Performance Characteristics (cont.)

Typically, when the current is higher and the temperature is lower, the operating voltage will be lower. This is due to the higher “IR” drop that occurs with increasing current and the cell’s increasing resistance at the lower temperatures. However, at moderate discharge rates ($\approx C/5$), the effect of low temperature on the capacity of the nickel-metal hydride battery is minimal.

5.3 Capacity: Effect of Discharge Rate and Temperature

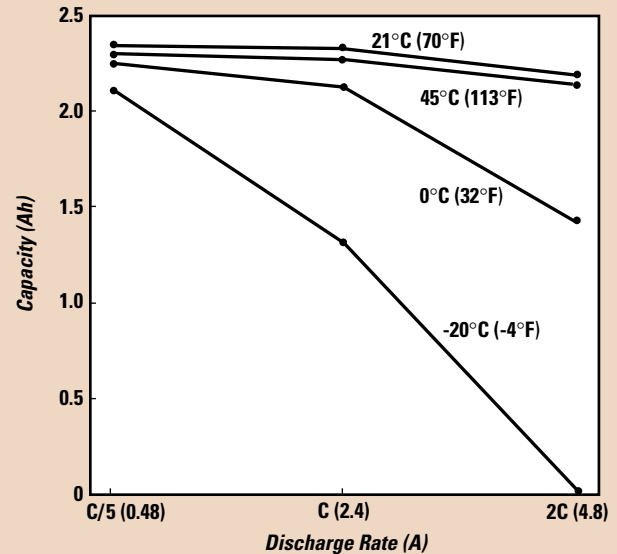
The ampere-hour capacity of the battery is dependent on the discharge current and temperature, as can be observed in **Figure 5.3.1**. It should be noted that the delivered capacity is dependent on the cutoff or end voltage. The delivered capacity can be increased by continuing the discharge to lower end voltages. However, the battery should not be discharged to too low a cut-off voltage (less than 0.9 volts per cell) as the cells may be damaged (see Section 5.6). The recommended cutoff voltage for nickel-metal hydride batteries is 1.0 volt per cell.

Typically, optimum performance of the nickel-metal hydride battery is obtained between 0°C and 45°C (32°F and 113°F). The performance characteristics of the battery are affected moderately at higher temperatures. At lower discharge temperatures, performance decreases more significantly, caused primarily by the increase in internal resistance. Similarly, the effects of temperature on performance are more pronounced at higher discharge rates. The capacity of the battery decreases more noticeably as the current increases, particularly at lower temperatures.

5.4 Energy Density

Energy density is the ratio of the energy available from a battery to its volume or weight. A comparison of the performance of various battery systems is normally made on practical, delivered energy density per-unit-weight or volume using production-based batteries and performance as opposed to theoretical energy density. Comparing energy densities, one must consider the influence of cell size, internal design, discharge rate and temperature conditions, as these parameters strongly impact performance characteristics.

FIGURE 5.3.1



Typical capacity of DURACELL DR30 batteries under constant current discharges at various temperatures. [Conditions: Charge: 1C to $-\Delta V = 60\text{mV}$ @ 21°C (70°F); Discharge to 6.0V]

Performance Characteristics (cont.)

Figure 5.4.1 compares the gravimetric and volumetric energy density of nickel-metal hydride and nickel-cadmium cells. As indicated, nickel-metal hydride cells deliver more energy per weight or volume than nickel-cadmium cells.

5.5 Constant Power Discharge Characteristics

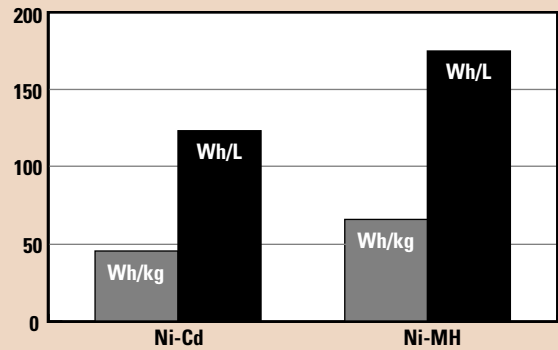
The output energy characteristic of nickel-metal hydride batteries under the constant power mode at different power levels is shown in **Figure 5.5.1**. As illustrated, the energy delivered does not vary significantly with increasing power. The power levels are shown on the basis of E-Rate. The E-Rate is calculated in a manner similar to calculating the C-Rate. For example, at the E/10 power level, the power for a battery rated at 17.3 watt-hours is 1.73 watts.

