# Cadnica Table of Contents

# 1

# Overview of CADNICA Batteries



## 1–1 Advantages and Characteristics of CADNICA (Nickel–Cadmium) Batteries

As an energy storage and conversion system, CADNICA batteries excel in ease of operation and electric characteristics, even though being classified as a secondary battery. Anticipating diversified market requirements, Sanyo Electric Co., Ltd. has put CADNICA batteries to use in sophisticated applications that call for such requirements as high-speed charging and high-temperature operation, while maintaining all the features of general-use CADNICA batteries. Significant features of the CADNICA battery are as follows.

(1) Outstanding economy and long service life which can last over 500 charge/discharge cycles.
(2) Low internal resistance which enables high-rate discharge, and constant discharge voltage which guarantees excellent sources of DC power for any battery-operated appliance.
(3) Sealed construction which prevents leakage of electrolyte and is maintenance free. No restriction on mounting direction so as to be incorporated in any appliance.
(4) Ability to withstand overcharge and overdischarge.
(5) Long storage life without deterioration in performance; and recovery of normal performance on being recharged.
(6) Operational within a wide temperature range.
(7) Casing made from metal provides extra strength.
(8) Similarities in discharge voltage between CADNICA and dry cells allow interchange ability.
(9) High reliability in performance due to high standard quality control in manufacturing process based on ISO9000 standards.

## 1-2 Theory of Operation, Manufacturing Processes and Structural Designs of CADNICA Batteries

### 1-2-1 Theory of Operation

As its name suggests, the Nickel-Cadmium battery has a positive electrode made of nickel hydroxide and a negative electrode in which a cadmium compound is used as active material. Potassium hydroxide is used as its electrolyte. During change and discharge, the following reactions take place:

(At the positive)

$$NiOOH + H_2O + e^- \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} Ni(OH)_2 + OH^- \quad 0.52V \cdots (1)$$

(At the negative)

$$Cd + 2OH^- \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} Cd(OH)2 + 2e^- \quad -0.80V \cdots (2)$$

(Overall)

$$2NiOOH + Cd + 2H_2O \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} 2Ni(OH)_2 + Cd(OH)_2$$

$$1.32V \cdots (3)$$

(Standard electromotive force)

Namely, at the positive electrode, changes take place between nickel oxyhydroxide and nickel hydroxide, and at the negative electrode between cadmium metal and cadmium hydroxide.

In Eq. (3) above, potassium hydroxide does not play a role in the electrochemical reaction of the Nickel-Cadmium battery apparently. In addition, it is a well-known fact that the $H_2O$ molecules which are generated during charge disappear during discharge. Therefore, variations in electrolyte concentration are insignificant. Because of this reaction, the Nickel-Cadmium battery excels in temperature characteristics, high-rate discharge characteristics, durability, etc. Most significant is the fact that the amount of electrolyte in a cell can be sizably reduced in order to allow completely sealed cells to be manufactured.

With any other types of batteries, the discharged active materials will be exhausted as the batteries reach a fully charged state. Consequently, electrolysis of water contained in electrolyte commences. It is well-known that at this stage oxygen and hydrogen gases begin to be generated respectively at the positive and negative electrodes. This will result in a decrease of water contained in electrolyte. At the same time, the gases will build up the internal pressure of a battery. Finally, the battery will be destroyed or electrolyte will run short, deteriorating the charge/discharge characteristics.

Because of its unique design, the CADNICA battery is capable of completely consuming the gases that evolve internally, extending its normal service life. Some of its notable design features are as follows:

(1) Active materials have greater capacity at the negative than at the positive electrode.
(2) The electrode used features superior conductivity and exemplary uniform distribution of its active materials.
(3) The electrodes are thin plates having a large surface area. The negative and positive electrodes sandwich a separator through which gases freely move. These are wound tightly and housed in the casing.
(4) The electrolyte in a cell is kept to the precise quantity needed for the required output capacity.

Fig.1-1 illustrates the charging process of the CADNICA battery. As shown in this process chart, the positive electrode becomes fully charged well before the negative electrode which is larger in capacity. Then, oxygen gas is generated by the electrolysis of water in the following manner.

$$4OH^- \longrightarrow 2H_2O + O_2 + 4e^- \quad \cdots\cdots\cdots\cdots (4)$$

Oxygen gas migrates to the negative electrode where it is recombined and removed from the gas phase.

Thus, the negative electrode will not become fully charged and there will be no generation of hydrogen gas. Because cadmium reacts quickly to oxygen, they produce cadmium hydroxide at the negative electrode where cadmium metal is produced on charge. This takes the process described in Eq. (5).

$$Cd + 1/2O_2 + H_2O \xrightarrow{\text{Gas Recombination}} Cd(OH)_2 \quad \cdots\cdots\cdots (5)$$

$$Cd(OH)_2 + 2e^- \xrightarrow{\text{Charge}} Cd + 2OH^- \quad \cdots\cdots\cdots (2)'$$

The cadmium hydroxide produced by the process described in Eq. (5) is originally a discharge product of the negative electrode as is clear from Eq. (2)'. If overcharge current is limited, the reaction rate in Eq. (5) will ultimately catch up with the reaction rate in Eq. (4) and a balance will be achieved. In other words, the apparent charging of the negative electrode will cease to continue any further. This means that the negative electrode will remain short of being fully charged all the time and the generation of hydrogen gas will not occur.

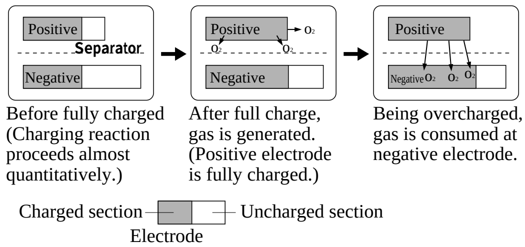
Besides the chemical recombination mechanism of oxygen gas described above, oxygen gas is recombined electrochemically in the CADNICA battery.

As explained previously, the CADNICA battery is composed of electrodes which have very large surface areas. These are placed side by side, sandwiching a separator which allows the free passage of gaseous substance. Accordingly, the oxygen gas generated at the positive electrode moves through the separator and reaches into the negative electrode, where it is quickly reduced due to the prevalent state of potential. Consequently, at the boundaries of three phases — namely oxygen gas (gas), electrolyte (liquid) and negative electrode (solids) — the reaction shown in Eq. (6) takes place, causing oxygen gas to be recombined.

$$2H_2O + O_2 + 4e^- \longrightarrow 4OH^- \quad \cdots\cdots\cdots(6)$$

The CADNICA battery has a mechanism of completely disposing of the entire quantity of oxygen gas generated in its sealed casing.

**Fig.1–1: Gas–Recombining Mechanism of CADNICA Battery**




## 1–2–2 Manufacturing Processes of CADNICA Batteries

In order to guarantee the performance characteristics which a sealed sintered Nickel-Cadmium cell should possess, its manufacturing processes are very sophisticated and consist of many stages, A sintered plate, for example, is processed as follows to guarantee the critical quality needed to maintain the excellent performance of CADNICA batteries.

First of all, nickel powder, which is very small in apparent specific gravity and large in specific surface area, is mixed with a thickening agent and water which in turn is applied on both faces of a core substance, such as thin nickel-plated steel plate, dried, and then sintered in reducing atmosphere so as to produce a sintered base plate of 80 to 85% porosity, and 0.4 to 0.8mm thickness. The quality of this plate, which supports active materials, has great bearing upon the performance characteristics of sealed cell to be manufactured.

In the next stage, active materials, which are produced from nickel and cadmium salts and which are insoluble in water, are loaded in the plate. This process is most important because the characteristics of the plate are determined in this stage. At Sanyo, this process is controlled with great care and constant improvements have been made for better results.

The active materials are then reactivated and washed clean before the electrodes are wound in a roll, being isolated from each other by a porous separator. In the final process, they are assembled into a cell and are made ready to undergo strict inspections prior to shipment form the factory.

## 1-2-3 Structural Designs of CADNICA

Sanyo CADNICA batteries range in type from standard batteries to fast-charge batteries, or high temperature batteries for exclusive use as well as in capacity from 45mAh to 20 Ah to meet diverse user requirements. Though each type has its own structural design according to its required performance, the basic structural design is identical.

Fig.1-2 illustrates the internal view of a CADNICA battery where the electrodes are very thin sintered plates wound compactly in a roll and insulated from each other by a porous separator. Almost the entire room inside the cell casing is occupied by this roll so that energy efficiency as well as charge/discharge, and temperature characteristics are raised to the highest possible levels. The cell casing is made of solid steel.

Although Sanyo CADNICA batteries are designed to completely recombine gas generated within their casings, they have a gas release vent, as illustrated in Fig.1-3, which opens automatically and releases excessive pressure when the internal gas pressure increases. Then it is resealed so that the battery can be used again. Furthermore, because Sanyo's original current collector is employed for both the positive and negative tabs(some models excepted), internal impedance is extremely small and excellent characteristics are exhibited, even under high-rate discharge conditions.

**Fig.1-2: Structural Design of CADNICA Battery**

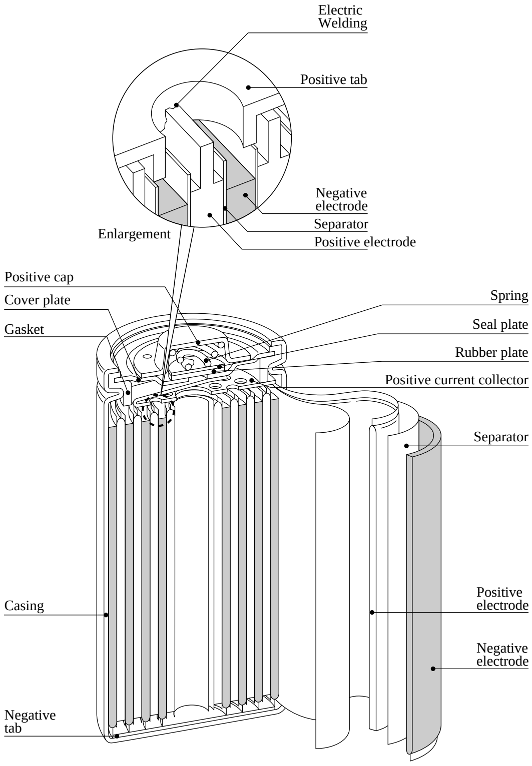
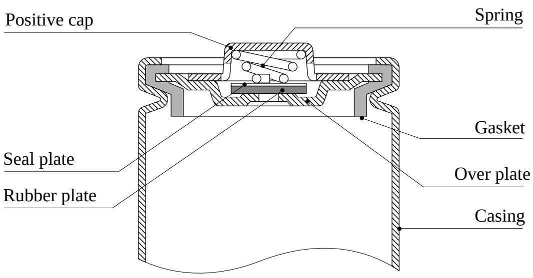



**Fig.1-3: Structural Design of Gas Release Vent**



# 2

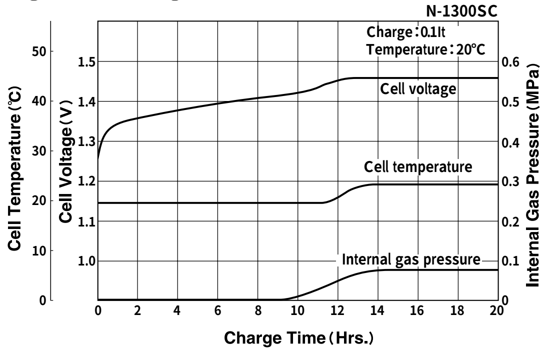
# Charge Characteristics



## 2−1 Outline of Charge Characteristics

CADNICA batteries should be charged with constant or quasi-constant current. As illustrated in Fig.2-1, the general characteristics of CADNICA batteries such as cell voltage, internal gas pressure and cell temperature vary during charge, depending on charge current and ambient temperature.

**Fig.2−1: Charge Characteristics**




As mentioned in Section 1-4 above, the sealed structure of CADNICA batteries has been achieved by recombining oxygen gas, which is generated at the positive electrode during overcharging, at the negative electrode. However, since recombining capacity is limited, the charge current of each model is determined by first calculating the balance of oxygen gas generated at the positive electrode against the negative electrode's gas recombination capability.

As long as the input rate is kept lower than the specified value, internal gas pressure during charging will stay low and oxygen generation will not be excessive even in the late period of charging.

The fast-charge type of Sanyo CADNICA batteries is designed to accelerate oxygen gas recombination, permitting a charge rate of 0.3It for some models. 1 hour charge is also possible with a simple external circuit.

## 2−2 Charge Efficiency

"Charge efficiency" is the term expressing how effectively input energy is used for charging the active materials into a useful, dischargeable form as against total input energy and can be defined as follows:

Charge Efficiency(%)

$$= \left\{ \frac{\text{Discharge Current} \times \text{Discharge Time to Discharge End Voltage}}{\text{Charge Current} \times \text{Charge Time} \times 100} \right\} \times 100$$

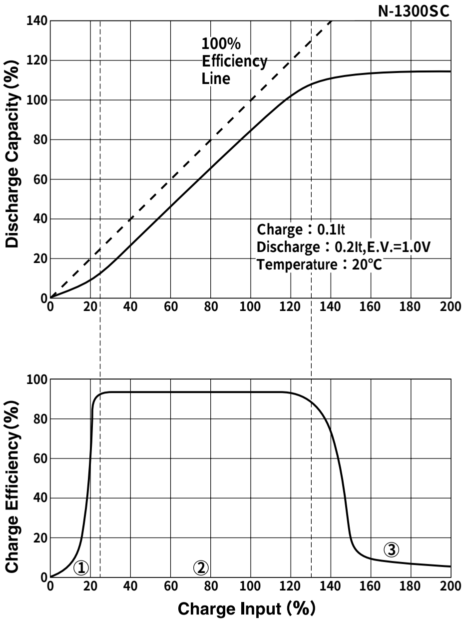
Input energy is used to convert the active materials into a charged form, and the side reactions to generate oxygen gas, etc. Fig.2-2 shows the correlations of input energy to the output capacity, and the charge input to charge efficiency when a completely discharged cell is charged at the rate of 0.1It. The figures given for charge input and discharge capacity are shown as a percentage of nominal battery capacity. Charge efficiency varies considerably in the course of charging as seen in the figure. The dotted line indicates an ideal cell of 100% charge efficiency.

In area①, of the charts below, electric energy is mainly consumed for the conversion of active materials in the electrode into a chargeable form. Therefore, charge efficiency is low at this stage.

In area②, which marks the middle of the charging process, charging is carried out in a near ideal state, with almost all of the input energy used for the conversion of active materials.

In area③, the cell approaches the state of full charge. There the input energy is used for the reaction which generates oxygen gas. The charge input is lost and consequently charge efficiency decreases.

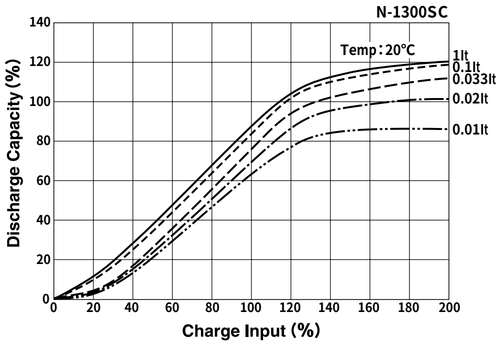
**Fig.2−2: Charge Efficiency**




Charge efficiency depends on charge rate. Fig.2-3 is a chart on the correlations existing between the charge input and the output capacity, as functions of charge rate. The chart shows that the charge efficiency as well as the output capacity is lower at a lower charge rate.

Be sure to charge within the current range specified. When charging is performed out of the specified current range, charging efficiency is reduced and the battery cannot be fully charged.

**Fig.2−3: Charge Efficiency vs Charge Rate**




Charge efficiency also depends on ambient temperature during charge. Fig.2-4 illustrates the correlations between charge input and discharge capacity, using the ambient temperature as a parameter. It is noted that there is a slight decrease in cell capacity in the high temperature range due to a fall in potential for oxygen gas generation at the positive electrode. This decrease in cell capacity is a temporary phenomenon and the cell capacity will be recovered when charged at normal temperature. Fig.2-5 illustrates the cell capacity vs ambient temperature.

**Fig.2−4: Charge Efficiency vs Ambient Temperature**

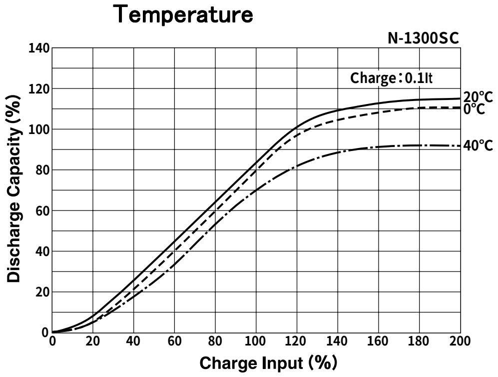
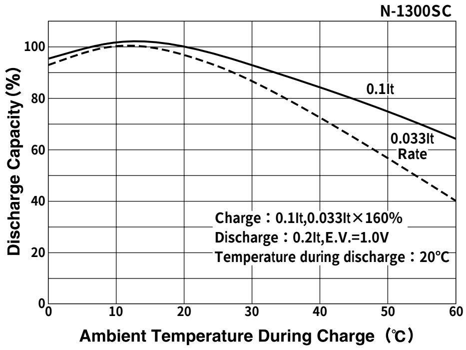


**Fig.2–5: Discharge Capacity vs Ambient Temperature**




The charge efficiency depends largely on charge rate and ambient temperature; therefore the appropriate type of CADNICA battery should be selected according to the operating requirements.

## 2–3 Cell Temperature during Charge

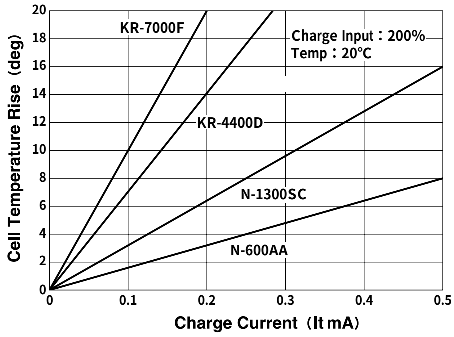
Though charging reaction in CADNICA batteries is in itself endothermic, cell temperature changes very little during the initial and intermediate steps of charging and is compensated by heat generated by internal resistance. Input energy during overcharge is converted to heat energy which is generated through gas recombination reaction; therefore the cell temperature rises. The following factors may cause cell temperature to rise:

(1) Charge current
(2) Cell design
(3) Design of battery, (shape, number of cells, etc.)
(4) Ambient condition, (temperature, ventilation, etc.)

Fig.2-6 illustrates the correlation cell temperature rise vs charge current with respect to different types of batteries. Here generated heat increases with charge current, and so does the value of temperature rise which also depends on battery type in proportion to its size. The battery arrangement or the thermal conductance of casing materials becomes important for battery assemblies where the closely packed arrangement, or the poor thermal conductance of casing materials, causes a larger temperature rise.

Any battery should be charged at a normal ambient temperature, and the charging conditions should be carefully selected after due consideration to the heat generation of cells. The fast-charge batteries are controlled according to generated heat during over-charge, so the investigation of heat generation becomes more significant. Details on this subject may be found in paragraph 6-2.

