RECENT FIELD EXPERIENCE SUPPORTS GREATLY REDUCED MAINTENANCE WITH Ni-Cd TELECOM BATTERIES

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ABSTRACT

Nickel-Cadmium (Ni-Cd) battery deployment in telecom is continuing and growing. The NCX and STL type Ni-Cd batteries are primarily installed in Outside Plant (OP), Remote Terminal (RT) applications. As they continue, recommended maintenance practices are confirmed and some are optimized.

Low maintenance was a primary design goal when considering Ni-Cd for OP applications. This paper focuses on the NCX which uses Sintered positive and Plastic Bonded negative Electrode (S/PBE) technologies and a built in Central Watering System (CWS). Its flooded electrolyte design, only requires infrequent-periodic watering maintenance.

Several trial sites were installed in the 'hot' regions of the United States. Three trial sites were installed between 1997 and 1999 and continue to be measured today. With full instrumentation at each site, an evaluation between measured parameters and typical maintenance practice are made. Related metrics like water usage rate (watering interval) and hydrogen generation rate are discussed. Also, the importance of proper installation and how it impacts normal operation and maintenance is discussed.

In addition, comparisons between lab data and field data are discussed.

NI-CD TELECOM BATTERY SYSTEM

The Ni-Cd Technology

The low maintenance feature of the Ni-Cd is primarily due to the unique electrode design. The sintered positive electrode is chemically impregnated with nickel hydroxide (NiOH) and the plastic bonded negative electrode is mechanically impregnated with cadmium hydroxide ($Cd(OH)_2$). Together, they are commonly referred to as the S/PBE technology. The S/PBE electrodes are alternately stacked with a separator system to form a medium to low discharge rate design.

The separator system mechanically isolates each electrode. Layers of non-woven plastic and membrane material form a porous zone between the electrodes for free electrolyte flow while providing mechanical separation. The non-woven plastic zone of the system ensures a continual contact of electrolyte on the surface of the electrodes. The membrane provides mechanical separation and its sub-micron pore size minimizes gas transport between the electrodes.

Each cell is flooded with alkaline electrolyte comprised primarily of potassium hydroxide (KOH, ≅ 20% by weight) and water (H_2O, ≅ 80% by weight). While the Ni-Cd technology will require periodic watering maintenance, the quantity of electrolyte included in each cell provides sufficient reserve to ensure infrequent intervals. A Central Watering System (CWS) facilitates the watering process of a battery string.

The electrodes, separator system and electrolyte combine to form a battery system with a volumetric energy density of 63Wh/L. Its energy density allows for a direct replacement of Valve Regulated Lead Acid batteries that are commonly used in Remote Terminal (RT), bulk power applications today.