5.6 Polarity Reversal During Overdischarge

When cells are connected in series, the cell with the lowest capacity will reach a lower point of discharge than the others. The more cells that are connected in series, the greater the possibility of a cell being fully discharged and driven into overdischarge and polarity reversal. During reversal, hydrogen gas evolves from the positive electrode. Hydrogen gas will be reabsorbed by the negative electrode and eventually oxygen gas will evolve from the negative electrode. Extended overdischarge will lead to elevated cell pressure and opening of the safety vent within the nickel-metal hydride cells.

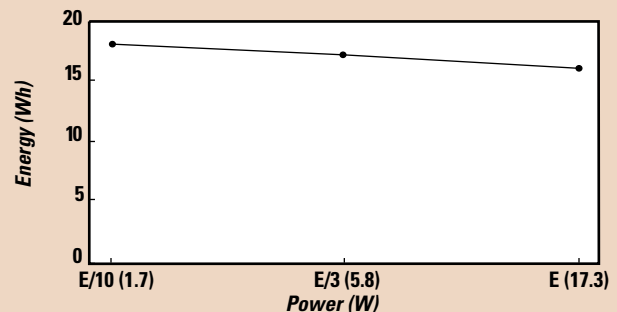
To minimize the occurrence of polarity reversal, the cells in DURACELL rechargeable batteries have capacities that are “matched” to each other. Device designers can help prevent overdischarge by designing a cutoff voltage for device operation of 1.0 volt per cell.

FIGURE 5.4.1



Gravimetric and volumetric energy density of Ni-Cd and Ni-MH cells.

FIGURE 5.5.1



Typical energy of DURACELL DR30 batteries under constant power discharges.
[Conditions: Charge: 1C to $-\Delta V = 60\text{mV}$; Discharge to 6.0V; Temperature: 21°C (70°F)]

Performance Characteristics (cont.)

5.7 Internal Impedance

DURACELL nickel-metal hydride batteries have low **internal impedance** because they are manufactured using cells designed with thin plate electrodes which offer large surface areas and good conductivity. **Figure 5.7.1** shows the change in internal impedance with **depth of discharge**. As demonstrated, the impedance remains relatively constant during most of the discharge. Towards the end of the discharge, the impedance increases due to the conversion of the active materials to a non-conductive form.

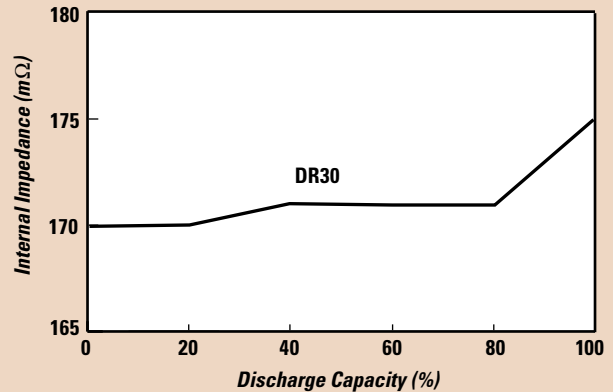
5.8 Self-Discharge and Charge Retention

The state-of-charge and capacity of the nickel-metal hydride battery decrease during storage due to self-discharge of the cells. Self-discharge results from the reaction of residual hydrogen in the battery with the positive electrode, as well as the slow and reversible decomposition of the positive electrode. The rate of self-discharge is dependent upon the length of time and temperature at which the battery is stored — the higher the temperature, the greater the rate of self-discharge. As illustrated in **Figure 5.8.1**, cells stored at 0°C (32°F) retain more of their capacity than those stored at 20°C and 45°C (68°F and 113°F), particularly after 30 days.

Generally, long term storage of a nickel-metal hydride battery in either a charged or discharged condition has no permanent effect on capacity. Capacity loss due to self-discharge is reversible and nickel-metal hydride batteries can recover to full capacity by proper recharging. For example, full capacity of a nickel-metal hydride battery that was stored at room temperature for up to one year can be restored by cycling through repeated charge/discharge cycles.

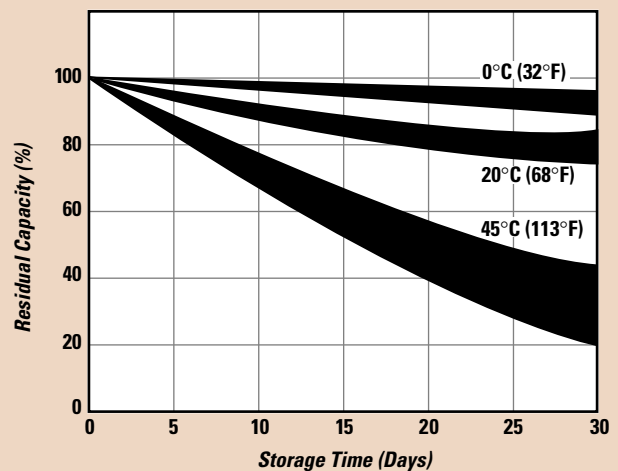
As with operation at elevated temperatures, however, long term storage at high temperatures can lead to deterioration of seals and separators and should be avoided. The recommended temperature range for long term storage of nickel-metal hydride batteries is 10°C to 30°C (50°F to 86°F).