**Fig.2–6: Charge Current and Cell Temperature Rise**



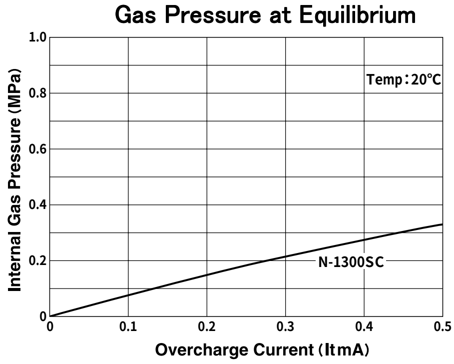

Note: Measured With Single Cell

## 2–4 Internal Gas Pressure during Charge

In CADNICA batteries, oxygen gas generated during overcharge is recombined in the sealed cell. When continuing charging with the specified cur-rent, the internal gas pressure achieves a balance according to the gas generation and recombination rate.

Fig.2-7 shows changes in internal gas pressure when a newly produced cell is tested by varying the charge input after the onset of overcharge. Oxygen gas is generated in an amount proportionate to the charge current on overcharge and causes the internal gas pressure to build up.

**Fig.2–7: Overcharge Current and Internal Gas Pressure at Equilibrium**




The internal gas pressure tends to increase with lower ambient temperature as shown in Fig.2-8. The gas recombination rate at the negative electrode decreases with lower ambient temperature so that the charge current should be accordingly lower. Fig.2-9 shows a sample of recommended charging current at low temperatures.

**Fig.2-8: Charge Temperature and Internal Gas Pressure**

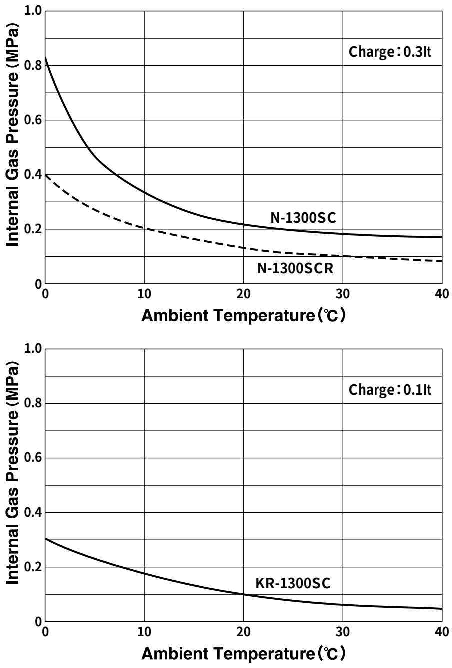
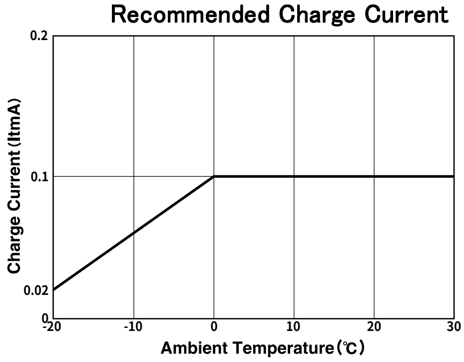



**Fig.2-9: Ambient Temperature and Recommended Charge Current**




Note: For some models, charge currents differ from the figures shown above.

## 2-5 Cell Voltage

The cell voltage of Sanyo CADNICA batteries varies, depending on charge current, ambient temperature during charge, cell design and other factors.

The cell voltage increases in the course of charging, and drops slightly in the end to its equilibrium value because of heat generation within the cell, as shown in Fig.2-1. Fig.2-10 illustrates the cell voltage as a function of charge current where charge voltage goes higher with an increase in charge input, accompanied by increased internal resistance and polarization values inside the cell.

The cell voltage also depends on ambient temperature, as shown in Fig.2-11, where the temperature rise results in voltage decrease.

As the temperature climbs, there is a decrease in internal resistance as well as in oxygen gas generation potential. During charge at the 0.1It rate, charge voltage fluctuates within a range of −3.0 to 4.0mV/degree. Fig.2-12 illustrates the range of cell voltage at the end of charging in relation to ambient temperatures at the charge rate of 0.1It.

**Fig.2-10: Charge Current and Cell Voltage**

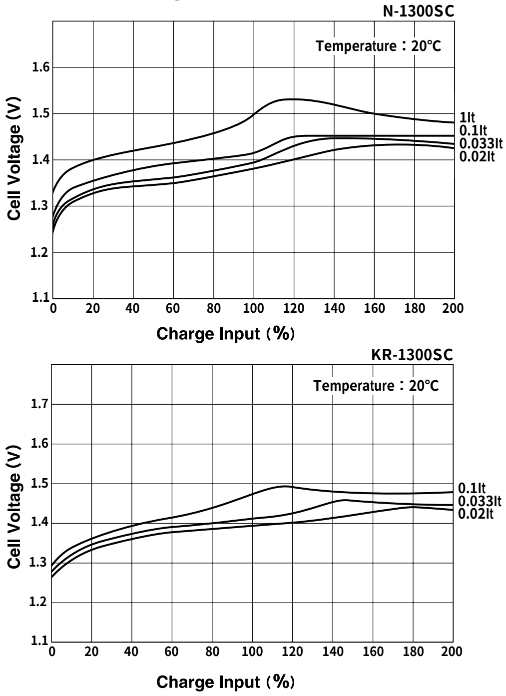


**Fig.2–11: Ambient Temperature and Cell Voltage**

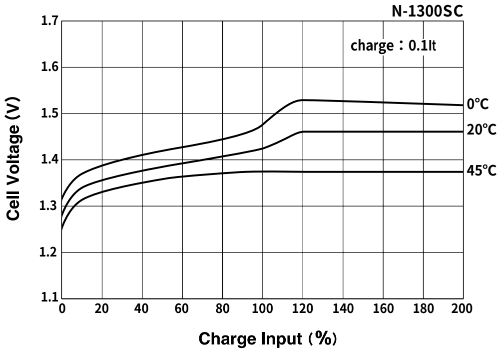
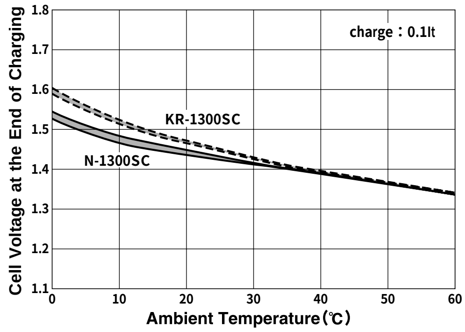



**Fig.2–12: Ambient Temperature and Cell Voltage at the End of Charging**



# 3

# Discharge Characteristics

3–1 Outline of Discharge Characteristics

3–2 Internal Resistance

3–3 Discharge Capacity

3–4 Polarity Reversal

## 3–1 Outline of Discharge Characteristics

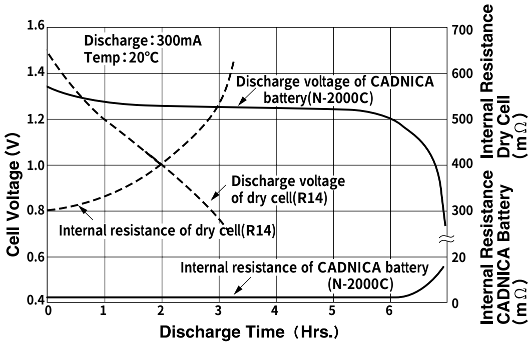
Discharge voltage and cell capacity (self-sustaining discharge duration) are the units commonly employed to express the discharge characteristics of batteries. The voltage of a Nickel-Cadmium cell remains almost constant at 1.2V until most of its capacity is discharged. Discharge voltage drops very little even during high current discharge, and a great amount of current more than 100It can be discharged in a very short time.

The capacity of CADNICA batteries is defined in terms of the time from the start to the end of discharge multiplied by the discharge current, where the unit is Ah, (ampere hours), or mAh, (milliampere hours).

The capacity given for each type of CADNICA battery is specified by a 5 hour rate at 0.2It discharge current. However, the actual capacity depends on discharge current and ambient temperature.

Fig.3-1 compares the discharge characteristics of an ordinary dry cell and a CADNICA battery. The cell voltage decreases with discharge in an ordinary dry cell, while the CADNICA battery exhibits an excellent characteristics of constant discharge voltage due to its low internal resistance, and less variation during discharge.

**Fig.3–1: Discharge Characteristics of Ordinary Dry Cell and CADNICA Battery**



## 3–2 Internal Impedance

As mentioned previously, the discharge voltage of a CADNICA battery remains stable for a long duration. One of the factors which explain this is the battery's low internal impedance. The low internal impedance is due mainly to the use of thin and large surface sintered nickel plates which exhibit excellent conductivity. and a thin separator of nonwoven fabric which exhibits excellent electrolyte retention. Internal impedance is a key parameter for the discharge characteristics of batteries.

### 3–2–1 Components of Internal Resistance

Discharge voltage of CADNICA batteries is expressed as below:

$$V = E_0 - IZ$$

where: $E_0$ = no load or open circuit voltage
I = discharge current
Z = internal resistance

This equation confirms that discharge voltage is higher with lower internal resistance. Internal resistance consists of 3 resistive components: $Z = r + r\eta + jX$. In this equation, "r" represents ohmic resistance due to conductivity or structure of current collector, electrode plates, separator, electrolytes, etc. The "$r\eta$" denotes the resistance due to polarization, when polarization is a phenomenon where the electrode potential's value deviates from the equilibrium one when current circulates through the electrodes. Ohmic resistance "r" is independent of current, while polarization "$r\eta$" varies in a complicated way according to current. "$r\eta$" also value with time and needs several seconds to reach its equilibrium value. Thus "$r\eta$" is negligible for discharge pulse duration of a few milliseconds. "jX" denotes reactance for example, the resistance caused by alternating-current wave.

The reactance is very low at normal charge/discharge. Thus, discharge voltage during discharge is written as below:

$V = E_0 - I \times (r + r\eta)$ (during discharge)
$V = E_0 - I \times r$ (momentary, after start of discharge and for discharge pulses of a few milliseconds.)

The internal impedance of a cell varies due to various factors. As shown in Fig.3-2, the internal impedance of CADNICA batteries undergoes almost no change during discharge from the state of full charge to the point where 90% of its capacity has been dissipated. After that point it increases due to the conversion of active materials in the electrode plates into hydroxides, which tend to lower electrical conductivity.

Fig.3-3 illustrates the effect of ambient temperatures on internal resistance. The internal impedance increases as the temperature drops, because the conductivity of electrolytes is lower at lower temperatures.

**Fig.3–2 Internal Impedance and Discharge Capacity**

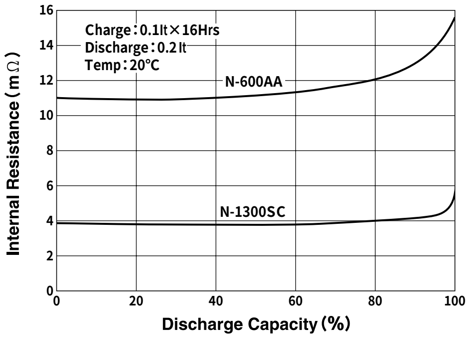
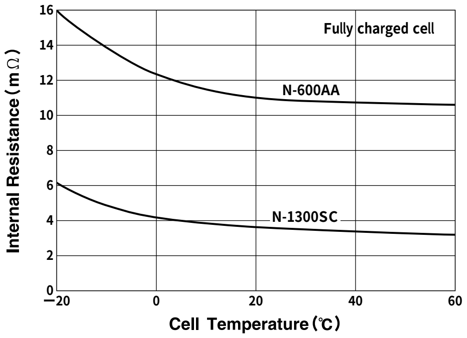



**Fig.3–3: Internal Impedance and Cell Temperature**




### 3–2–2 Measurements of Internal Impedance

There are two methods of measuring internal impedance; the direct-current method and the alternating-current method. The internal impedance of CADNICA batteries is difficult to estimate because of its low impedance and complicated variables.

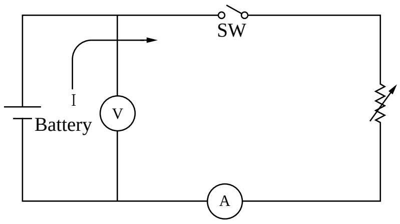
(1) Direct-current method

Fig.3-4 illustrates a basic wiring diagram for this method. Close the switch Sw and record the changes of current and voltage while adjusting the variable-resistance Rv. When the change of variable-resistance is low, then the voltage change is approximated by a straight line; where it drops off and gives the value of internal impedance.

$$\text{That is, } R = \frac{\Delta V}{\Delta I}$$

The internal impedance estimated by the direct-current method is equal to $r + r\eta$, as mentioned before, where the polarization term is included, so that it varies with the increase in current, or the current circulation period.

**Fig.3–4: Internal Impedance Measured by Direct Current Method**




(2) Alternating-current method

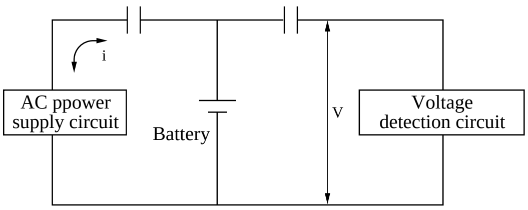
The alternating-current method is used to avoid the influence of polarization. The basic circuit for the alternating-current method consists of an AC power supply circuit and a voltage detection circuit, as shown in Fig.3-5.
The alternating-current impedance is calculated from the voltage drop at constant alternating-current through a cell as:

$$Z = \frac{\Delta v}{\Delta i}$$

The impedance estimated by the alternating-current method is equal to r + jX, where the reactance term is included, though polarization is negligible.

Impedance when using AC current varies according to current frequency. The technical data of Sanyo gives the value estimated by the alternating-current method (at 1 KHz) unless otherwise specified.

**Fig.3–5: Measuring Internal Resistance by Alternating–Current Method**




## 3–3 Discharge Capacity

The capacity of CADNICA batteries is derived from the discharge current and the time from start to finish of discharge. Here the influence of discharge end voltage, discharge rate, ambient temperature during discharge, etc., on discharge capacity will be discussed.

### 3–3–1 Discharge End Voltage

When estimating battery capacity and discharge in actual applications, the discharge end voltage is defined as the limiting voltage when a battery is considered to have no residual capacity. The standard end voltage adopted for CADNICA batteries is 1.0 V/cell. The end voltage can be 1.1 V/cell, (for signal of emergency lamps), or 1.02 V/cell, (for automatic fire alarms), according to operational requirements. CADNICA batteries have extremely stable voltage characteristics during discharge, and the voltage drop occurs suddenly at the end of discharge, so that the difference in the discharge capacity is minor when specified in terms of the end voltage around 1.0 V/cell. The difference in the discharge time at the 1 It rate would be within a range of 1 to 2 minutes between the end voltage, 1.0 V/cell and 1.1 V/cell. Since the cell voltage drops at high current discharge, the energy stored in the battery may not be fully discharged with discharge end voltage higher than 1.0 V/cell.

## 3−3−2 Discharge Rate

The discharge capacity of a cell decreases as the discharge current increases, as shown in Fig.3-6, since the active materials of electrodes are used less effectively with higher discharge current. Fig.3-7 illustrates that the discharge voltage drops as the discharge current increases. The reason is an increased loss of energy due to internal resistance.

Compared with other batteries, CADNICA batteries have an excellent high current discharge capabilities where the continuous discharge at the rate of 4 It or, in some types, a high current discharge of over 10 It is possible.

**Fig.3−6: Discharge Rate and Discharge Capacity**

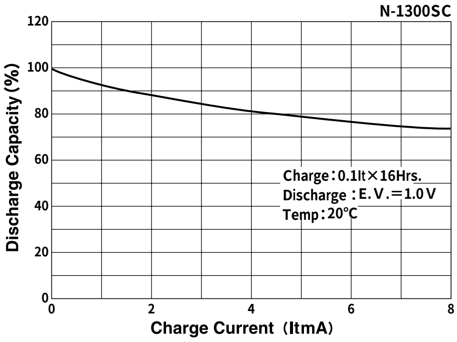
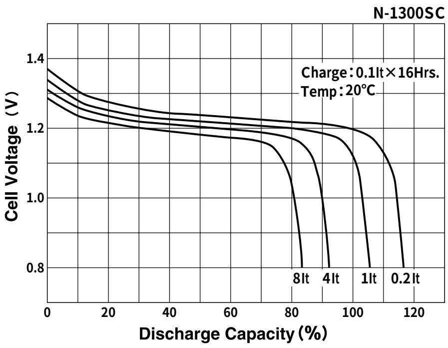



**Fig.3−7: Discharge Voltage Characteristics**




## 3−3−3 Ambient Temperature

Sanyo CADNICA batteries can be used over a very wide temperature range, from. −20℃ to + 60℃. Though the discharge characteristics will not change as the temperature increases, a drop in temperature causes internal impedance to be higher, and active materials to be less reactive, so that the discharge capacity as well as the discharge voltage decreases. The tendency is more marked in higher rates of discharge. This decrease of discharge capacity is a temporary phenomenon, much like the decrease in capacity at high-temperature. Figs.3-8 and 3-9 illustrate the discharge temperature characteristics and the discharge voltage characteristics of CADNICA batteries.

**Fig.3−8: Discharge Temperature Characteristics**

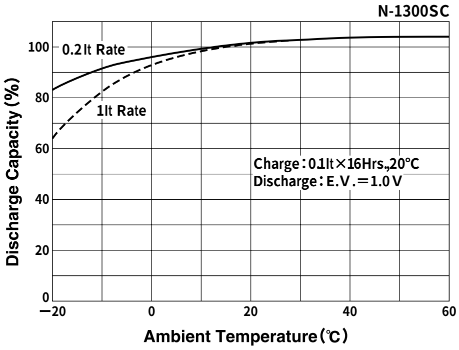
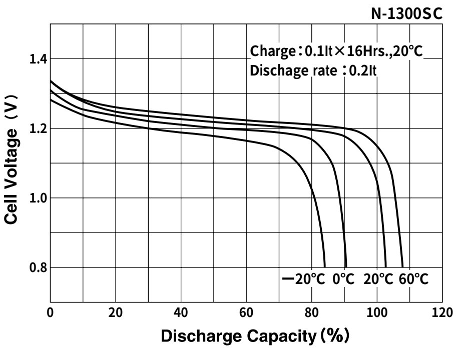



**Fig.3−9: Discharge Voltage Characteristics**



## 3–4 Polarity Reversal

Deep discharge of series connected cells, when differences in residual capacity between cells exist, may cause one of the cells to reach the state of complete discharge sooner then the others. As it becomes over-discharged, its polarity is reversed. See Fig.3-10 for the discharge voltage curve of the cell on forced discharge, including polarity reversal.