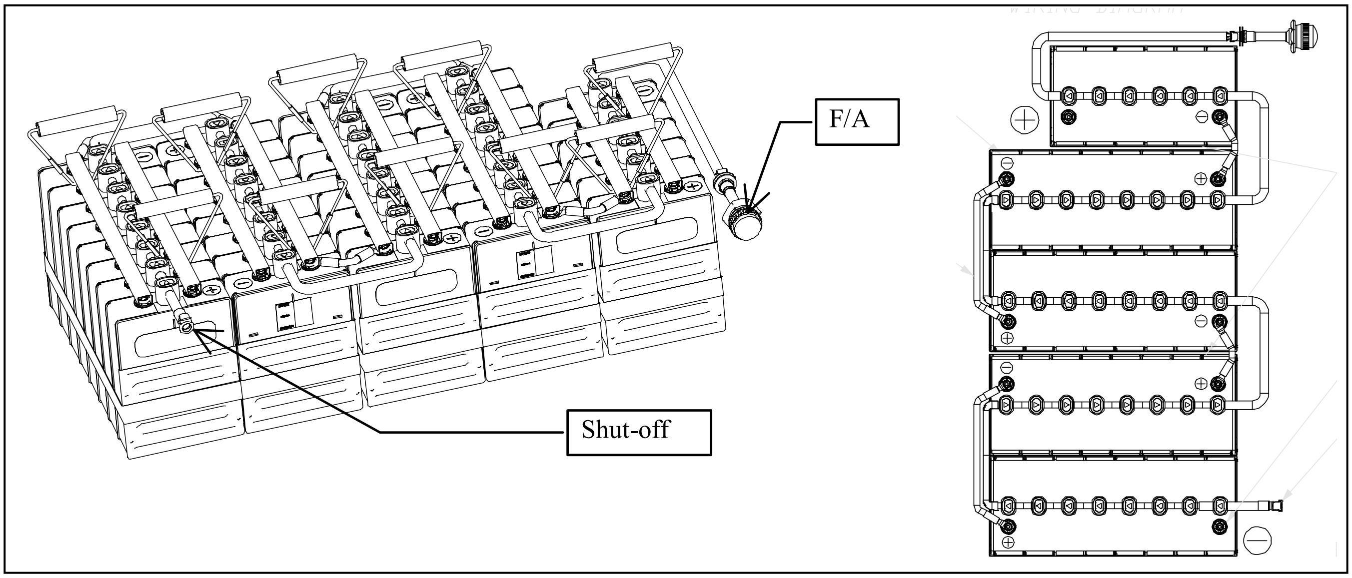

FIGURE A. An example NCX battery string. Comprised of electrically and hydraulically interconnected blocks or modules, the 38 cell string operates on a typical 48V telecom buss. A single flame arrestor (F/A) is installed on the (+) side of the string for single point gas exhaustion and explosion protection.

Modular Blocks with Central Watering System (CWS)

Battery strings are configured with 3 to 8 cell blocks with a nominal voltage range of 3.6V to 9.6V per block. The variable size blocks allow for adaptation in customer specific footprints. The example shown in Figure A illustrates four 8-cell blocks and one 6-cell block connected in series. A complete string for a typical 48V telecom application, is comprised of 38 cells connected in series.

The battery block design incorporates a Central Watering System (CWS). The CWS includes factory installed chimneys that interconnect cells. Each cell within a block shares a common gas space through these connections. Each battery block within a string is connected with flexible tubes. Each block, through these connections, will in turn share a common gas space. A flame Arrestor (F/A) Assembly and a Shut-off Assembly are included at each end of the string. The F/A, a porous ceramic plug, prevents a spark or flame from entering the battery string and further provides a central exhaust port for internal gasses. The CWS channels internal gasses of the string to a central exhaust point (through the F/A) thereby enabling the string to operate at atmospheric pressure. It further provides a single-point watering inlet when topping the string with water.

TRIAL SITES

Ni-Cd strings were installed in several trial sites in the United States. Sites with high average temperatures were specifically chosen as installed batteries are typically characterized as having an accelerated aging rate[1,2]. Table A summarizes the three trial sites of interest.

TABLE A. Summary of Ni-Cd Trial Sites of Interest

#	Rated Capacity	# strings installed	Date installed	Zone[2]	Cabinet Type
O	100 Ah	1	Jun. 1997	IV	Fujitsu 6200
H	125 Ah	2	Mar. 1998	IV	Reltech Reliance 101
P	125 Ah	2	Sep. 2000	II	Alcatel (DSC) LSC2030

As referenced in Table A, the Temperature Zone Model[(2)] defines the United States as four parallel and "horizontal" zones. The zone boundaries are 30N, 35N, and 40N parallels. North of each parallel are Zone III, Zone II, and Zone I, respectively. South of the 30N parallel is Zone IV and in terms of average yearly temperature, it is the hottest region.

Remote accessed data collection instrumentation was installed. The instrumentation measures and records operating parameters of each string. Periodically, at regular intervals, the data is remotely downloaded via a modem and dedicated telephone line. The recorded parameters include: buss voltage; half battery string voltage; float current; re-charge current; discharge current; battery string temperature; internal cabinet temperature; internal cabinet humidity; a/c power input to the rectifier; and total rectifier output current.

MAINTENANCE

In general, for all regions, watering the Ni-Cd string at 5 year intervals is the recommended maintenance practice[(3)]. As learned through the trial sites, this recommendation is acceptable for most regions. However, as some of the following results suggest, in the driest climate, a shorter interval should be considered (3 years). This will ensure enough margin for a safe, long-lasting, and normal operating battery string.

Charging and Water Usage

Basically, water is consumed while over-charging the battery string, as a result of electrolysis (e.g., $2 \bullet H_2O \rightarrow O_2 + 2 \bullet H_2$). It is not consumed during discharge, initial re-charge followed by a discharge, or storage. Other mechanisms such as oxygen (O_2) recombination and evaporation can also affect water usage. During overcharge, all three mechanisms (electrolysis, recombination, and evaporation) affect net water balance. Defining the electrolyte as the control volume, electrolysis and evaporation use water whereas recombination creates water. Or, the net change in the total amount of water during overcharge is:

the control volume is the electrolyte

(Water created from recombination) – (Water used by electrolysis) – (Water used by evaporation) = **Net change in water**

Unlike the Valve Regulated Lead Acid (VRLA), the Ni-Cd is not designed to recombine overcharge gas (O_2). It is designed with a membrane zone in the separator system whereby gasses are largely prevented from mass transport within the electrode stack. With minimal transport, gas recombination is also in turn significantly minimized.