FIGURE 5.7.1



Internal impedance of DURACELL DR30 Ni-MH batteries at various discharge capacities.
[Conditions: Charge: C/5 for 7.5 hours; Discharge: C/5; Temperature: 21°C (70°F); Measurements at 1000 Hz]

FIGURE 5.8.1



Self-discharge characteristic of Ni-MH cells at various temperatures.
[Conditions: Charge: C/3 for 5 hours; Discharge: C/5 to 1.0V; Temperature: 21°C (70°F)]

Performance Characteristics (cont.)

5.9 Voltage Depression (“Memory Effect”)

Although many years of premium performance can be enjoyed from a nickel-metal hydride battery that is properly handled, the capacity delivered in each charge/discharge cycle will eventually begin to decrease. This inevitable decrease in capacity can be accelerated by overcharging, storage or usage at high temperatures, or through poor matching of cells within a pack. Often, battery users who experience short service life have incorrectly attributed capacity loss to a phenomenon called “memory effect.”

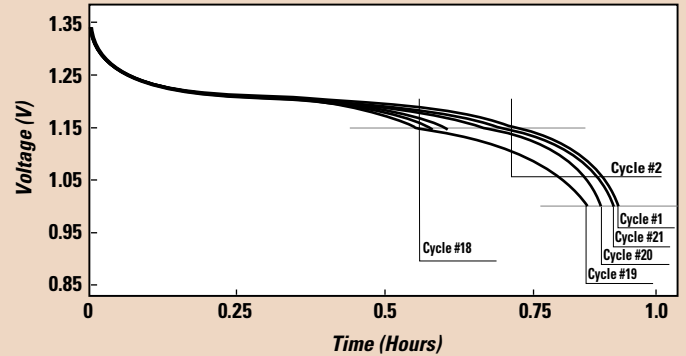
The term memory effect is used synonymously with the term “voltage depression.” Voltage depression is a scientifically measurable characteristic of all batteries, however, nickel-cadmium batteries demonstrate particularly acute sensitivity. A properly designed application with nickel-metal hydride batteries will result in neither permanent performance loss nor perceivable temporary capacity decreases from this characteristic.

A reversible drop in voltage and loss of capacity may occur when a nickel-metal hydride battery is partially discharged and recharged repetitively without the benefit of a full discharge, as illustrated in **Figure 5.9.1**. After an initial full discharge (Cycle #1) and charge, the cell is partially discharged to 1.15 volts and recharged for a number of cycles. During this cycling, the discharge voltage and capacity drop gradually in very small increments (Cycles #2 to #18). On a subsequent full discharge (Cycle #19), the discharge voltage is depressed compared to the original full discharge (Cycle #1).

Because the cell appears to “remember” the lower capacity, this voltage depression phenomenon is often referred to as memory effect. However, the cell can be quickly restored to full capacity with a few full discharge/charge cycles, as indicated in Cycles #20 and #21.

The voltage drop occurs because only a portion of the active materials in the cell is discharged and recharged during shallow or partial discharging. The active materials that have not been cycled change in

FIGURE 5.9.1



Effects on Ni-MH cell capacity due to repetitive partial discharges.

[Conditions: Charge: (Cycle #1– #21) = 1C to $-\Delta V = 12\text{mV}$. Discharge: Cycle #1 = 1C to 1.0 V, (Cycle #2– #18) = 1C to 1.15V, (Cycle #19– #21) = 1C to 1.0V; Temperature: 21°C (70°F)]

physical characteristics and increase in resistance. Subsequent full discharge/charge cycling will restore the active materials to their original state.

The extent of voltage depression and capacity loss depends on depth of discharge and can be avoided by discharging the battery to an appropriate cutoff voltage. Voltage depression is most apparent when the discharge is terminated at higher cutoff voltages, such as 1.2 volts per cell. A smaller voltage depression and capacity loss occurs if the discharge is cut off between 1.15 volts to 1.10 volts per cell. Discharging to 1.0 volts per cell should not result in significant voltage depression or capacity loss during subsequent discharges.

A device properly designed with nickel-metal hydride batteries will minimize the effects of voltage depression and capacity loss. The voltage depression and capacity loss in DURACELL nickel-metal hydride batteries is only a small fraction (less than 5 percent in worst cases) of the battery’s capacity and most users will never experience a perceptible performance loss.