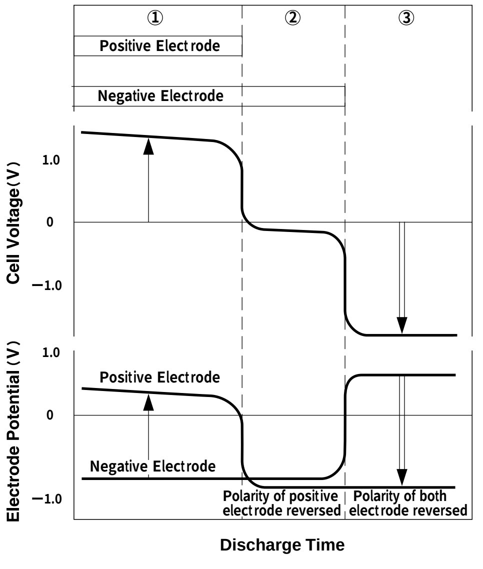
Section① of the graph shows the period when recharged active materials remain on both positive and negative electrodes, with charging voltage at normal levels.

Section② shows the period when all the active materials on the positive electrode have been discharged and hydrogen gas starts to be generated on the positive electrode, creating a hydrogen gas build up inside the cell. Active materials still remain at the negative electrode, however, and discharging continues at this electrode. Cell voltage changes according to discharge current, but stays about −0.2 ～−0.4V.

In section③, discharging has been completed at both the positive and negative electrode, and oxygen gas starts being generated at the negative electrode. In prolonged discharging where this type of polarity reversal takes place, gas pressure within the cell rises, resulting in operation of the gas release vent. This also leads to a breakdown of the balance of the charging capacity of the positive and negative electrodes, thus prolonged discharge should be strictly avoided.

If a cell is left connected to a load for a long period of time, the cell will eventually become completely discharged and its output voltage will drop to 0V. If this occurs, the polarity of the positive electrode will become negative(−0.8V) and electrolyte may easily creep. Therefore, avoid leaving a cell connected to a load for too long a time.

**Fig.3–10: Polarity Reversal**



# 4

# Storage Characteristics



## 4–1 General

Generally speaking, a loss of voltage and capacity of batteries due to self-discharge during storage is unavoidable. With open-type Nickel-Cadmium batteries, or manganese dry cells, this self-discharge is less notice-able than with CADNICA batteries which have a large facing electrode area and a limited amount of electrolyte, all of which are completely sealed.

The following 2 factors greatly affect the self-discharge of Nickel-Cadmium batteries while storage:

(1) Instability of active materials.
Nickel oxide is thermodynamically unstable at its charged state and self-decomposes gradually to generate oxygen gas, which in turn oxidizes the negative electrode. Thus, the self-discharge proceeds.

(2) Impurities in electrodes or electrolyte.
A typical example is the self-discharge due to nitrate impurities. Nitric ion, $NO_3^-$, is reduced from a negative electrode to nitrous ion, $NO_2^-$ which diffuses to a positive electrode, and is oxidized. Thus, the self-discharge proceeds.

The portion of the capacity of CADNICA batteries which is dissipated by self-discharge may, however, be completely restored when recharged.

## 4–2 Storage Conditions

### 4–2–1 Storage Temperature

CADNICA batteries can be stored at temperatures ranging from −30℃ to 50℃ without essential deterioration in performance. The organic materials, such as gasket or separator, may deteriorate or become deformed at high temperatures during prolonged storage. Thus, it is recommended that CADNICA batteries be stored at temperature below 35℃ if there is a possibility of prolonged storage surpassing 3 months.

A decrease in capacity during storage is determined mainly by ambient temperature. Fig.4-1 illustrates self-discharge characteristics of CADNICA batteries stored at 0, 20, 30 and 45℃.

### Fig.4–1: Storage Characteristics

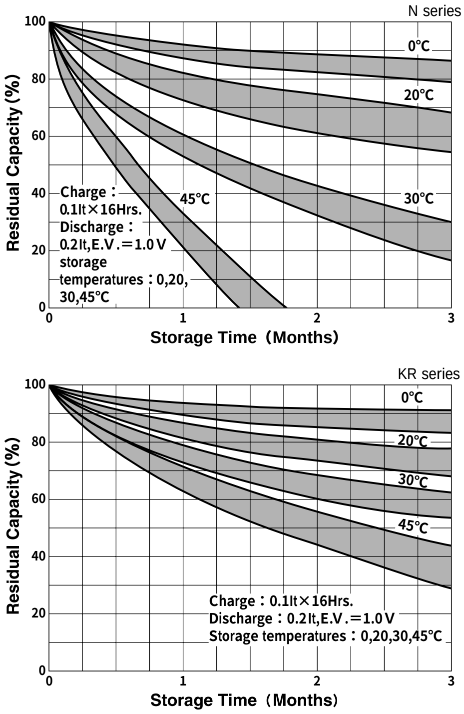
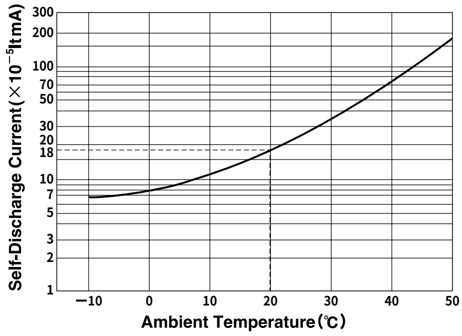



Fig.4-2 shows the relationship between ambient temperature and the self-discharge current of CADNICA batteries, using this graph, the approximate self-discharge current can be determined as shown by the example.

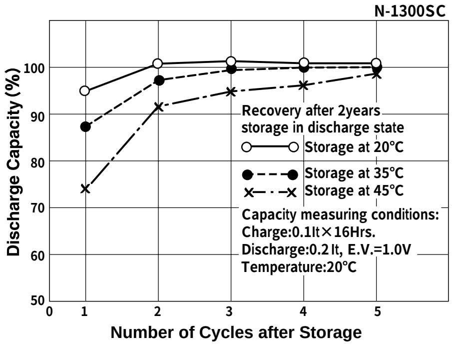
### Fig.4–2 Self–Discharge Current and Ambient Temperature




**Example:The self-discharge current Is of N-600AA at 20°C** is estimated as:
Is=(nominal capacity)×(self-discharge current ItmA)
=(600)×(18×10$^{-5}$)(mA)=108×10$^{-3}$(mA)
=108(μA)

Fig.4-3 illustrates the capacity recovery characteristics after prolonged storage at respective temperatures. The inactivity of active material is increased during high-temperature storage, and as a result, the capacity recovery time may be longer. As mentioned before, it is recommended that CADNICA batteries be stored at low temperatures.

### Fig.4–3: Storage Temperature and Capacity Recovery Characteristic

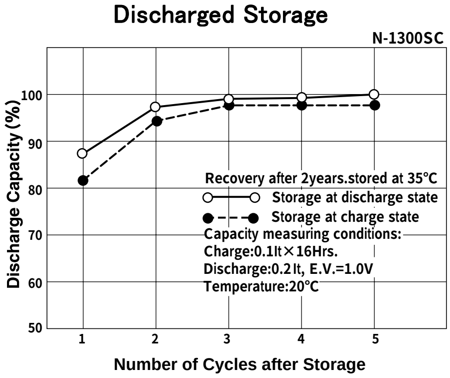



## 4–2–2 Battery Conditions

CADNICA batteries may be stored in charged or discharged state. Fig.4-4 compares the capacity recovery characteristics of charged and discharged CADNICA batteries after prolonged storage. Though the capacity is recovered with a couple of charge/discharge cycles in either case, the capacity recovery of a discharged battery is more quickly achieved.

Due to differences in self-discharge rate, sealed cells in a CADNICA assembled battery may have varying degrees of available capacity after having been in storage for an extended period of time, so they should be recharged prior to being returned to service. If this is not done, polarity reversal may occur in some of the cells. It is advisable for prolonged storage that batteries be in the discharged state.

### Fig.4–4: Charged Storage vs Discharged Storage



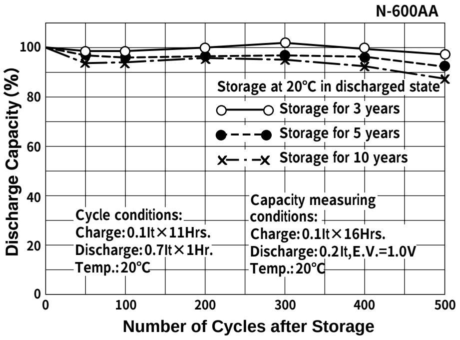
### 4-2-3　Storage period

Sanyo CADNICA batteries can be stored indefinitely without the deterioration of electrodes, which is often observed in lead-acid batteries.

Fig.4-5 illustrates sample cases concerning the cycle characteristics of cells stored for 3, 5 and 10 years respectively.

Even in the case of long-term storage, the cell's high rate capacity does not significantly decrease and superior cycle characteristics are maintained.

**Fig.4-5　Cycle Characteristics After Prolonged Storage**




## 4-3 Items to be Remembered for Storage

Though CADNICA batteries are maintenance-free, and require no supply of electrolytes, or water during storage, the following guidelines should be observed to make best use of battery capacity:

(1) Batteries should be completely discharged prior to prolonged storage.

(2) Batteries should be stored at the possible lowest temperature. The temperature should never exceed +35℃ for prolonged storage.

(3) Batteries should be recharged prior to use after prolonged storage.

# 5

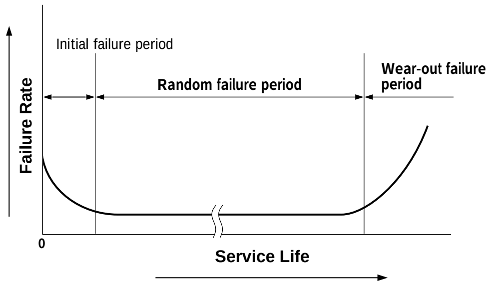
# Battery Service Life



## 5-1 General

The service life is defined as, "The length of time it takes a battery to reach a state of "wear-out failure," where it can no longer drive the necessary load. Here the wear-out failure denotes the failure during the period when the failure rate increases with time due to the elements of fatigue, abrasion of aging, and is distinguished from the initial failure and the random failure, which denote the failure due to errors in design/production or unsuitable specifications, and accidental failure, between the initial failure and the wear-out failure period, respectively.

**Fig.5-1: Failure Rate Curve**




The wear-out failure of CADNICA batteries is classified into 2 types. One is due to an internal short circuit caused by changes in active materials and the deterioration of organic materials, such as a separator. The other is due to the electrolyte drying up. In normal charge and discharge cycles no electrolyte will leak outside the cell due to CADNICA battery's completely sealed structure. A small amount of leakage may occur from the safety vent or the sealed part if the battery is charged with a current higher than specified, overdischarged until polarity reversal occurs, or used at extremely high/low temperatures. Repeated loss of electrolyte will eventually increase internal resistance and decrease capacity.

The service life of CADNICA batteries is generally considered to terminate when their available capacity has been lowered to less than 60% of the nominal capacity.

This rule, however, is not applicable in conditions where, depending upon operating requirements, the termination point of their service life is set higher or lower than the above mentioned level. Shown in Fig.5-2 is the number of charge/discharge cycles in relation to discharge capacity. CADNICA batteries exhibit excellent cycle characteristics where no noticeable drop is observed after 500 charge/ discharge cycles under Sanyo specified conditions.

In addition, CADNICA batteries exhibit excellent cycle characteristics even for pulse discharge cycle applications.

Fig.5-3 shows sample pulse discharge cycle characteristics.

Fig.5-4 provides data regarding continuous charging. As the figures demonstrate, CADNICA batteries can be used for extremely long periods on continuous charge cycles.

**Fig.5–2: Cycle Characteristics**

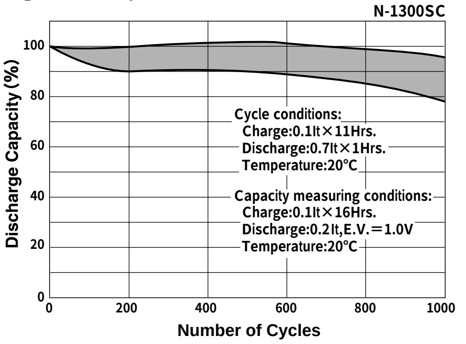



**Fig.5–3: Pulse Discharge Cycle Characteristics**

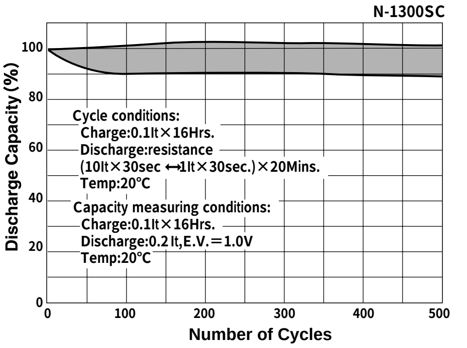
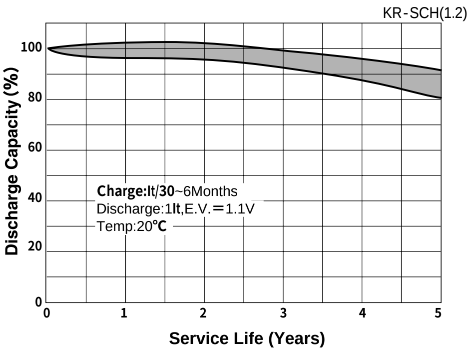



**Fig.5–4: Continuous Trickle Charge Cycle Characteristics**



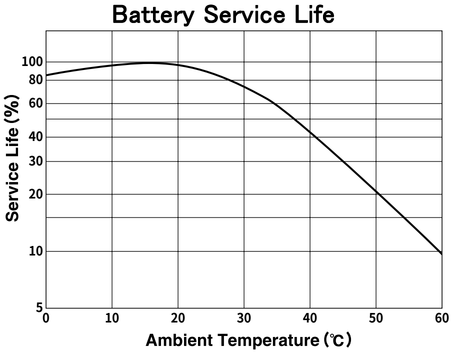

## 5–2 Factors Influencing Service Life

### 5–2–1 Cell Temperature

One of the most important factors affecting the service life of a CADNICA battery is ambient temperature. Fig.5-5 illustrates an approximate relation between ambient temperature and battery service life. Generally speaking the optimum temperature is room temperature and temperatures higher than 40℃ will deteriorate cell performance. Exposure to a high temperature for a short time however will not cause permanent damage and will recover with a couple of charge/discharge cycles at room temperature. The most adverse effects of a prolonged rise in cell temperature may be seen as damage to organic materials. Used at high temperatures for a long time, the separator in particular is gradually damaged, and its insulation function decreases, resulting in internal short circuit.

Overcharging and continuous charging at high temperatures should be avoided. This accelerates deterioration of the separator through oxidization resulting from oxygen generated at the positive electrode during overcharging.

**Fig.5–5: Ambient Temperature and Battery Service Life**




### 5–2–2 Charge Conditions

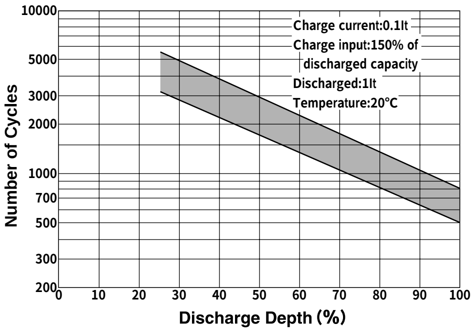
The charge current of a CADNICA battery is specified according to its design. As long as a CADNICA battery is charged at an input rate below the specified value, internal gas pressure remains at a low level. However, heat generated by gas recombination causes a rise in cell temperature. When overcharging is repeated often, heat deteriorates the cell and shortens its service life. Charging at rates over specified value increases internal gas pressure, occasionally causing operation of the gas release vent and should be avoided.

The batteries as standby power sources of emergency lights or signal lights, are continuously charged with trickle charge current in order to maintain a fully charged state. Nickel-Cadmium batteries, in general, show the discharge voltage drop, due to crystal deformation of active materials with continuous charging over long periods. This is rarely observed in CADNICA batteries.

### 5-2-3 Discharge Conditions

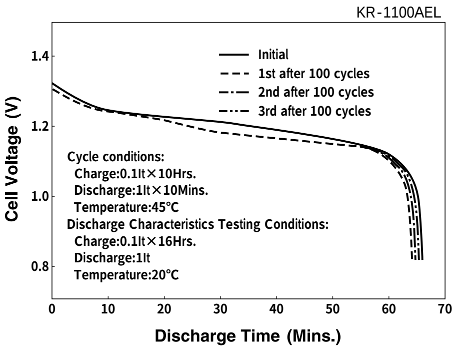
Even when fully discharged, a CADNICA battery recovers its capacity by charging. Over-discharge has only a minor effect on CADNICA batteries compared with lead-acid batteries."Depth of discharge"is the term used to express percentage wise the capacity removed from a battery at the onset of discharge from the state of full charge. The number of cycles CADNICA batteries can withstand depends on the depth of discharge as illustrated in Fig.5-6. When the cell is discharged to a greater depth, the number of cycles decreases.

**Fig.5-6: Discharge Depth and Battery Service Life**



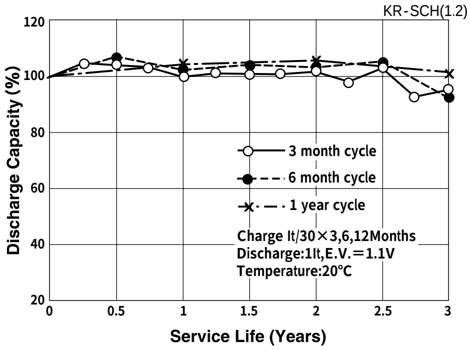

Nickel-Cadmium batteries have a "memory-effect" in which the voltage drops by 2 levels during discharge after shallow charge/discharge cycles. In application when discharge end voltage is highly established, apparent decreases in capacity and operating voltage are shown. This phenomenon doesn't occur after 1 or 2 complete discharge cycles.

**Fig.5-7: Memory Effect**




The battery performance is hardly affected by the discharge frequency during continuous charge of reserve power supply, as illustrated in Fig.5-8, which represents the continuous charge cycle characteristics in 3, 6 and 12 months.

**Fig.5-8: Discharge Frequency and Cycle Characteristics**

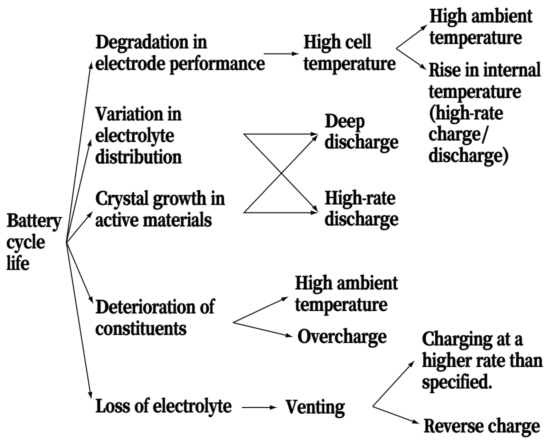



## 5-3 Summary of Service Life

In the preceding paragraphs various factors affecting the service life of Sanyo CADNICA batteries have been discussed. The conclusion of the discussion is that, if they are used under normal operating conditions, a very long service life can be expected.

CADNICA battery life is determined by these factors which relate to one another in an intricate manner. Thus, it is difficult to predict how long they will generally perform well.

The relevant factors to battery life are summarized below:




Good understanding of these relevant factors will assist the designer of battery-powered devices in obtaining the longest life, optimum performance, and greatest reliability from Sanyo CADNICA batteries.