Overcharging only occurs when the battery string is float charging. Figure B shows the typical recharge characteristics of a Ni-Cd battery string. Starting with a fully discharged string, approximately 24 hours are needed to reach a 'fully' charged state. Charging beyond this point is characterized as float charging or over-charging. Electrolysis occurs during this period. The rate at which gas (O_2, H_2) is generated and expelled is directly proportional to the level of float current. Higher float currents result in increased gas generation.

Evaporation is a function of battery temperature and humidity. The CWS maintains a 'high-humidity' environment, inside the battery, where evaporation is suppressed.

Overcharge gasses (H_2, O_2, and H_2O vapor), in the Ni-Cd, are all exhausted through the F/A (see Figure A). See a detailed discussion about gas generation rates in the following section, **Gas Generation**.

With a fixed buss voltage setting of 54.4 VDC, the typical float current is approximately C/2000 (0.063 Amps for NCX125 where C=125) and is dependent on the string temperature and buss voltage fluctuations. Figure C shows the measured float current, for approximately one week, from a battery string installed in trial site **P** (see Table A). While the provided data is from a single site, it is representative of data collected from the other sites. As shown, the float current depends on the temperature and buss voltage.

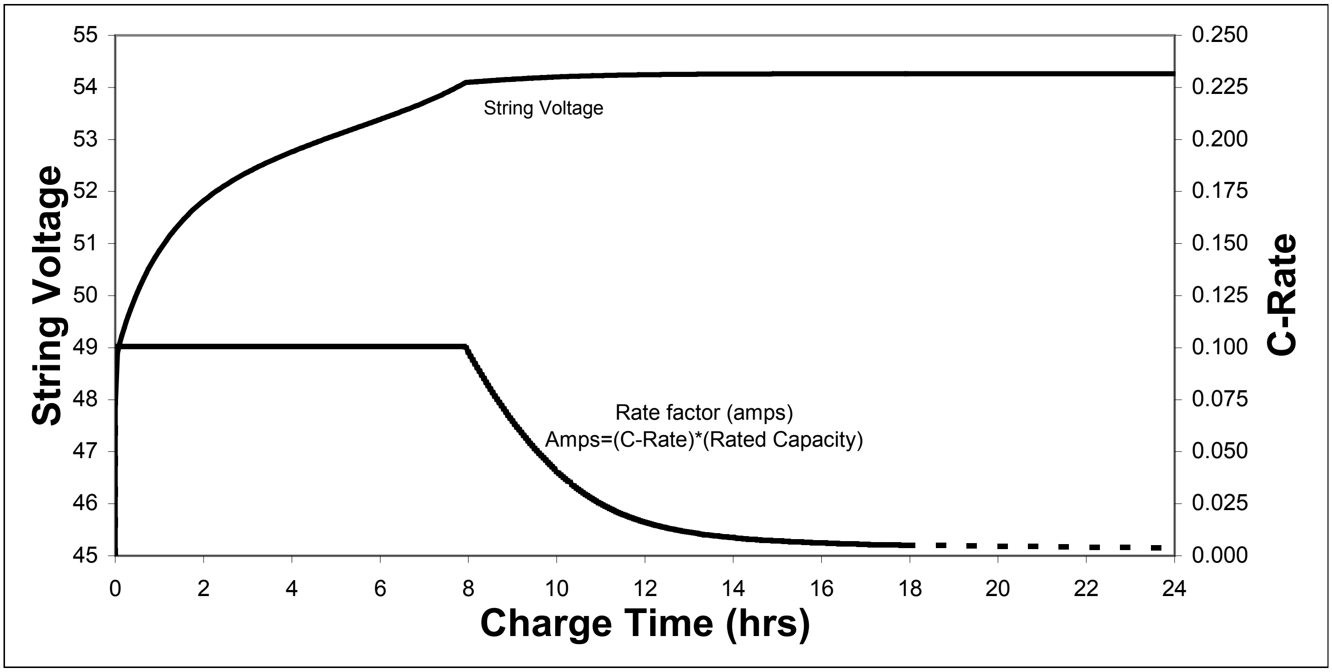

FIGURE B. The typical re-charge characteristics of an NCX type telecom battery string. At time zero the battery string is completely discharged. The max. voltage setting = 54.35 VDC, max. available current = 0.1C (12.5 Amps for NCX125 where C=125) and the temperature was ambient room. After 24 hrs, the string is 'fully' charged and 'float charging'. Water is only consumed during this period of over-charging.