# 6

# Special Purpose Batteries

6-1 High-Capacity CADNICA Batteries

6-2 Fast-Charge CADNICA Batteries

6-3 High-Temperature CADNICA Batteries

6-4 Heat-Resistant CADNICA Batteries

6-5 Memory-Backup CADNICA Batteries (CADNICA BACKUP)

CADNICA Batteries may be used in various fields with excellent results as mentioned before. Sanyo has designed CADNICA batteries for special purposes that concur with necessary requirements, and further improve the efficiency of the devices in which they are used.

The basic structural design of CADNICA batteries for exclusive use, is the same as that of standard CADNICA batteries. The characteristics of CADNICA batteries for exclusive use succeed respective excellence of standard CADNICA batteries. CADNICA batteries for exclusive use are by no means limited to a particular field, but may be used for many purposes.

## 6-1 High-Capacity CADNICA Batteries

### 6-1-1 Characteristics

The growing use of compact and lightweight equipment has rapidly increased the need for a high-capacity battery. In anticipation of this trend, Sanyo has developed high-capacity CADNICA batteries with approx. a 40-percent higher capacity featuring a significant improvement in energy density while employing the same manufacturing method used for highly-reliable standard CADNICA batteries. They can also be charged in as little as one hour.

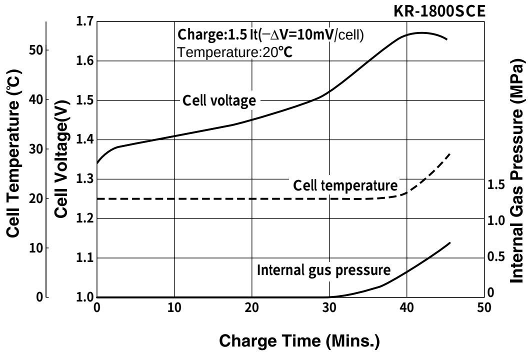
### 6-1-2 Charge Characteristics

High-capacity CADNICA batteries are designed for improved gas recombination in order to facilitate fast charging. They are capable of one-hour charging via $-\Delta V$ sensor fast charge system.

Fig.6-1 shows the charge characteristics for $-\Delta V$ sensor fast charging.

Please refer to Chapter 7-3 for information regarding $-\Delta V$ sensor fast charging.

**Fig.6-1: Charging Characteristics**



### 6−1−3 Discharge Characteristics

The discharge voltages of standard CADNICA batteries show extremely smooth voltage characteristics up to the end of the discharge period. High-capacity CADNICA batteries share this advantage, and in addition, through a significant improvement in energy density, they exhibit a capacity 40% greater than previous models.

Fig.6-2 shows the discharge characteristics of high-capacity CADNICA batteries, while Fig.6-3 shows the relationship between discharge current and discharge capacity. As the figures demonstrate, high-capacity CADNICA batteries maintain a higher capacity than standard CADNICA batteries at low, medium or high current discharge levels.

**Fig.6−2: Discharge Characteristics**

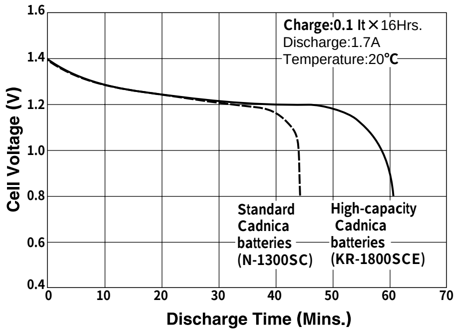
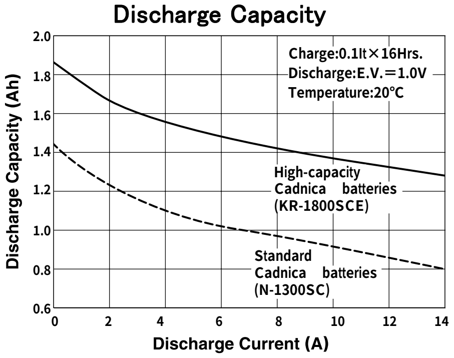



**Fig.6−3: Discharge Current and Discharge Capacity**

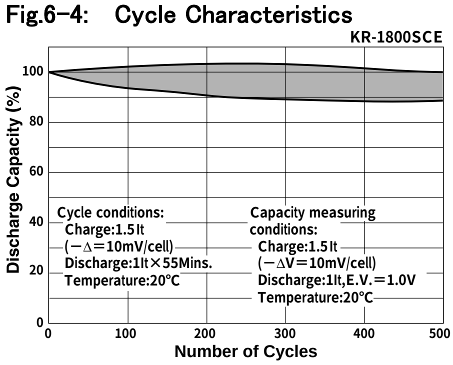



### 6−1−4 Service Life

The service life of high-capacity CADNICA batteries differs according to the conditions of use. The manufacturing process for high-capacity CADNICA follows that of standard CADNICA batteries, which have consistently demonstrated high reliability. Therefore high-capacity CADNICA batteries also attain a cycle service life equivalent to that of standard CADNICA batteries.

Fig.6-4 shows an example of cycle characteristics with −ΔV sensor fast charging. It is possible to use high-capacity CADNICA batteries for more than 500 charge/discharge cycles.

**Fig.6−4: Cycle Characteristics**




## 6−2 Fast−Charge CADNICA Batteries

### 6−2−1 Characteristics

Standard CADNICA batteries require a charging period of 14 to 16 hours at a standard charge current of0.1It. In order to meet demands for a faster charging speed, fast-charge CADNICA batteries have been developed. Designed to facilitate recombination of oxygen gas generated at the electrode, they offer the following advantages:

(1) One-hour quick-charge capability

With the temperature sensor fast-charge system or the −ΔV sensor fast charge system, charging time can be reduced to as little as approx. one hour.

For −ΔV sensor fast charging and temperature sensor fast charging, see chapter 7-3.

(2) Excellent high current discharge characteristics

Through the use of Sanyo's original highly-efficient current collecting method, plus an electrode that demonstrates superior discharge characteristics, these batteries possess excellent voltage characteristics at high rate discharge.

## 6-2-2 Operating Principle of Fast-Charge CADNICA Batteries

Sanyo CADNICA batteries generate oxygen at the positive electrode as the state of full charge is approached, according to the following equation, as discussed already in 1-4.

$$4OH^- \longrightarrow 2H_2O+O_2+4e^- \quad \cdots\cdots\cdots\cdots\cdots(1)$$

In the overcharge region, the charging current is completely consumed in gas generation. When the charge current is"a"A, oxygen gas is generated at a rate of 208 × a ml/hr. at 1atm and 20℃. Generated gas is recombined at the negative electrode according to the following formulas:

$$Cd+1/2O_2+H_2O \longrightarrow Cd(OH)_2 \quad \cdots\cdots\cdots\cdots(2)$$
$$O_2+2H_2O+4e^- \longrightarrow 4OH^- \quad \cdots\cdots\cdots\cdots\cdots(3)$$

Oxygen gas is generated in proportion to the charge current so that the oxygen consumption reaction in Eqs. (2) and (3)must be accelerated in order to charge at a higher current. Otherwise, unconsumed oxygen gas increases the internal pressure to such a level that the safety vent will operate. As seen from Eqs. (2) and (3), the oxygen consumption reaction takes place in the 3-phase zone where the 3 phases, electrolyte (liquid), oxygen(gas)and electrode(solid), come into contact with each other.

Fast-charge CADNICA batteries are specifically designed in terms of electrode structure and electrolyte distribution so that a large number of 3-phase zones may be formed. This design makes possible fast charging over a period of approx. 1 hour.

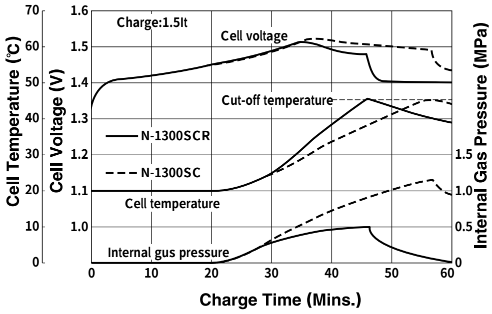
With the temperature-sensor fast-charge system, the charging condition is assessed by detecting the surface temperature of the battery. The oxygen gas recombination reaction at the negative electrode is shown by the above Eqs.(2) and (3). Eq. (2) details an oxidized reaction of the metal cadmium, which results in high heat generation. This heat in turn causes an increase in the battery surface temperature. Fast-charge CADNICA batteries are designed for faster recombination of generated oxygen gas and feature improved internal heat conductivity, making a quick increase in surface temperature possible.

## 6-2-3 Charge Characteristics

Fig.6-5 shows the charge characteristics of fast-charge CADNICA batteries in comparison with standard CADNICA batteries. In order to increase gas recombination capability, fast-charge CADNICA batteries possess a slightly reduced cell capacity. Therefore their peak voltages appear earlier during the charging cycle.

Fast-charge CADNICA batteries show lower charge voltages at the end of charging due to the ease with which heat is generated within the cell, a result of their high capability for oxygen gas recombination.

**Fig.6-5: Fast-Charge Characteristics**




The internal gas pressure of a standard CADNICA battery cell quickly increases during charging, while that of a fast-charge CADNICA battery stabilizes at approx. 5kg/cm$^2$.

When only gas recombination is taken into consideration, fast-charge CADNICA batteries can be said to be capable of withstanding overcharging at a current level as high as 1.5It. If overcharging continues, however, the cell temperature will continue to increase. After a time, it may badly damage the battery. In order to prevent the occurrence of this problem, fast charging must be suspended after the appropriate amount of time.

Fig.6-6 shows the relationship between the level of overcharge current and the internal gas pressure, while Fig.6-7 shows the relationship between the ambient temperature during charging and the internal gas pressure.

**Fig.6-6: Overcharge Current and Internal Gas Pressure**

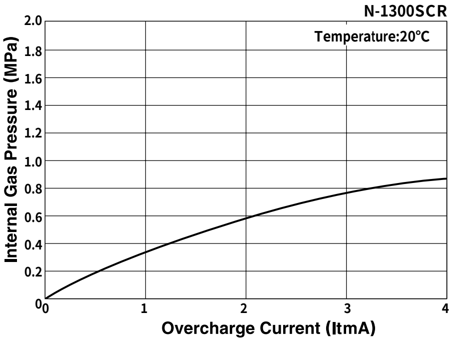
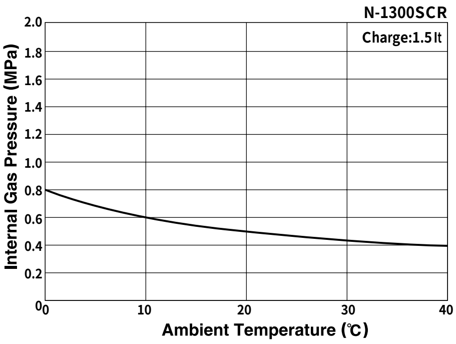



**Fig.6-7: Ambient Temperature and Internal Gas Pressure**

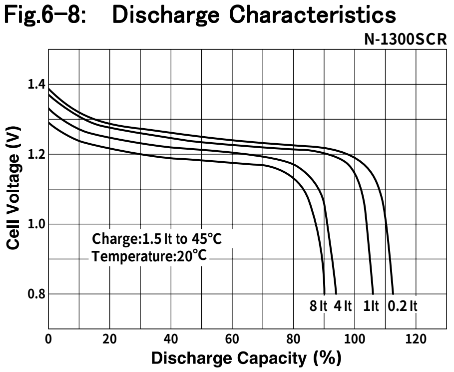



## 6-2-4 Discharge Characteristics

Fast-charge CADNICA batteries employ sintered plates which exhibit excellent discharge characteristics for both the positive and negative electrodes. In addition, through the utilization of Sanyo's original highly-efficient current collecting method which demonstrates superior discharge characteristics, these batteries offer an extremely stable discharge performance, even at high current levels.

Fig.6-8 shows an example of discharge characteristics.

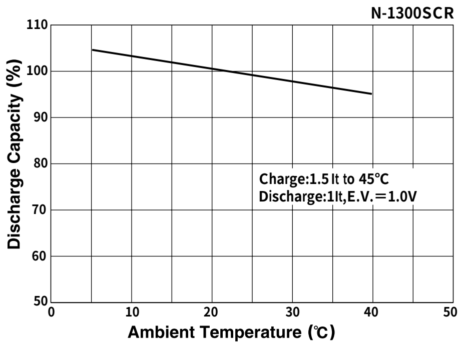
**Fig.6-8: Discharge Characteristics**




## 6-2-5 Temperature Characteristics

One of the greatest features that −ΔV-sensor and temperature-sensor fast-charge systems offer is the capability of achieving stable cell capacity over a wide range of temperatures. However, at low temperature, gas recombination capacity is reduced and internal gas pressure can increase to a level that adversely affects service life. Therefore, be sure to perform fast-charging under the specified temperature. Fig.6-9 shows charge temperature characteristics.

**Fig.6-9: Charge Temperature Characteristics**




## 6-2-6 Service Life

The gas recombination capability does not decline even after many cycles. Battery service life does, however, differ according to ambient conditions.

Although the factors affecting the service life of fast-charge CADNICA batteries are essentially the same as those of standard CADNICA batteries, the charging conditions of the two are very different. In the case of fast-charge models, the period of overcharge from the onset of temperature increase to charge cut-off, should be made as short as possible in order to ensure a long service life. Therefore the following precautions should be observed when designing fast-charge control circuits.

(1) Temperature-sensor fast-charge control
- (a) In the case of assembled batteries that easily radiate heat it takes a long time to reach the cut-off temperature. Sanyo recommends a design under which temperature increases are maximized, either by thickening the materials of the battery case or by utilizing materials which feature low heat conductivity.
- (b) Charged with a temperature-sensor system, CADNICA batteries tend to be overcharged in proportion to the difference between the ambient and cut-off temperatures. Decrease the setting value of the cut-off temperature when using at low temperature.

(2) −ΔV-sensor fast-charge control
- (a) In the case of assembled batteries that easily radiate heat, cell voltage decreases gently after reaching its peak. Sanyo recommends a design

under which temperature increases are maxim-ized, especially for CADNICA batteries of small capacity.

(b) The higher the $-\Delta V$ value becomes, the more the battery becomes overcharged. Set the $-\Delta V$ value to 10~20mV per single cell.

Fig.6-10 shows temperature-sensor fast-charge cycle characteristics. Use for more than 500 charge/disch-arge cycles is possible.

Fig.6-11 shows continuous-charge cycle characteris-tics.

Fig.6-12 shows super-fast-charge cycle characteris-tics. Use for more than 500 charge/discharge cycles is possible.

**Fig.6–10: Cycle Characteristics**

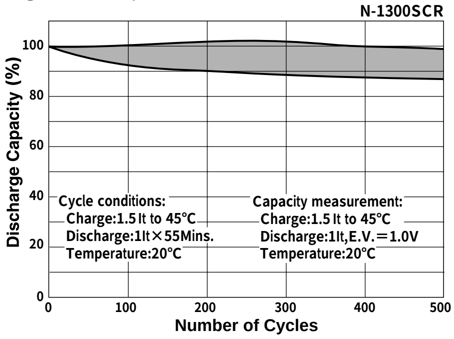



**Fig.6–11: Continuous–Charge Cycle Characteristics**

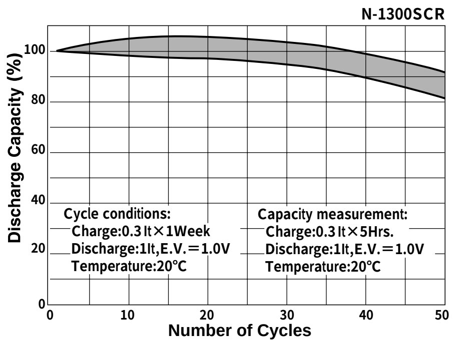
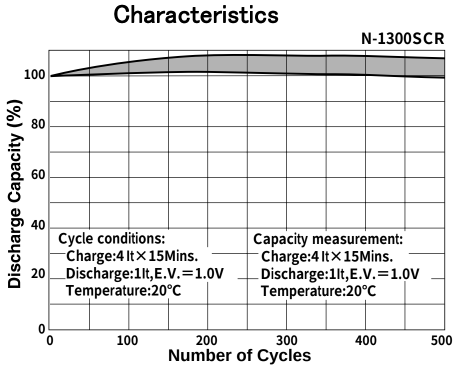



**Fig.6–12: Super–Fast–Charge Cycle Characteristics**




# 6–3 High Temperature CADNICA Batteries

## 6–3–1 Advantages of High Temperature CADNICA Batteries

Being maintenance-free, and having a high all-owance for overcharge, which no other secondary batteries have, high temperature CADNICA batteries are highly suitable for use in emergency lighting. For use in this case, the batteries are continuously charged with a low current, (trickle-charged), at a relatively high temperature, (35℃ to 45℃). High temperature CADNICA batteries were designed to meet necessary requirements for use in high temperature situations. Advantages in using high temperature CADNICA batteries are:

(1) Outstanding charge/discharge characteristics at high temperature.

The high temperature CADNICA battery has a high trickle-charge efficiency even in tempera-ture as high as 35℃ to 45℃.

(2) Long service life and high reliability.

The high temperature CADNICA battery shows a minor cycle-deterioration even at high temperature, and also withstand overcharge, ensuring a long service life.

## 6–3–2 Operating Principles of High Temperature CADNICA Batteries

The charging of Nickel-Cadmium batteries in general becomes more difficult at higher temperature, and with lower current. As explained in Chapter 2, this is because the charging reaction of active material (1), and the oxygen generation reaction (2), compete with each other at the positive electrode towards the end of charging.

$$Ni(OH)_2 + OH^- \longrightarrow NiOOH + H_2O + e^- \quad \cdots\cdots(1)$$
$$4OH^- \longrightarrow 2H_2O + O_2 + 4e^- \quad \cdots\cdots(2)$$

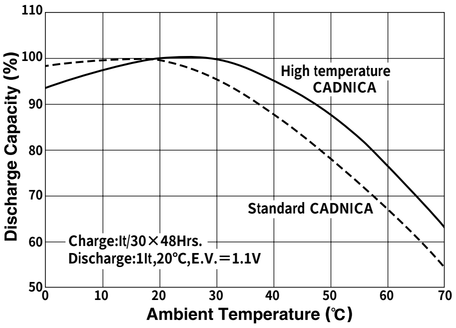
When oxygen gas is generated, the charging reaction at the positive electrode becomes reluctant to proceed. The generation potential of oxygen becomes lower with the increase of cell temperature, so that oxygen is generated in the earlier stage. As a result, the charge voltage is low, the charge efficiency at the electrode deteriorates, and the charge capacity becomes lower.

The high temperature CADNICA battery is made with specially designed electrodes and electrolyte, in order to maintain a high generation potential of oxygen, even at high temperature.

## 6-3-3 Temperature Characteristics

The high temperature CADNICA battery guarantees its outstanding characteristics even in high temperature. Fig.6-13 illustrates cell capacity as a function of ambient temperature where the cell capacity at 20℃ is taken as a standard (100%). The high temperature CADNICA battery exhibits maximum capacity at just over 20℃. Though its high temperature characteristics are much improved as compared with those of the standard CADNICA battery, the high temperature CADNICA battery has slightly lower discharge capacity at low temperature, as a result of improving its high temperature quality. However, the high temperature CADNICA battery can withstand a charge at 0℃, and a discharge at −20℃, as well as the standard CADNICA battery, so no practical problem exists.

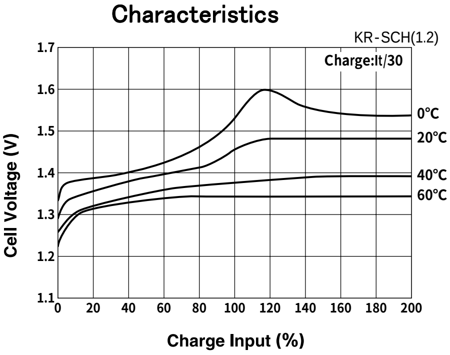
**Fig.6-13: Temperature Characteristics**




## 6-3-4 Charge Characteristics

The high temperature CADNICA battery is usually used at a trickle-charge of It/20 to It/50. Fig.6-14 illustrates the trickle-charge voltage characteristics with It/30 current. The charge voltage of the high temperature CADNICA battery is slightly higher than that of the standard CADNICA battery due to the improvement of its oxygen generating potential, as mentioned in 6-3-2.

**Fig.6-14: Trickle-Charge Voltage Characteristics**




## 6-3-5 Discharge Characteristics

The high temperature CADNICA battery has the same basic structure as the standard CADNICA battery. Thus, its discharge voltage exhibits a flat characteristics at the same voltage level as the standard CADNICA battery. The high temperature CADNICA battery shows improved discharge characteristics when trickle-charged in high ambient temperature. Figs.6-15 and 6-16 illustrate the high temperature trickle-charge characteristics, examples A and B, 45℃ characteristics as specified by JIS C 8705, respectively.

The discharge voltage drop often observed in Nickel-Cadmium batteries is only slightly detect-able in CADNICA batteries when charged continuously at high temperatures.

**Fig.6-15: High Temperature Trickle-Charge Characteristics Example A**

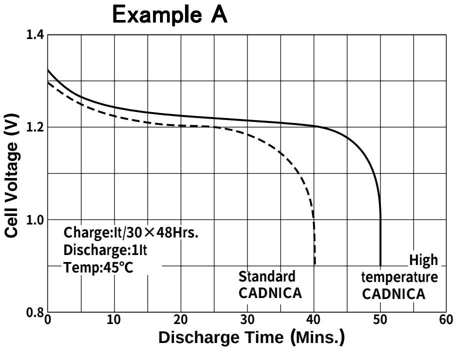
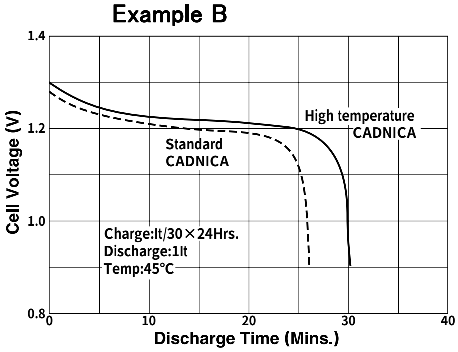



**Fig.6-16: High Temperature Trickle-Charge Characteristics Example B**

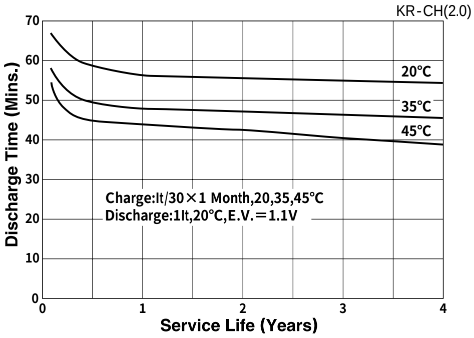


### 6-3-6 Service Life

The service life of the high temperature CADNICA battery depends largely on the ambient conditions, as mentioned in Chapter 5, though expected as over 4 years under normal conditions. Fig.6-17 illustrates cycle characteristics when trickle charged. The effects of ambient conditions on the service life are discussed in Chapter 5. As a rule the service life is shortened with higher ambient temperature and/or high charge current, but will be affected very little by a trickle charge current between It/50 and It/20.

High ambient temperature may deteriorate the electrodes and/or the cell constituents, and eventually shorten the life of the battery. In CADNICA batteries, appropriate materials are used to prevent this deterioration.

**Fig.6-17: Trickle Charge Service Life**




## 6-4 Heat-Resistant CADNICA Batteries

### 6-4-1 Features

Conventional batteries can be maintained in optimum condition when used at normal temperature. If they are used at high temperature however, service life greatly decreases. In anticipation of the growing need for batteries that perform well in warm environments, Sanyo developed high-temperature CADNICA batteries for use as a power source for emergency lighting, etc.

However, since high-temperature CADNICA batteries often require extended periods of charge at low rate(It/50~It/20), Sanyo developed heat-resistant CADNICA batteries which permit fast charging at high temperature.

Heat-resistant CADNICA batteries possess the following features:

(1) Quick charging at 0.3It is possible, even at temperature as high as 45 °~70℃

(2) Long service life and high reliability attained. Cycle deterioration at high temperature remains small.

### 6-4-2 Charge Characteristics

Fig.6-18 shows charge characteristics.

Fig.6-19 shows the relationship between ambient temperature and cell voltage.

In the high-temperature range, the cell voltage decreases significantly as the electrode potential of the cell is changed.

**Fig.6-18: Charge Characteristics**

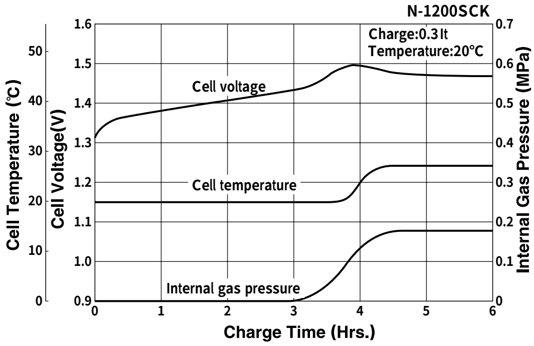
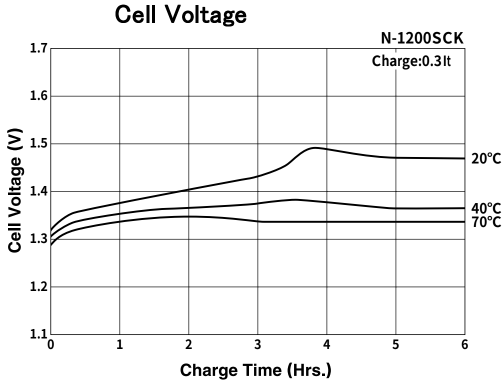



**Fig.6-19: Ambient Temperature and Cell Voltage**

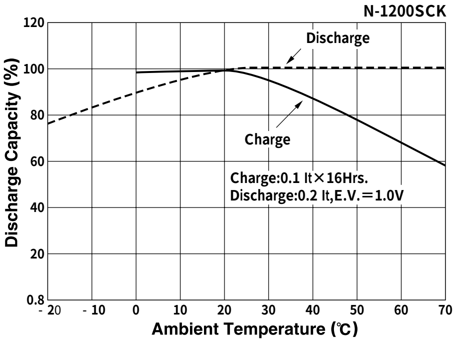


### 6-4-3 Temperature Characteristic

The temperature characteristics of heat-resistant CADNICA batteries are similar to those of standard CADNICA batteries. Compared with the latter, however, heat-resistant models are capable of charging and discharging at higher temperature.

Fig.6-20 shows the temperature characteristics of heat-resistant CADNICA batteries. Internal resistance and storage characteristics are almost the same as those of standard CADNICA batteries.

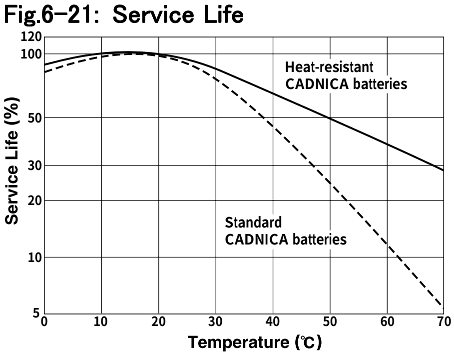
**Fig.6-20: Temperature Characteristics**




### 6-4-4 Service Life

Fig.6-21 shows the relationship between ambient temperature and service life for both standard and heat-resistant CADNICA batteries. At high temperature, the decrease in the performance of the electrode and the deterioration of other battery components become big factors shortening battery life. Through the use of specially selected materials, heat-resistant CADNICA batteries have been developed to provide a long service life, even at high temperatures.

**Fig.6-21: Service Life**




## 6-5 Memory-Backup CADNICA Batteries(CADNICA BACKUP)

### 6-5-1 Advantages of CADNICA BACK UP

Recent progress in electronics has increased the number of devices using semiconductor memories. Most memories tend to lose their memory the moment power is removed. A small sealed Nickel-Cadmium battery is used to compensate for this power failure. CADNICA BACKUP has been designed to overcome this failure with the following advantages:

(1) Long service life and high reliability.
CADNICA BACKUP has been especially designed for memory backup with a long and reliable service life.

(2) No leakage
There is no leakage of alkaline electrolyte, to damage printed circuit boards.

(3) Improved storage characteristics
The rate of self-discharge is reduced to half the rate of the standard CADNICA battery.

(4) Directly soldered to printed circuit board
The terminals are pin-shaped so that they can be soldered directly to the printed circuit board.

(5) Capable of high-rate discharge
The use of sintered electrodes makes it possible to discharge with a current as high as 1A, therefore, CADNICA BACKUP may be used as the power supply for large transistors.

### 6-5-2 Operating Principle of CADNICA BACKUP

A CADNICA BACKUP is a module composed type N-50SB1, N-50SB2, N50SB3, N-SB1, N-SB2, N-SB3, N-SB4, which are specially designed for memory backup. CADNICA BACKUP is provided with access terminals to printed circuit boards, so is easily mounted.

CADNICA BACKUP is developed to provide long service life under the condition that deep charge and rest or shallow discharge with a low current of several $\mu$A are repeated alternately. Generally, in this application, it is well known that crystal growth of negative active materials tends to cause internal short circuits.

However CADNICA BACKUP uses improved electrodes, separator and electrolyte which guarantee a long service life as well as outstanding storage characteristics.

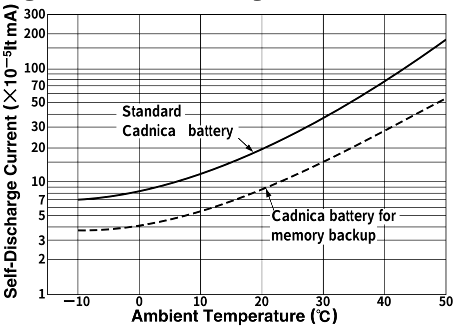
## 6−5−3 Discharge Characteristics

When a battery is used for memory backup, the discharge current can be as low as a few μA, which in some cases is lower than the self-discharge current of the battery. The time of memory retention thus depends on the self-discharge rate of the battery. Fig.6-22 compares the self-discharge current of the CADNICA BACKUP with that of standard CADNICA battery.

Compared with standard CADNICA batteries, CADNICA BACKUP has a minimal self-discharge current. Therefore, memory retention time is great even when operation has stopped for long periods of time, making it extremely suitable as a memory backup.

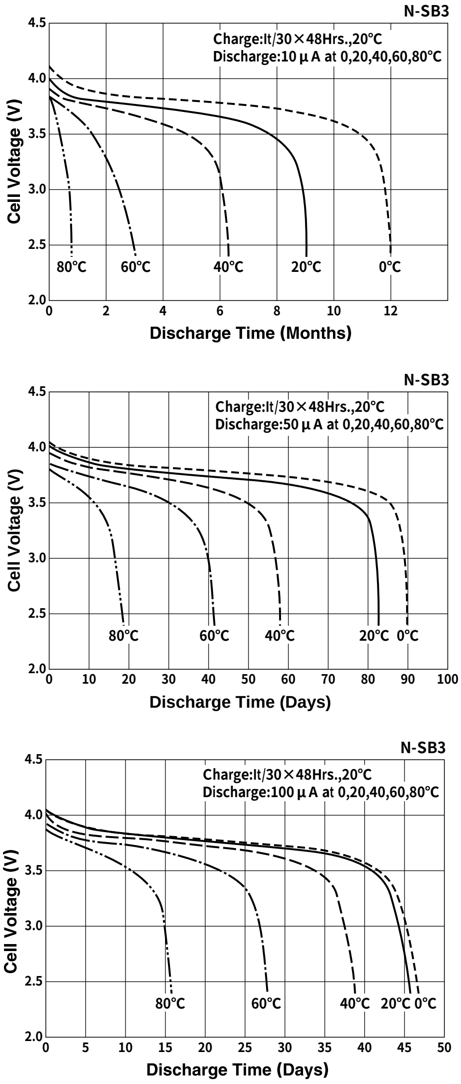
Fig.6-23 shows low-rate discharge characteristics.

**Fig.6−22: Self−Discharge Characteristics**




(Note:refer to page 20 for calculation method of self-discharge current.)

**Fig.6−23: Low−Rate Discharge Characteristics**



The CADNICA BACKUP is designed for low-rate discharge. Thus, its internal resistance is slightly higher than the standard CADNICA battery. Its discharge qualities, therefore, are not as good as those of the standard CADNICA battery at a high-rate discharge over 2It. The CADNICA BACKUP, however, is capable of high-current discharge because of the high-quality sintered electrodes.

**Fig.6–24: Discharge Characteristics**

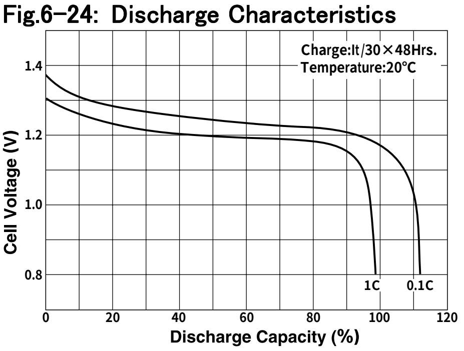
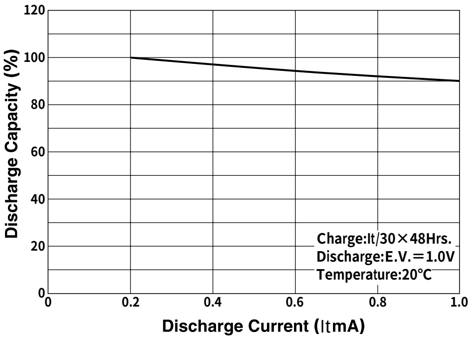


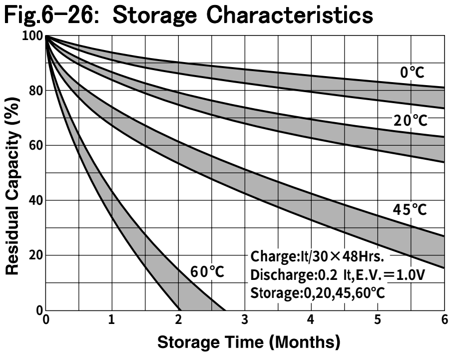

**Fig.6–25: Discharge Rate Characteristics**




## 6–5–4 Storage Characteristics

The CADNICA BACKUP also offers outstanding high temperature storage quality in comparison with the standard CADNICA battery. Fig.6-26 illustrates storage characteristics of the CADNICA BACKUP.

**Fig.6–26: Storage Characteristics**




## 6–5–5 Other Characteristics

CADNICA BACKUP as well as the standard CADNICA battery guarantees stable temperature characteristics over a wide range of temperature as shown in Fig.6-27. CADNICA BACKUP exhibits an extraordinary long life, unlike the standard CADNICA battery, when used for low current charge/discharge, Fig.6-28 illustrates the effect on the service life when tests were performed under extreme temperature conditions accelerating battery deterioration.

The factors affecting the service life of CADNICA BACKUP are the same as those for the standard CADNICA battery, discussed in Chapter 5. Since the ambient temperature plays an important role in battery service life, CADNICA BACKUP should be mounted away from any heat generating parts on the circuit board.

**Fig.6–27: Temperature Characteristics**

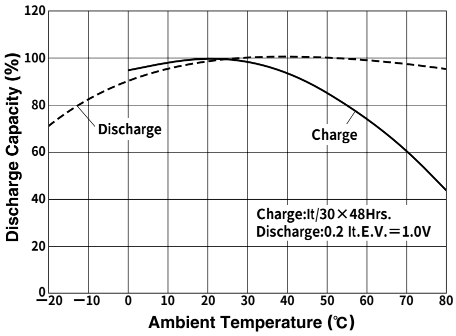
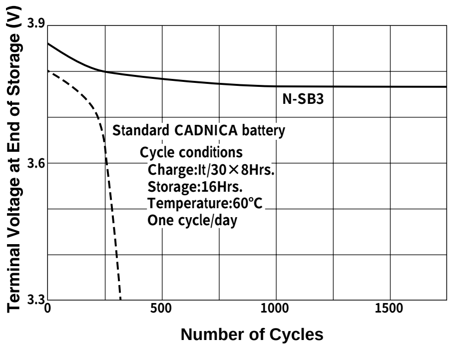



**Fig.6–28: Accelerated Service Life Characteristics**



# 7

# CADNICA SLIM



## 7–1 Characteristics of CADNICA SLIM

As the trend for lightweight and compact equipment continues, there is a requirement for batteries to perform to even higher standards. In answer to this need, Sanyo has developed CADNICA SLIM“KF Series” batteries that maintain the superior characteristics for which all CADNICA batteries (cylindrical type) have gained a high reputation.

The development of CADNICA SLIM is based on the high capacity technology first introduced by Sanyo in its CADNICA “E Series” batteries, allowing the energy density to be increased by 50% over conventional CADNICA batteries.

A further advantage of new CADNICA SLIM batteries over conventional batteries is that their shape (form factor) allows creating volume efficiency in equipment. This means that the battery space can be reduced, while the capacity remains same.

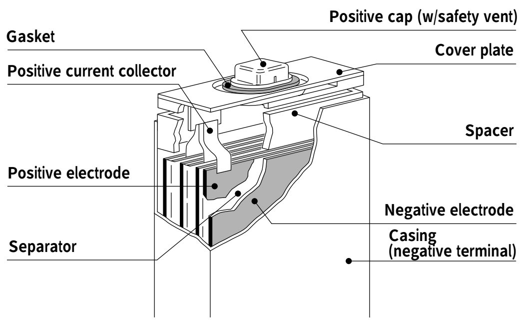
## 7–2 Structure of CADNICA SLIM Batteries

Fig.7-1 shows the inner structure of CADNICA SLIM.

The electrodes have been manufactured using the method outlined in 1-4-2. For CADNICA SLIM batteries, the finished electrodes are cut to predetermined dimensions and placed in the metal casing. There are then hermetically sealed in place to the cover plate. All sides of the casing and the cover plate are laser welded together to prevent electrolyte leakage and thus ensure high reliability.

To guard against the possibility of misuse, the same safety system has been built into these batteries as is used in conventional cylindrical CADNICA batteries.