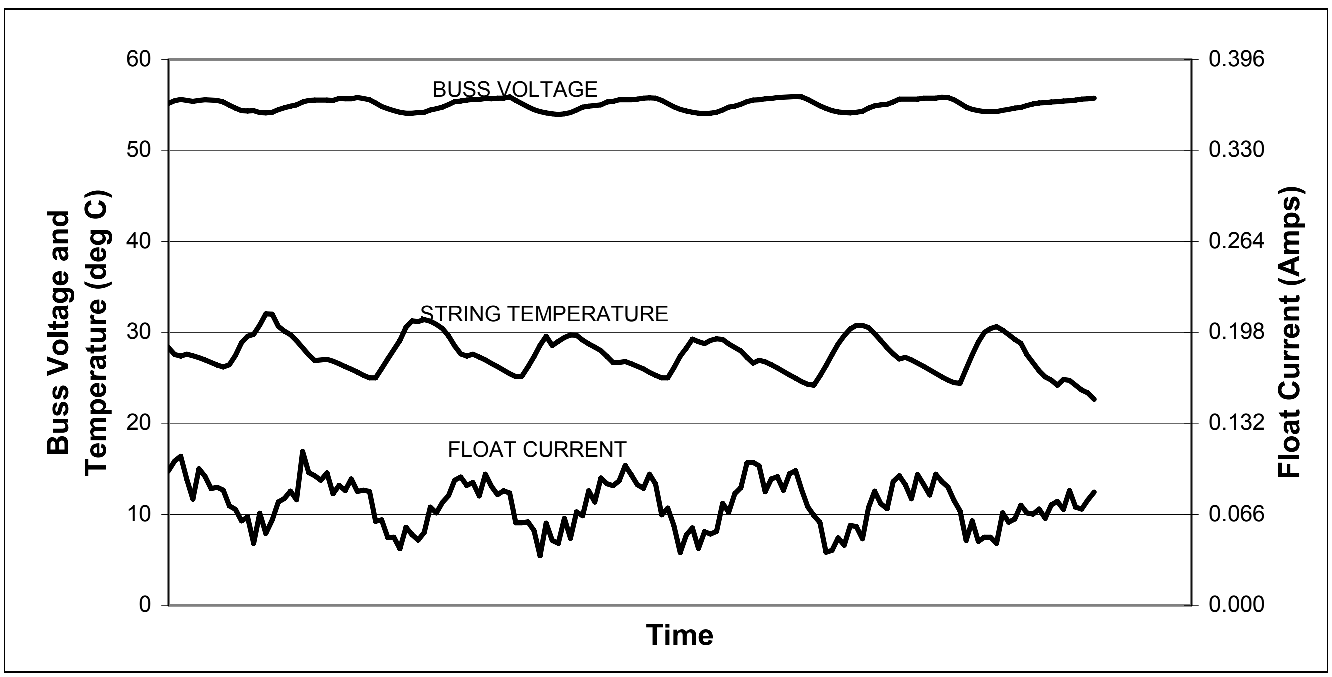

FIGURE C. The measured float charge characteristics of an Ni-Cd battery string installed in trial site #P (see Table A). Float current variations are a result of the temperature and buss voltage fluctuations.

TABLE B. Maximum Water Usage Rate of Each Trial Site

Site #	Maximum Level/Weight Change Measured for Period	Period of Operation for Measurement	Usage Rate (cm^3/month/Rated Ah/cell)
O	2 mm (Note 1)	12 months	0.015
H	74 grams (Note 2)	18 months	0.035
P	2477 grams (Note 3)	9 months	0.058

Note 1: The water usage conversion factor is 9 cm^3/mm. Measured from single cells. Five cell samples used.

Note 2: Total weight change from single cells. Ten cell samples used.

Note 3: Total weight change of a complete string of 38 cells. Summed the total weight change for each block and averaged over 38 cells. Two string samples used.