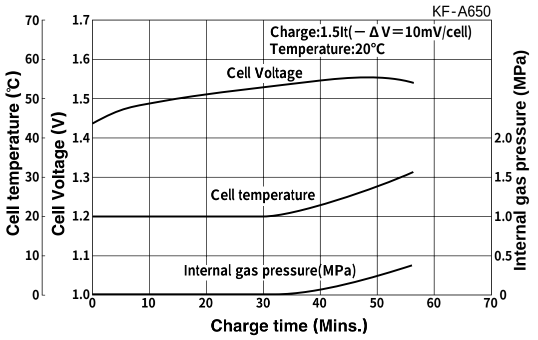
**Fig.7–1: Structural Design of CADNICA SLIM**



## 7–3 Charge Characteristics

To allow fast, approx. one-hour charging, the gas recombination capability has been improved. Fast charging control circuit, battery voltage sensoring system or $-\Delta V$ voltage sensoring system is employed. Fig.7-2 shows fast-charge characteristics.

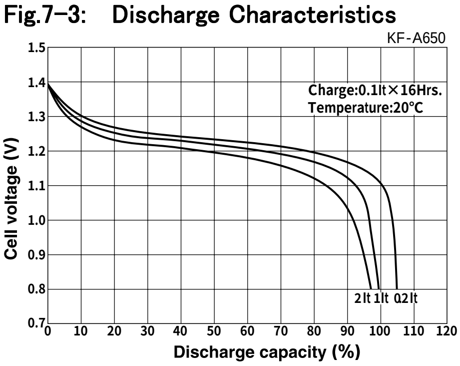
**Fig.7–2: Charge Characteristics**




## 7–4 Discharge Characteristics

CADNICA SLIM uses sintered plates which have superior discharge characteristics at both positive and negative electrodes. Thus, extremely flat regulated battery voltage characteristics are maintained throughout discharge. Although CADNICA SLIM exhibits the same superior discharge characteristics as cylindrical CADNICA batteries, the new cell structure has higher internal resistance. Therefore, when a current greater than 4It is applied, the discharge characteristics are slightly reduced compared to conventional batteries. Fig.7-3 provides a sample of discharge characteristics.

**Fig.7–3: Discharge Characteristics**

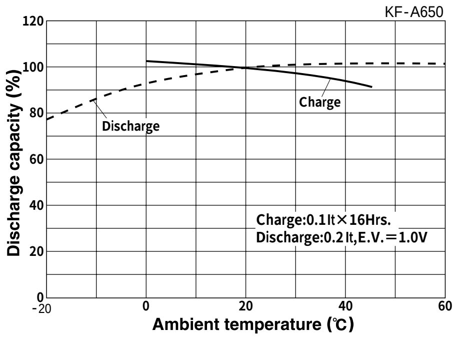



As the assembled batteries use a specific tab, your nearest Sanyo representative should be consulted when continuous discharge at a current higher than 4It or pulse discharge required.

## 7–5 Temperature Characteristics

CADNICA SLIM exhibits the same superior temperature characteristics as cylindrical CADNICA batteries. Fig.7-4 provides a sample of temperature characteristics.

**Fig.7–4: Temperature Characteristics**



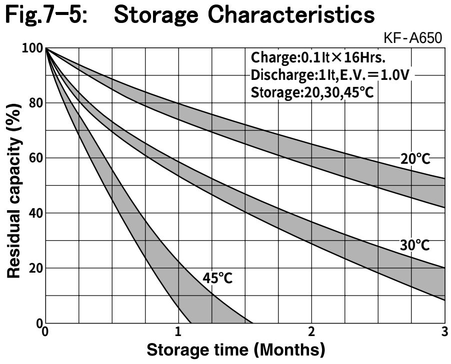

## 7–6 Storage Characteristics

Like cylindrical CADNICA batteries, CADNICA SLIM batteries do not need maintenance during its usable life. To ensure the best performance, the following precautions should be taken:

1. When batteries are stored for long periods of time, the battery should be discharged and they should be removed from any equipment or load and stored in an open circuit condition.
2. Batteries should be stored at as low temperatures as possible. When storing for extended periods, the temperature should be maintained under 35℃.
3. If batteries have not been used for some time, they should be recharged before use.

Fig.7-5 shows storage characteristics for each temperature.

**Fig.7–5: Storage Characteristics**



## 7-7 Battery Service Life

Employing the same manufacturing methods, the life cycles of CADNICA SLIM and cylindrical CADNICA batteries are the same. However, service life will depend on conditions of use.

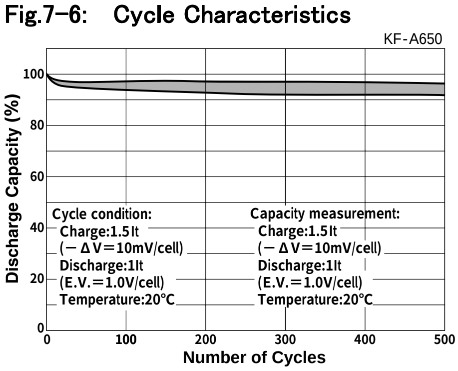
The factors affecting service life are the same as those for cylindrical CADNICA batteries. Where fast charging is conducted, care should be taken to prevent over charging battery, as factors such as overcharging may reduce service life. When designing the battery design, care should be taken of the following points:

- When the $-\Delta V$ voltage sensor system is used for charging, the amount that the sensored voltage decreases due to cell temperature increase allows the charging operation to be controlled. The layout in which the batteries are assembled is important for avoiding excessive voltage decrease or abnormal temperature increase.
- The higher the $-\Delta V$ value, the greater the risk of overcharging. To avoid this, the $-\Delta V$ value should be set 10~20mV per cell.
- For absolute voltage control, the predetermined voltage must be adjusted according to charge current and ambient temperature.

Fig.7-6 provides a sample of cycle characteristics under fast charge through the $-\Delta V$ voltage sensor system.

It is possible to charge/discharge each cell more than 300 times.

**Fig.7-6: Cycle Characteristics**



# 8

# Charging Methods and Charging Circuits



## 8–1 Outline of Charging Methods

Charging is the replacing of energy to cells whose stored energy has been discharged. The discharge rate and the frequency of use should be considered when selecting the proper charging current.

Sanyo CADNICA batteries, as described in Chapter 2, have a mechanism which recombines gas generated by electrolysis of electrolyte on the negative plate. Considering the balance between the speed of the gas recombination on the negative plate and the rate of gas generation, the input current is specified 0.1It. At this charge rate, the time needed to charge cells to full capacity from complete discharge is 14 to 16 hours.

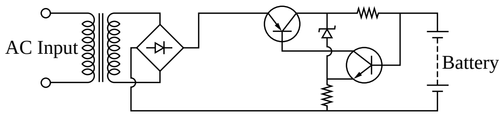
## 8–2 Charging Methods

There are various methods charging CADNICA batteries. In selecting the most suitable one, the frequency of use, the discharge rate, and the application of its use, should be considered. The methods are discussed in the following paragraphs.

### 8–2–1 Constant–Current Charge

Charging efficiency is high when a cell is charged with continuous constant current. The necessary charge input is easily determined by the charge time, and the number of cells may be changed, with a constant current simultaneously within a range of the output voltage of the power supply, However, the constant current needed for DC power supply is costly, so quasi-constant current is generally used in charging.

**Fig.8–1: Constant–Current Charge Circuit**




**Note: Generally, Impossible to charge batteries on the above circuit when battery voltage is under 0.6V**

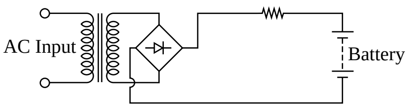
## 8-2-2 Quasi-Constant Current Charge

In this method, the constant current is produced by inserting resistance between the DC power supply and the cell in series, so as to increase the impedance of the charging circuit. The value of the resistance is adjusted according to the charge current at the end of charging, which should not exceed the specified current value. Quasi-constant current is widely used in charging CADNICA batteries because the circuit configuration is simple, and less expensive. An example of this circuit plan is illustrated in Fig.8-2.

As to the equipment having both AC and DC circuits, additional charger is not necessary.

The battery can be charged by the DC circuit in the equipment.

**Fig.8-2: Quasi-Constant Charge Current Circuit**



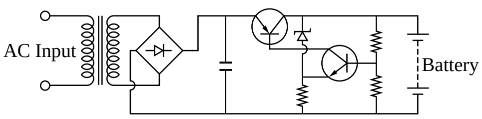

## 8-2-3 Constant Voltage Charge

When charging a CADNICA battery, the charge current is regulated by using the potential difference between the power supply and the cell voltage. In this method the charge current becomes high during the initial charging period, and becomes low at the end of charging. It varies in response to fluctuations in the power supply voltage, so that the charge current should be set to reach the maximum permissible input rate when the power supply voltage is at its highest.

Also, with this method, since cell voltage decreases after reaching its peak at the end of charging, the charge current increases. This in turn leads to a rise in the cell temperature.

Furthermore, as the cell temperature increases, the voltage decreases further. This may lead to a phenomenon so called thermal runaway at the end of charging and damage the battery's performance. For this reason, constant-voltage charging is not recommended for CADNICA batteries.

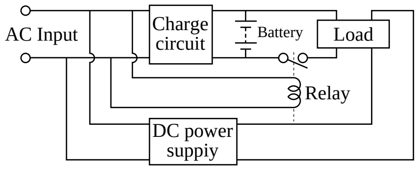
**Fig.8-3: Constant-Voltage Charging Circuit**




## 8-2-4 Trickle Charge

In trickle charge, the battery is continuously charged at a very low rate, from It/50 to It/20, and is kept fully charged and ready for use. Trickle charge is applied to CADNICA batteries used in fire alarms and emergency lighting. Fig.8-4 is an example of trickle charge circuit.

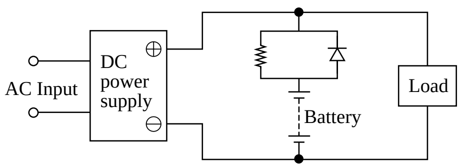
**Fig.8-4: Trickle Charging Circuit**




## 8-2-5 Floating Charge

The CADNICA battery is connected by the circuit to a charging power supply with a load in parallel. Normally, power flows from the DC source to the load, and when the load increases to a maximum, or when power stops being supplied by the source, power will be discharged from the cell. In this system, charge current is determined by the pattern of use, namely, the frequency of discharge and the discharge rate. This method is mainly used in emergency power supply, memory backup, or for electric clocks, where no power cut is allowed. Fig.8-5 illustrates the block diagram for floating charge where the resistance should be adjusted so the current will be equal to the specified rate.

**Fig.8-5: Floating Charge Block Diagram**

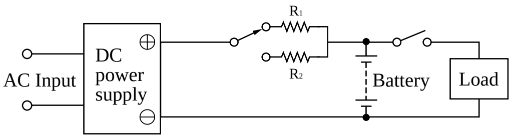


### 8-2-6 Step Charge

In step charge, the initial charge current is kept relatively high. As the state of full charge is determined by measuring the CADNICA battery's charge voltage, the circuit is switched to trickle charge, such as, from 0.2It to 0.02It.

This is the most ideal method of charging, the disadvantages being the complicated circuitry and resulting in high cost. There are also some existing problems in detecting the end of charge at the high rate. Fig.8-6 illustrates the pattern of step charge.

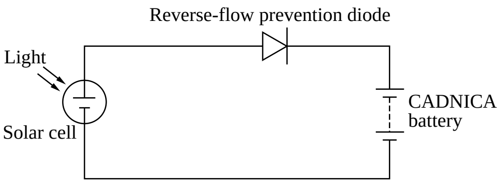
**Fig.8-6: Step Charge Block Diagram**




### 8-2-7 Charging via Solar Cells

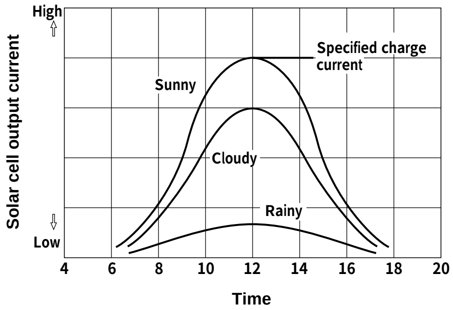
This is the most simple charge circuit. Use the reverse-flow prevention diode with a small voltage drop in order to achieve high charging efficiency. Outdoors, temperature variations are apt to be wider, so it is recommended that charge circuits utilizing solar cells are designed so that temperature variations do not exceed the predetermined temperature range.

**Fig.8-7: Charge Circuit Using Solar Cells**




The output current of solar cells is affected by weather conditions. Fig.8-8 shows how the output current of a solar cell relates to the time of the day. When cloudy, charge input is insufficient. However, solar cells must be designed so that maximum output current in sunny weather will not exceed the specified current.

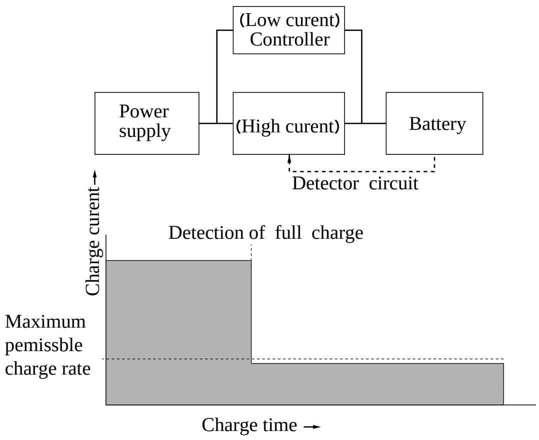
**Fig.8-8: Solar Cell Output Current**




## 8-3 Quick Charge

For charging in a short time with a high current, an external control circuit is necessary. This method detects cell voltages and cell temperatures at the end of the charging cycle and stops charging. Fig.8-9 shows the block diagram for this method.

**Fig.8-9: Quick-Charge Circuit Block Diagram**



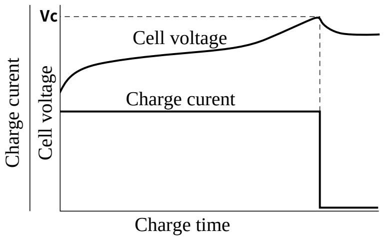
## 8-3-1 Cell Voltage Detection

Cell voltage is detected near the end of high-rate charge to activate the controller and divert charging current to low-rate current through the bypass circuit. Fig.8-10 illustrates outline.

In this system, a compensation circuit is required to cope with the charge voltage fluctuation due to charge current, ambient temperature, etc., as discussed in Chapter 2.

Since the cut-off voltage(Vc) must be predetermined lower than the peak value of the charge voltage, auxiliary charge at a low current level is often combined in order to secure charge capacity.

**Fig.8-10: Cell Voltage Detection**



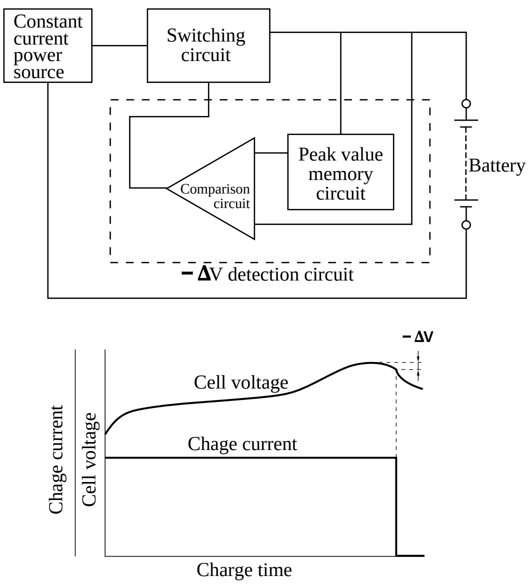

## 8-3-2 −ΔV Detection Control System

Under this system, the charge current is controlled by detecting the decrease(ΔV) in the cell voltage at the end of charging.

Fig.8-11 shows an outline of the −ΔV detection control system.

The method employs a voltage detection system. However, an ambient temperature compensation circuit is not required as the cell voltage peak value is stored, and based on this value, the charge current is cut off when a certain voltage reduction level is reached.

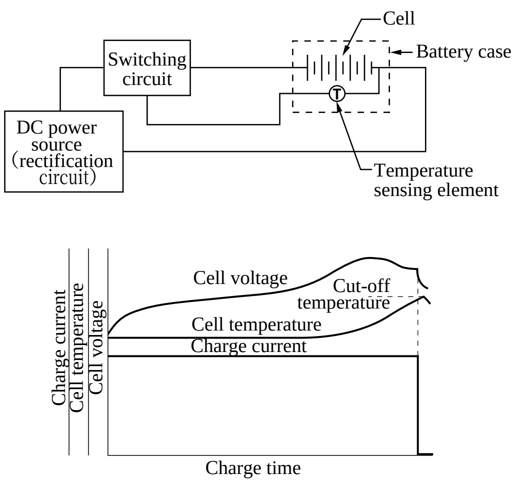
**Fig.8-11: −ΔV Detection Control System**




## 8-3-3 Cell Temperature Detection

At the end of charge, cell temperature shows a rise due to heat generated by the recombination of oxygen gas on the negative electrode. It is feasible to detect this temperature charge by setting a sensor such as a thermister or a thermostat on the exterior of the cell casing for the purpose of charge current control. Under this method, current is controlled in the overcharge range, which means that exclusive batteries with superior overcharge characteristics must be employed. Fig.8-12 shows outline. Here the cell itself should be suitable for temperature detection. Sanyo has developed batteries suitable for this system as shown in Section 6-2. the control system is simple and less expensive.

**Fig.8-12: Cell Temperature Detection System**



### 8-3-4 Timer Control

Charging is performed over a certain length of time specified in advance by a timer, so that charge input is nearly constant. This method is adequate in charging a cell with no residual capacity, but may cause overcharging a cell with some residual capacity. Therefore, the charging condition should be carefully selected.

### 8-3-5 Miscellaneous

There are other quick-charge methods available, such as the multiple detection method, where 2 or more methods described above are combined, the peak voltage detection method, or the $\Delta T/\Delta t$ detection method.

In the peak voltage detection method, charging is stopped when the charge voltage reaches its highest point.

In the $\Delta T/\Delta t$ detection system, the control circuit calculates the degree of temperature rise and terminates charging according to the predetermined value.

## 8-4 Designing Charging Circuits

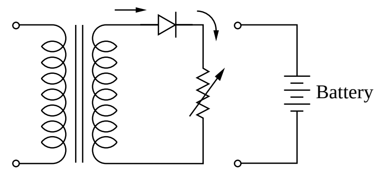
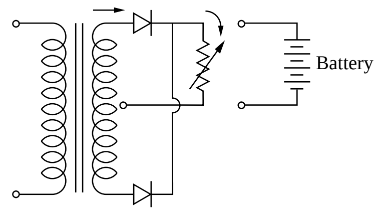
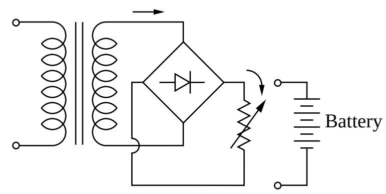
The power supply and the detector are the most crucial parts in the design of a charging circuit for ordinary and quick charge units.

Charging current usually fluctuates with changes in input voltage and frequency. Accordingly, charging circuits must be designed on a basis of the maximum AC input voltage, 110% of the rated value.

### 8-4-1 Rectification Methods

The number of Nickel-Cadmium sealed cells built into battery-powered devices, and space for a transformer, should be taken into account when selecting an appropriate current rectifying method-a single-phase half-wave, or single-phase full-wave circuit. Table 8-13 compares respective rectification methods.

**Table 8-13: Rectification Methods**

| Single-phase half-wave (half wave) |
|---|
|   |
| Single-phase full-wave (center wave) |
|   |
| Single-phase full-wave (bridge) |
|   |

### 8–4–2 Selection of Transformers

Charging circuits are normally provided with a small built-in transformer which steps down and rectifies voltage. Charging is performed by virtue of a difference in the potential between the secondary voltage of the transformer and the cell voltage. The charging current is monitored by placing a fully charged cell into the circuit as a load.

### 8–4–3 Compact and Lightweight Transformer

Greater charge current requires a transformer with larger capacity, which is naturally larger in size as well. A transducer is often required, due to the restrictions of space and weight, where the transformer is part of the circuit. The switching regulator type is widely used for this purpose. Since in a switching regulator transformer, the frequencies are converted into several tens or hundreds of KHz, great care should be taken with regard to internally generated noise.

### 8–4–4 Designing the Detection Circuit

There are various detection circuits in use, as described in chapter 8-3. Their design must be based on a thorough knowledge of the cell characteristics.

The following cell characteristics may affect the setting of the detection level:

For voltage detection
····· (1) charge current
(2) ambient temperature
(3) battery history

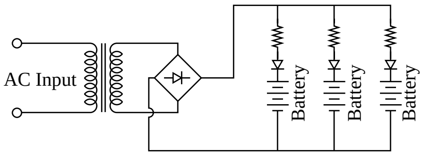
For temperature detection
···· (1) charge current
(2) ambient temperature
(3) assembled battery configuration
(4) ventilation

Should any question arise concerning battery characteristics when designing a detection circuit, please contact Sanyo.

## 8–5 Parallel Charge and Parallel Discharge

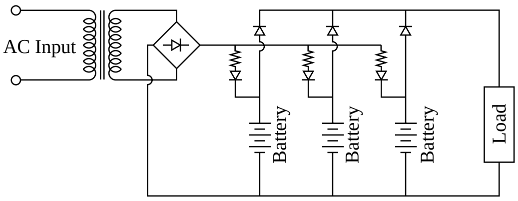
When charged in parallel, the difference in charge voltage among CADNICA batteries causes lager current flow into the cell with less charge voltage. The charge voltage of the CADNICA battery reaches its peak near the end of charging, then decreases after being fully charged, so the charge current increases to infinity and ultimately destroys the battery. Thus, parallel charging should be avoided. When parallel charging is unavoidable, due to the structural arrangement of the device, parallel charging with diodes in the circuit may be used as shown in Fig.8-14.

**Fig.8–14: Parallel Charging Circuit**




The slight difference in cell voltage in CADNICA batteries may cause no particular problem by parallel discharging. When a battery which has abnormally low voltage is used, caused by a short or some other deviation, the high current which flows into the battery may generate heat, burn the lead wire and eventually damage the device in which it is being used. To avoid this situation the circuit is adopted as shown in Fig.8-15

**Fig.8–15: Parallel Charging Discharging Circuit**



# 9

# Assembled Battery



## 9–1 Outline of Assembled Battery

In designing assembled batteries, the specifications of the equipment, available space, and the ambient conditions should be taken into consideration as follows:

## 9–2 How to Assemble Batteries

### 9–2–1 Types

At the design stage, a variety of items must be taken into consideration, as follows:

Specifications of the equipment, conditions of use and temperature ranges for the selection of battery models.

Available space and fixing method for configuration.

The thickness of materials, heat conductivity and thermal resistance of the battery case when $-\Delta V$ sensor or temperature sensor is used.

For reference, Sanyo's standard assembled battery types are shown below. If standard configurations prove to be inconvenient, or if a customized battery design is required, please contact Sanyo.

### 9–2–2 Connection

CADNICA batteries are connected by spot welding, using tabs which are made of alkaline-resistant material with low electrical resistance.

Nickel and nickel-plated steel are often used for tabs or connectors at the points of contact due to their conductivity and good soldering capabilities.

Stainless steel, by itself, is unsuitable for soldering to lead wire, therefore, the nickel plating is necessary.

The connecting plate should be 0.1 to 0.2mm thick. If it exceeds this thickness, it should be shaped specially so as to afford welding strength.

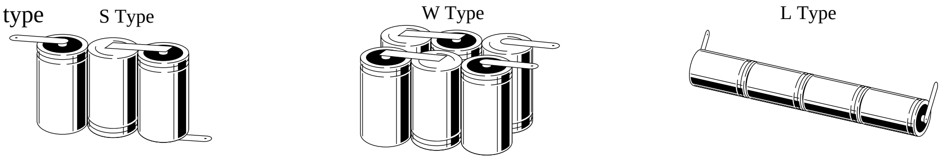
A specific terminal plate is required to connect CADNICA SLIM. For details, contact Sanyo.

### 9–2–3 Design Layout

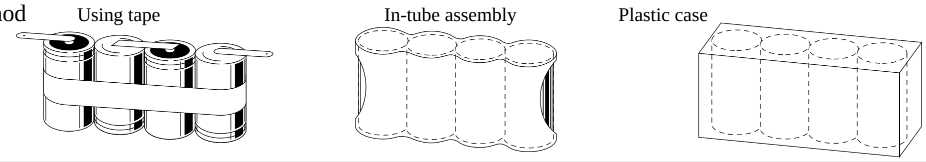
The battery may leak alkaline electrolyte when the safety vent is in operation, due to increased internal pressure of abnormal amounts. Thus, the enclosed battery should be placed so that no problems may occur by possible leakage of electrolyte.

Direct mounting of a battery to printed circuit board may cause corrosion of the circuit board foil, and thus, should be avoided.

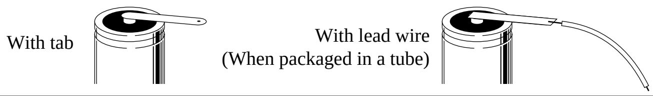
●Connecting type




●Fixing method

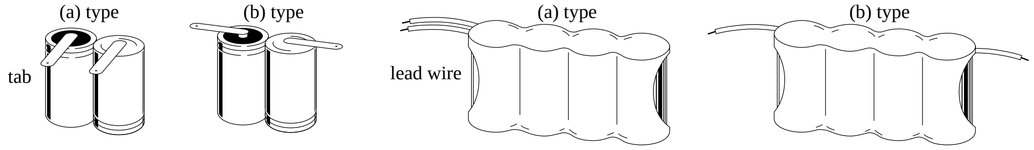



●Terminal

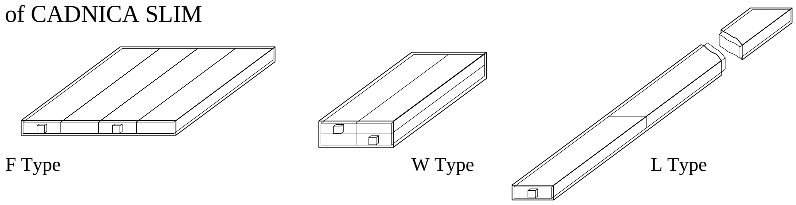



| Battery size | TA,AAA | AA,A | SC,C | D | F | 10000M | 20000M |
|---|---|---|---|---|---|---|---|
| Connecting tab (width×length×thickness) | 3×11×0.15 | 3×15×0.15 | 5×22×0.15 | 7×32×0.15 | 7×32×0.15 | 11×40×0.15 | 11×40×0.15 |
| Lead wire (Length:approx.200mm) | UL1007 AWG22 | UL1007 AWG22 | UL1007 AWG20 | UL1007 AWG16 | UL1007 AWG16 | UL1007 AWG16 | ϕ0.26/37 |

●Terminal direction




●Connection types of CADNICA SLIM




## 9-3 Interchangeability with Dry Cells

### 9-3-1 Configuration

To be interchangeable with dry cells, CADNICA batteries of identical size are most simply applied. Specially designed batteries are often used in order to reduce poor contact between individual cells, as well as for easy access.

In such a case, the design is restricted in configuration.

Two examples of design are shown below.

●When CADNICA batteries are same-sized as the conventional dry cell:

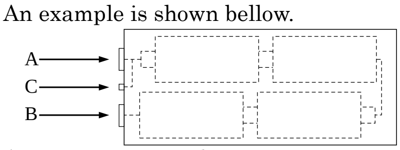
●Cells should connected by spot-welding.
●The battery case should no wall in its direction.

●When CADNICA batteries are smaller than the conventional dry sell:

●Use N-250AAA or N-190N for AA size.
●Use N-1300SC/KR-1300SC or smaller for C size.
●Use N-2000C/KR-2000C or smaller for D size.

### 9-3-2 Charging Method

Charging batteries with an external device is the ideal method. When charged with a built-in charger, the charger should be designed not to charge dry cells. An example is shown bellow.




A: Positive terminal
B: Negative terminal
C: Positive terminal used exclusively for charging, which is connected to A
Charging is done with terminals B and C.
Discharging is done with terminals A and B

# 10

# General Remarks and Precautions

When using CADNICA batteries or when incorporating them into equipment, careful attention should be paid to the following points, making best use of product characteristics and preventing problems caused by misuse.

## 1 Charging

### 1) Charge Current

- Be sure to fully charge CADNICA batteries with current levels and charging times specified.
  If charged at a higher than specified current level, the gas recombination rate will not match the gas generation rate at the end of overcharging. This increases battery internal pressure leading to activation of the gas release vent, and finally to deterioration in performance and possible electrolyte leakage.
  (Overcharging: continued charging after battery has completed charging cycle.)
- Fast charging with a current higher than specified requires circuitry than controls the charging current to avoid overcharging. Please contact Sanyo regarding needed circuitry.
- Perform trickle charging within 0.02 to 0.05ItmA range. Charging at low levels with current less than 0.02ItmA decreases charging efficiency and results in insufficient charging.
  Charging with current greater than 0.05ItmA results in overcharging that causes battery performance to deteriorate, and leakage to occur.

### 2) Charging Temperature

- Always charge within specified temperature range. Ambient temperatures affect charge efficiency. The optimum temperature range for efficient charging is from 5 to 30℃.
- Charging at temperature below 0℃ increases the gas pressure within the cell and sometimes causes the gas release vent to operate.
- Charge efficiency decreases at temperature above 45℃ and cell materials may deteriorate if charging is performed at high temperature.

### 3) Parallel Charging

- When CADNICA batteries are to be charged using a parallel connection, take the utmost care over the design of the charger and the cell connection method. If parallel charging is required, please contact Sanyo.

### 4) Overcharging

- Be sure to charge within specified current level range and charging times. Repeated overcharging may cause battery performance to deteriorate. Overcharging at high currents may damage the gas release vent function, as battery generates heat.

### 5) Reverse Charging

- When CADNICA batteries are charged with poles inverted, the batteries generate heat which may damage the gas release vent function.

## 2 Discharging

### 1) Discharge Current

- Discharging at high current levels will decrease discharge efficiency and cause the battery to heat. Sanyo should be consulted when continuous discharging current levels exceed 4It or when pulse discharging is required.
  Special attention is needed when using CADNICA SLIM cells for assembling a battery as special tabs are used.

### 2) Discharge Temperature

- Discharging should be within the specified temperature range.
- When discharging at low temperatures, below –20℃, internal impedance will rise and discharge reaction speed will decrease. This also causes rated battery voltage and capacity to decrease.
- Discharging at temperatures exceeding 60℃ causes battery materials to deteriorate.

### 3) Overdischarging

- When cells of different capacities are connected in series and discharged at high current levels, the smaller capacity cells polarity may be inverted. Polarity reversal should be avoided as it can adversely affect battery performance. In view of these considerations, the number of cells in an assembled battery should be limited to 20, except in special cases. In addition, the end voltage for discharge should be predetermined for assembled batteries using following formulas,

  When 1 - 6 cells are connected in series:
  (number of cells x 1.0)v
  When 7 - 20 cells are connected in series:
  {(number of cells − 1) × 1.2}v
- Prolonged overdischarging may cause temporary decrease in charge efficiency due to cell inactivation and can cause leakage.
- If CADNICA SLIM batteries are used, the number of cells that make up an assembled battery should be limited to ten. If more than ten cells are required to assemble a battery, please contact your nearest Sanyo representative.

## 3 Storage

### 1) Storage Temperature and Humidity

- Batteries should be stored within the specified temperature range in low humidity conditions free from corrosive gas.
- Storage outside the specified temperature range or in extreme high humidity may accelerate deterioration of battery materials, cause leakage or corrosion of metal sections.

### 2) Long-Term Storage (more than 3 months)

- CADNICA batteries should be stored in a chemically-safe discharged state as they self discharge during storage and may become in-active through long periods of storage.
- When CADNICA batteries are stored for long periods while connected to a load, the electrolyte may leak due to the battery's creeping characteristics. Be sure not to store CADNICA batteries for prolonged periods connected to a load.
- Though capacity is less at first charge after a long storage period, full capacity will be restored after two or three charge/discharge cycles.

## 4 Built-in Use

### 1) Connection between Battery and Equipment

- Avoid soldering the battery.
  Direct soldering onto a battery damages materials such as the gas release vent, gasket and separator. Such damage causes leakage or short circuits.
- Spot weld the tabs onto both ends of the battery, then solder lead wires to these tabs.
- Avoid using spring contact-type connector as an oxide layer forms on the contact surface after long periods of use, resulting in contact failure. If contact-type connectors are necessary, the battery should be removed periodically and contact surfaces cleaned with a cloth to maximize electrical conductivity.

### 2) Equipment Terminal Materials

- There may be some leakage of alkaline electrolyte from the seal if the gas release vent is activated due to abnormal use or if the battery is used for a long period. Be sure to use an anti-corrosive alkali-resistant metal for the equipment terminals. Metals with superior alkali-resistance include nickel and nickel-plated steel. Metals with inferior alkali-resistance properties include copper, tin, aluminum and brass.

### 3) Precautions when Designing Equipment

- Since charging efficiency drops and cell materials deteriorate at high temperatures, care should be taken to avoid contact between the battery and any heat-generating part of the equipment, such as transformers. In addition, adequate ventilation for the equipment or battery should always be provided. When the temperature rises to 45℃ and above, alkaline electrolyte can leak from the battery and damage equipment. That also causes separator deterioration which short-circuit battery life.
- As CADNICA batteries contain useful natural resources, it is recommended that they be used in products that allow easy battery removal to facilitate material recycling.

## 5 Safety Instructions

**Please keep in mind the following points when designing and manufacturing equipment. Please insert these points in your instruction manual.**

### 1) Short Circuit

● Avoid short-circuiting CADNICA batteries. Short circuiting generates heat which may damage equipment and cause burns. In worst cases, the battery may rupture.

### 2) Disassembly and Deformation

● Do not disassemble or deform CADNICA batteries by pressure. Strong alkaline electrolyte may damage skin or eyes upon contact.

### 3) Incineration and Heating

● Do not incinerate or heat CADNICA batteries as expansion or rupture may result.

### 4) Immersion in Water

● Do not immerse CADNICA batteries in water as battery function may be damaged.

### 5) Soldering

● Never solder lead wire directly to CADNICA battery terminals. Soldering heat may damage the gas release vent in the positive cap after a terminal plate is spot-welded on the battery terminal, solder a lead wire on it.

### 6) Reversed Polarity Use

● Do not use CADNICA batteries with polarities reversed as expansion and rupture can result.

### 7) High Current Overcharging

● Be sure to charge within the current levels and charging times specified, or battery performance may be significantly degraded. Heat generated by the battery may damage the gas release vent and cause rupture. When the battery is fully charged, decrease the charge current to 0.02It-0.05ItmA or stop charging by charge control. Follow the value specified according to cell size, configuration of battery pack, and number of cells.

### 8) Reverse Charge and Over-discharge

● Do not over-discharge or charge with poles inverted. A rapid increase of internal pressure makes the gas release vent operate, greatly impairing battery performance. In worst cases, heat generated by the battery may damage the gas release vent, causing rupture.

### 9) Battery Charger

● Do not charge CADNICA batteries with the battery charger not specified or change the specifications of the specified charger.

### 10) Sealed Structure

● Avoid using sealed structures when CADNICA batteries are to be incorporated in the equipment. If used incorrectly, the batteries may rupture. Gas generated by chemical reactions in the battery may cause damage if ignited by sparks from motors or switches.

### 11) Other Applications

● Inappropriate use may cause the battery to rupture and/or damage equipment.

### 12) Mixed Use

● Do not use CADNICA batteries mixing older or newer ones, different kind of batteries, or batteries by other manufactures. The difference in characteristics may damage batteries or equipment.

### 13) Ingestion

● Avoid swallowing CADNICA batteries. Keep out of the reach of small children. When designing equipment, please ensure that small children cannot easily remove the batteries.

## 6 Others

### 1) Charging after Long-term storage

●If a battery is not used for a long period of time, the capacity decreases through self discharge. Be sure to charge correctly before using.

### 2) Precaution when Handling Lead Wires or Connectors

●Never forcibly pull lead wires or connector as soldered or spot-welded connections may break.

### 3) Used Batteries

●As sealed-type Nickel-Cadmium storage batteries mainly contain chemical materials, disposal should not be with regular refuse. Please contact Sanyo when large quantities of Nickel-Cadmium storage batteries are to be disposed of.

### 4) Export of Batteries and Battery Built-in Products

●When batteries or products with batteries built-in are exported, Sanyo should be contacted regarding battery import/export regulations of the countries of destination.

●Please understand that for improvements, external appearances, types and specifications are subject to change without notice.

**Note:**

●For safety reasons, please contact Sanyo regarding use conditions and equipment structure before marketing products with built-in battery(ies).

# (CADNICA® Batteries Handling Precautions)

Carefully read this entire instruction manual before using CADNICA batteries for the first time. Important: For your safety and that of your customers observe all cautionary information provided in this manual. Save this manual for future reference. The following information is intended to highlight potential safety hazards that can be associated with the misuse, misapplication or damage to CADNICA batteries, Please carefully evaluate the information in this section when using CADNICA batteries (single cell or packed cells) or when designing or manufacturing equipment incorporating CADNICA batteries.
This manual is no substitute for your independent evaluation of equipment incorporating CADNICA batteries. Customers incorporating CADNICA batteries into their equipment must assure that their completed product has been properly designed, manufactured and tested. End users of equipment incorporating CADNICA batteries should also be provided with sufficient warnings and instructions on their safe operation. As appropriate, some or all of the following warnings and information should be incorporated by you into the instruction manual accompanying your equipment.

## ⚠ Danger!

●Failure to carefully observe the following procedures and precautions can result in battery leakage, heat generation, bursting and serious personal injury!
Never dispose of CADNICA batteries in a fire or expose to high temperatures.

- Do not connect the positive (＋) and negative (－) terminals of CADNICA batteries together with electrically conductive material, including lead wires. Do not transport or store CADNICA batteries with their uncovered terminals or connected with a metal necklace or other conductive material.
  Only charge CADNICA batteries using those special chargers that satisfy Sanyo's specifications. Only charge batteries under the conditions specified by Sanyo. Failure to follow proper charging procedures can result in damage to the CADNICA batteries.
- Never disassemble, modify or reconstruct CADNICA batteries.
- Never solder lead wires directly on to CADNICA batteries.
- Special order CADNICA batteries, manufactured in accordance with the customer's equipment specifications, are packed by selected type and the number of assortments. Only use special order batteries in equipment for which they were specified.
- The positive (＋) and negative (－) polarities of CADNICA batteries are predetermined. Do not force the terminal connection to a charger or equipment. If the terminals cannot be easily connected to the charger or equipment, check if the (＋) and (－) terminals are correctly positioned.
- Do not directly connect CADNICA batteries to a direct power source or the cigarette lighter outlet in a car.
- The gas release vent is located at the positive (＋) section of CADNICA batteries. Never deform this section or cover or obstruct the gas release vent is located at this section.

●CADNICA batteries contain the strong colorless alkali liquid. The alkali is extremely corrosive and will cause skin damage. If any liquid from a CADNICA battery comes in contact with a user's eyes, they should immediately flush their eyes with clean water enough and consult a doctor. The strong alkali can damage eyes and lead to permanent loss of eyesight.

●When CADNICA batteries are to be incorporated in equipment or housed within a case, avoid sealed structures as this may lead to the equipment or case being damaged or may be harmful to users.

## ⚠ Warning!

●Do not apply water, seawater or other oxidizing agents to CADNICA batteries, as this can cause rust and heat generation. If a battery becomes rusted, the gas release vent may no longer operate, and can result in bursting.

●Never use CADNICA batteries if they are leaking, deformed, discolored, damaged or otherwise differ from their normal condition. External damage to the batteries can be a sign of a malfunction.

●Do not damage or remove the external tube of CADNICA batteries, as this may cause leakage, heat generation or bursting.

●Do not over-charge CADNICA batteries by exceeding the predetermined charging period specified by the battery charger's instructions or indicator. If CADNICA batteries are not fully charged after the battery charger's predetermined charging period has elapsed, stop the charging process. Prolonged charging may cause leakage and heat generation and bursting. Be sure to handle recharged batteries carefully as they may be hot.

●Strong alkali in the electrolyte may cause burns and be harmful if it comes in contact with skin. If so, wash the affected area with clean water immediately.

●Do not connect more than 20 CADNICA batteries in series, as this may cause electric shock, leakage or heat generation. Consult Sanyo if designing a battery pack containing more than 20 cells.

●When the usage time for a CADNICA battery becomes extremely short after charging, its operating life has ended and it should be replaced.

●Keep the equipment or batteries out of the reach of small children, in order to avoid them to swallow batteries. In the event the batteries are swallowed, consult a doctor immediately

## ⚠ Caution!

●If CADNICA batteries do not perform or function well with certain equipment, refer to the instruction manual or warnings of the subject equipment.
●Do not strike or drop CADNICA batteries. Sharp impacts or concussions to CADNICA batteries may result in leakage, heat generation and bursting.
●Do not mix charged and discharged CADNICA batteries together as this may cause leakage or heat generation.
●Do not use old batteries with new ones as this may cause leakage or heat generation.
●Do not use CADNICA batteries with any other battery type, including dry cell, or with those of different capacity or brand. Mixed-matching of batteries may result in leakage, heat generation and bursting.
●When more than two batteries are to be used together, charge them simultaneously prior to use.
●Do not connect CADNICA batteries in parallel as this may cause leakage, heat generation and bursting.
●Children should not use CADNICA batteries unless they have been carefully instructed on the contents of this instruction manual and their parents or guardians have confirmed that the children understand and appreciate the proper usage and safety hazards presented by the batteries.
●Store CADNICA batteries out of the reach of small children. Ensure that small children cannot remove the batteries from the charger or equipment. There is no substitute for proper adult supervision.
●Always follow the specified charging temperature ranges (refer to the rating table in the catalog). Failure to observe the temperatures indicated, may cause leakage, heat generation and a decrease in performance or operating life of CADNICA batteries.
●For the recommended charging method for CADNICA batteries, read the battery charger's instruction manual carefully.
●Do not charge CADNICA batteries beyond the recommended time described in the instruction manual for charger or equipment. Over charging cause leakage and heat generation.
●Do not carry the batteries by the connector or their lead wires as this may damage the batteries.
●Be sure to turn off the equipment after use of CADNICA batteries, as this may result in leakage.
●After they have been removed from equipment, store CADNICA batteries in a dry place and within the recommended storage temperature range. This will help preserve the batteries' performance and durability and to minimize the possibility of leakage or corrosion. (For the indicated storage temperature range, refer to the rating table of this catalog. Sanyo recommends a temperature range from 10℃. (50˚F) to 30℃. (86˚F) for longer product life).
●If the CADNICA battery terminals become dirty, clean them with a soft dry cloth prior to use. Dirt on the terminals can result in poor contact with the equipment, loss of power, or inability to charge.
●If corrosion, heat generation or other abnormalities are detected when using (new) CADNICA batteries, immediately stop using them and return them to the store that they were purchased from.
●If you have specific questions about CADNICA batteries, do not hesitate to contact Sanyo at the addresses provided below

*Regarding to recycle*

In some countries or regions, you may be obliged by law, to make marking for indicating that disposal of Ni-Cd batteries is prohibited or/and that they should be recycled, or to collect used batteries from the market.
In such a case, please follow the law.
Please contact Sanyo's office in your region for details.

## Attached Table: Standard Rating and Dimensions of Sealed Nickel-Cadmium Batteries

| JIS C8705–1998 (Japanese Industrial Standard) | | | IEC PUB.285 (International Electrotechnical Commision) | | | Dry Cell JIS (Reference) | | |
|---|---|---|---|---|---|---|---|---|
| Model | Dimensions (mm) | | Model | Dimensions (mm) | | Model | Dimensions (mm) | |
| | Dia. | Height | | Dia. | Height | | Dia. | Height |
| | | | | | | | | |
| **KR15/18** | $14.5^{0}_{-0.7}$ | $17.5^{0}_{-1.5}$ | **KR15/18** | $14.5^{0}_{-0.7}$ | $17.5^{0}_{-1.5}$ | | | |
| | | | | | | | | |
| **KR12/30** | $12.0^{0}_{-0.7}$ | $30.0^{0}_{-1.5}$ | **KR12/30** | $12.0^{0}_{-0.7}$ | $30.0^{0}_{-1.5}$ | **LR1** | $12.0^{0}_{-1.3}$ | $30.2^{0}_{-2.2}$ |
| **KR11/45** | $10.5^{0}_{-0.7}$ | $44.5^{0}_{-1.5}$ | **KR11/45** | $10.5^{0}_{-0.7}$ | $44.5^{0}_{-1.5}$ | **LR03** | $10.5^{0}_{-1}$ | $44.5^{0}_{-2}$ |
| **KR17/18** | $17.0^{0}_{-0.7}$ | $17.5^{0}_{-1.5}$ | **KR17/18** | $17.0^{0}_{-0.7}$ | $17.5^{0}_{-1.5}$ | | | |
| **KR15/30** | $14.5^{0}_{-0.7}$ | $30.0^{0}_{-1.5}$ | **KR15/30** | $14.5^{0}_{-0.7}$ | $30.0^{0}_{-1.5}$ | | | |
| **KR17/29** | $17.0^{0}_{-0.7}$ | $28.5^{0}_{-1.5}$ | **KR17/29** | $17.0^{0}_{-0.7}$ | $28.5^{0}_{-1.5}$ | | | |
| **KR17/43** | $17.0^{0}_{-0.7}$ | $43.0^{0}_{-1.5}$ | **KR17/43** | $17.0^{0}_{-0.7}$ | $43.0^{0}_{-1.5}$ | | | |
| **KR17/50** | $17.0^{0}_{-0.7}$ | $50.0^{0}_{-1.5}$ | **KR17/50** | $17.0^{0}_{-0.7}$ | $50.0^{0}_{-1.5}$ | | | |
| **KR15/51** | $14.5^{0}_{-0.7}$ | $50.5^{0}_{-1.5}$ | **KR15/51** | $14.5^{0}_{-0.7}$ | $50.5^{0}_{-1.5}$ | **LR6** | $14.5^{0}_{-1}$ | $50.5^{0}_{-1.5}$ |
| **KR23/27** | $23.0^{0}_{-1}$ | $26.5^{0}_{-1.5}$ | **KR23/27** | $23.0^{0}_{-1}$ | $26.5^{0}_{-1.5}$ | | | |
| **KR23/24** | $23.0^{0}_{-1}$ | $34.0^{0}_{-1.5}$ | **KR23/24** | $23.0^{0}_{-1}$ | $34.0^{0}_{-1.5}$ | | | |
| **KR23/43** | $23.0^{0}_{-1}$ | $43.0^{0}_{-1.5}$ | **KR23/43** | $23.0^{0}_{-1}$ | $43.0^{0}_{-1.5}$ | | | |
| **KR26/31** | $25.8^{0}_{-1}$ | $31.0^{0}_{-1.5}$ | **KR26/31** | $25.8^{0}_{-1}$ | $31.0^{0}_{-1.5}$ | | | |
| **KR26/50** | $25.8^{0}_{-1}$ | $50.0^{0}_{-2}$ | **KR26/50** | $25.8^{0}_{-1}$ | $50.0^{0}_{-2}$ | **LR14** | $26.2^{0}_{-1.5}$ | $50.0^{0}_{-1.5}$ |
| **KR33/44** | $33.0^{0}_{-1}$ | $44.0^{0}_{-2}$ | **KR33/44** | $33.0^{0}_{-1}$ | $44.0^{0}_{-2}$ | | | |
| **KR33/62** | $33.0^{0}_{-1}$ | $61.5^{0}_{-2}$ | **KR33/62** | $33.0^{0}_{-1}$ | $61.5^{0}_{-2}$ | **LR20** | $34.2^{0}_{-2}$ | $61.5^{0}_{-2}$ |
| **KR33/91** | $33.0^{0}_{-1}$ | $91.0^{0}_{-2.5}$ | **KR33/91** | $33.0^{0}_{-1}$ | $91.0^{0}_{-2.5}$ | | | |
| **KR44/91** | $43.5^{0}_{-2.5}$ | $91.0^{0}_{-2.5}$ | **KR44/91** | $43.5^{0}_{-2.5}$ | $91.0^{0}_{-2.5}$ | | | |
| | | | | | | **6F22** | $26.5^{0}_{-2} \times 17.5^{0}_{-2} \times 48.5^{0}_{-2}$ | |

# Glossary

| | |
|---|---|
| ACID BATTERY | The battery in which acid is used as electrolyte, e.g., lead-acid battery in which sulfuric acid is the electrolyte. |
| ACTIVE MATERIAL | Chemically reactive material which is used to generate electric current in the battery. In the Nickel-Cadmium cell, nickel hydroxide and cadmium hydroxide are used as active materials at the positive and negative electrodes, respectively. |
| ALKALINE STORAGE BATTERY | A battery which employs alkaline aqueous solution for its electrolyte. The Nickel-Cadmium battery as designed. |
| ASSEMBLED BATTERY | Any battery composed of multiple cells |
| C | C designates the nominal capacity of the battery. The charge-discharge current is specified in terms of a multiple of C. For example, the 0.1 It current for N-600AACL is equal to 600 × 0.1 = 60mA. |
| CADMIUM | Chemical symbol: Cd. This metallic element is the chemically-active material of the Nickel-Cadmium battery's negative electrode. When the battery is charged, the negative electrode surface consists of cadmium. As the battery discharges, the cadmium progressively changes into cadmium hydroxide〔$Cd(OH)_2$〕. |
| CADMIUM HYDROXIDE | Active material used at the negative electrode of the Nickel-Cadmium cell. |
| CADMIUM SALT | A chemical compound in which the hydrogen atom has been replaced by the cadmium atom.<br>(e.g.)$2HNO_3 + Cd(OH)_2 \rightarrow Cd(NO_3)_2 + 2H_2O$ cadmium nitrate. |
| CAPACITY | The quantity of electricity that can be obtained from a battery in one cycle from full charge to full discharge when the battery is discharged under conditions of rated current level and ambient temperature within the predetermined range. Generally,<br>capacity is expressed in units of mAh (mili ampere-hour). |
| CELL | The basic composing unit of a battery. It is an electrochemical device capable of storing electric energy. |
| CHARGE EFFICIENCY | The value which can be obtained when the dischargeable capacity of the battery is divided by the charged capacity. It indicates the degree of ease with which the battery can be charged. |
| CHARGE RETENTION | Residual capacity after a period of storage of a fully charged battery. |
| CHEMICAL CELL | The type of cells which convert energy obtained by chemical reactions into electric current. Most of the popularly used cells belong to this group. |
| CYCLE USE | A method of battery use involving repeated charging and discharging. |
| DEPTH OF DISCHARGE CAPACITY | Capacity removed from a battery as compared to its actual capacity. It is expressed in percentage. |
| DISCHARGE CAPACITY | Capacity that can be discharged from a battery. The unit as mAh, (mili ampere-hour). |
| DISCHARGE RATE | The discharge rate is the rate at which current is removed from a battery. When a battery is discharged at a current level "i", for a period until the end discharge voltage is reached "h", the discharge is referred to as the h-hour rate discharge, while "i" is known as the h-hour rate discharge current. For practical use, nominal capacity is used as the standard. |
| ELECTROLYTE | The chemical compound or solution that allows ions (electrically-charged particles) to be conducted between the electrodes of a battery. In the Nickel-Cadmium battery, a solution of potassium hydroxide (KOH) or sodium hydroxide (NaOH) is utilized. |
| ELECTROLYTE RETENTION CAPABILITY | The degree to which a separator retains electrolyte. |
| END-VOLTAGE | The voltage that indicates the end limit of discharge. This voltage is almost equivalent to limitation of practical use. |

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| ENERGY DENSITY | The amount of energy stored in a battery. It is expressed as a function of the unit weight or volume. (Watt-hours per kilogram, or watt-hours per cubic centimeter) |
| GAS PERMEABILITY | The degree of mobility of gas through porous film, fabric or other plate-separating material. |
| GAS RECOMBINATION ON NEGATIVE ELECTRODE | The method to suppress hydrogen generation by recombining oxygen gas on the negative electrode, and making the negative electrode chemically discharged when oxygen gas is generated at the positive electrode at the end of charging. |
| GAS RELEASE VENT | A safety mechanism that is activated when the internal gas pressure rises above a normal level. There are two types: Automatically resealable, and unresealable. |
| HIGH RATE DISCHARGE | Discharge at a comparatively high current rate in comparison with cell capacity. |
| HOUR RATE | The hour rate is associated with both discharging and charging the battery, and is expressed in terms of discharge time at its nominal capacity rating. "H-hour"represents the length of time it takes to discharge a battery, and "i" represents the rate of discharge. |
| IEC PUBLICATION | The standard specified at the International Electrotechnical Commission. |
| ION | An atom or a group of atoms charged either positively or negatively. |
| IR–DROP | A drop in cell voltage or voltage of inter-cell conductor due to cell internal resistance. |
| It | It is defined by the following formula. $It(A)=C_5(Ah) / 1(h)$ $C_5$ is the rated capacity(mAh). |
| LEAKAGE | The escape of electrolyte to the outer surface of the battery. |
| MOBILITY OF IONS | Velocity of ions moving in electrolyte between electrodes of opposite polarity. |
| NEGATIVE ELECTRODE | The plate which has an electrical potential lower than that of the other plate during normal cell operation. Electric current from the external circuit flows into the cell at the electrode during discharge. Also called the minus electrode. |
| NOMINAL CAPACITY | The standard capacity designated by a battery manufacturer to identify a particular cell model. |
| NOMINAL VOLTAGE | The standard voltage used to express the capacity of a particular battery model. It is generally equal to its electromotive force or its approximate voltage during normal operation. The nominal voltage of an Nickel-Cadmium battery is 1.2V per cell. |
| NICKEL HYDROXIDE | Active material used at the positive electrode of the Nickel-Cadmium cell. |
| OPEN CIRCUIT VOLTAGE | The voltage between terminals of the battery without any load. |
| OPERATING VOLTAGE | Voltage between the two terminals when a battery is subjected to a load. Usually, it is expressed by the voltage of the battery at the 50% discharge point. |
| OVERCHARGE | Continuous charge after the battery has been charged to full capacity. When the cell is driven into overcharge, its temperature rises. |
| OVER DISCHARGE | To discharge a battery to a level below the predetermined end voltage. |
| OVERVOLTAGE | The difference between the actual potential of electro-chemical reaction and the theoretical value at which the reaction becomes balanced. |
| POLARITY REVERSAL | Reversing of polarity of the terminals of a small-capacity cell in a multi-cell battery due to overdischarge. |
| POROSITY | The term expressing the porous degree of a sintered plate. The equation for its calculation is: $\text{Porosity} = (V_1/V_2) \times 100.$ $V_1$ is the volume of pores and $V_2$ is the total volume of the plate including pores. |
| POSITIVE ELECTRODE | The electrode which has a positive potential. Electric current from this electrode flows in the external circuit during discharge. |

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| POTASSIUM HYDROXIDE | A chemical compound which is used as electrolyte in alkaline batteries. Its chemical sign is KOH. |
| POTENTIAL OF OXYGEN EVOLUTION | Oxygen gas evolves due to the electrolysis of water in the battery being charged, when it reaches a certain potential. This is called the potential of oxygen evolution. |
| PRIMARY BATTERY | A battery operational for one discharge only, and incapable of being recharged. |
| QUANTITY OF CHARGE | The amount of electric energy supplied to a battery. Its unit is mAh, (mili ampere-hour.) |
| QUICK CHARGE | A method of charging an Nickel-Cadmium battery for a short time at a high current level. |
| RESIDUAL CAPACITY | Capacity remaining in a battery at any point of storage or after partial discharge |
| RATED CAPACITY | The quantity of electricity $C_5$ Ah(ampere hour) declared by the manufacturer which a single cell can deliver at the reference test current of 0.2It A to a final voltage of 1.0V at 20℃ after charging (1.0It×16hrs.), storing (1～4hrs.) at 20℃. |
| REVERSAL CHARGE | The Nickel-Cadmium cell is reverse-charged when connected to a charger in the wrong way, and current is forced to flow from the negative to positive electrodes, contrary to the direction of flow during normal charge. Here polarity is reversed, but all electric energy is consumed to generate gas. |
| SECONDARY BATTERY | A battery which can be recharged and used repeatedly. |
| SELF DISCHARGE | The decrease of cell capacity without any current flow to the external circuit. |
| SEPARATOR | A film to separate 2 electrodes to prevent short-circuiting and retain electrolyte. |
| SINTERED PLAQUE | A thin nickel-plated grid on which nickel powder has been coated. |
| SINTERED PLATE | The plaque on which active materials have been imbedded for charge and discharge reactions. |
| STEP CHARGE METHOD | One of the charging methods where the charge current is varied stepwise during charge. |
| 3 PHASE ZONE | The area where 3 phases, gas liquid, and solid, contact with each other, Reactions of substances composing these 3 phases take easily. |
| TRICKLE | In order to keep battery fully charged, always conduct a slow and continuous charge while the batteries are separated from the load. |