Water Usage Rate

To measure the water usage rate in field trials, the *net change in water* (see **Charging and Water Usage**) was quantified by either a weight change or linear level change at the block or cell level. It should be noted that a weight or level change, of the block/cell, while the battery string is in operation, is due only to the water change from electrolyte. For both methods, a baseline measurement of the level or weight was made. After a period of time in operation, the weight or level was re-measured. Table B summarizes the results for each trial site. Nominal and expected variations in water usage were observed. For the scope of this paper, only the maximum usage rate is reported.

The water usage rate at site **O**, was observed to be the lowest. This is not surprising since the Ni-Cd string was installed in parallel with two other VRLA strings and Temperature Compensated Voltage (TCV) control was operating. The TCV control, while protecting the VRLA's against thermal runaway, varied the total buss voltage inversely with the VRLA string temperature. The average buss voltage operated well below the recommended voltage set-point for the Ni-Cd. With this lower than recommended operating voltage, the float current of the Ni-Cd, was also lower than normal (measured range of 0.012 Amps to 0.028 Amps). The Ni-Cd design is optimized to operate with a constant voltage set-point (54.4 VDC for a 38 cell string) and independent of battery string temperature. It is not recommended to operate with TCV control. With the lower than recommended buss voltage, the usage rate was also lower than normal. Under TCV control conditions, the usage rate of 0.015 cm^3/month/Rated Ah/cell was expected and lower than the average rate observed in lab experiments (without TCV). With a constant voltage set-point of 54.4 VDC, the usage rate and available discharge capacity are balanced according to the specified needs of RT telecom applications(4).

At site **H**, the water usage rate was average. Over a period of one year, the battery temperature averaged approximately 39°C (102°F). During the hottest time of the year, the temperature of the cabinet and battery string exceeded 45°C (113°F). Figure D illustrates the cabinet and battery string temperature during one week at high ambient temperature. These temperature characteristics were also observed at site **O** and **P**. Without TCV control, the usage rate of 0.035 cm3/month/Rated Ah/cell was expected and agrees with average rate observed in the lab.

The water usage rate was highest at site **P**. Evaporation was a contributing factor in the high usage due to the low average Relative Humidity (RH) of the area.

By comparing area climate data for all three trial sites over a period of time, the differences and similarities become more

TABLE C. Historical Climate Data for Trial Sites(5)

Site #	Period Reported	Avg. Yearly RH	Avg. Yearly Temperature	Avg. Yearly High Temperature	Avg. Yearly Low Temperature
O	26 years	73%	23°C (73°F)	28°C (83°F)	17°C (62°F)
H	27 years	73%	21°C (69°F)	26°C (79°F)	14°C (58°F)
P	47 years	29%	19°C (67°F)	27°C (80°F)	12°C (54°F)

TABLE D. Calculated Watering Interval of Each Trial Site with 3.2 cm^3/Rated Ah/cell Electrolyte Reserve

Site #	Usage Rate (cm^3/month/Rated Ah/cell)	Watering Interval
O	0.015	17.7 years
H	0.035	7.6 years
P	0.058	4.6 years

evident. Table C summarizes historical climate data for the three trial sites. The average yearly environment temperatures range from 19°C (67°F) to 23°C (73°F); a 4°C variation. A similar range is observed for average yearly high and average yearly low temperatures, with 2°C and 5°C variations, respectively.

Since the temperature variations between the sites are small, RH is the main contributing factor to the higher usage rate measured at site **P**. Figure E illustrates the measured RH at site **P**, in a 3 month period. The average for this period is 33%. For comparison, Table C shows the average yearly RH for all 3 sites. Site **P** is significantly lower than the others.

Watering interval is determined by the usage rate and total reserve volume of electrolyte. The NCX type Ni-Cd has an electrolyte reserve volume of approximately 3.2 cm^3/Rated Ah/cell. So, for an NCX125 with a rated capacity of 125Ah, the electrolyte reserve volume is approximately 400 cm^3/cell. Table D summarizes the calculated watering interval of each trial site based on the measured usage rate and reserve volume of electrolyte.

In summary, site **O** demonstrated a low usage rate as a result of the low average buss voltage, due to temperature compensated voltage control. Site **H** has an average usage rate and site **P** has a high usage rate mostly affected by the relatively low humidity of the region. Given the maximum measured usage rates in the field and reserve volume of electrolyte, the standard watering interval for Ni-Cd batteries should be once every five years. In areas where the average

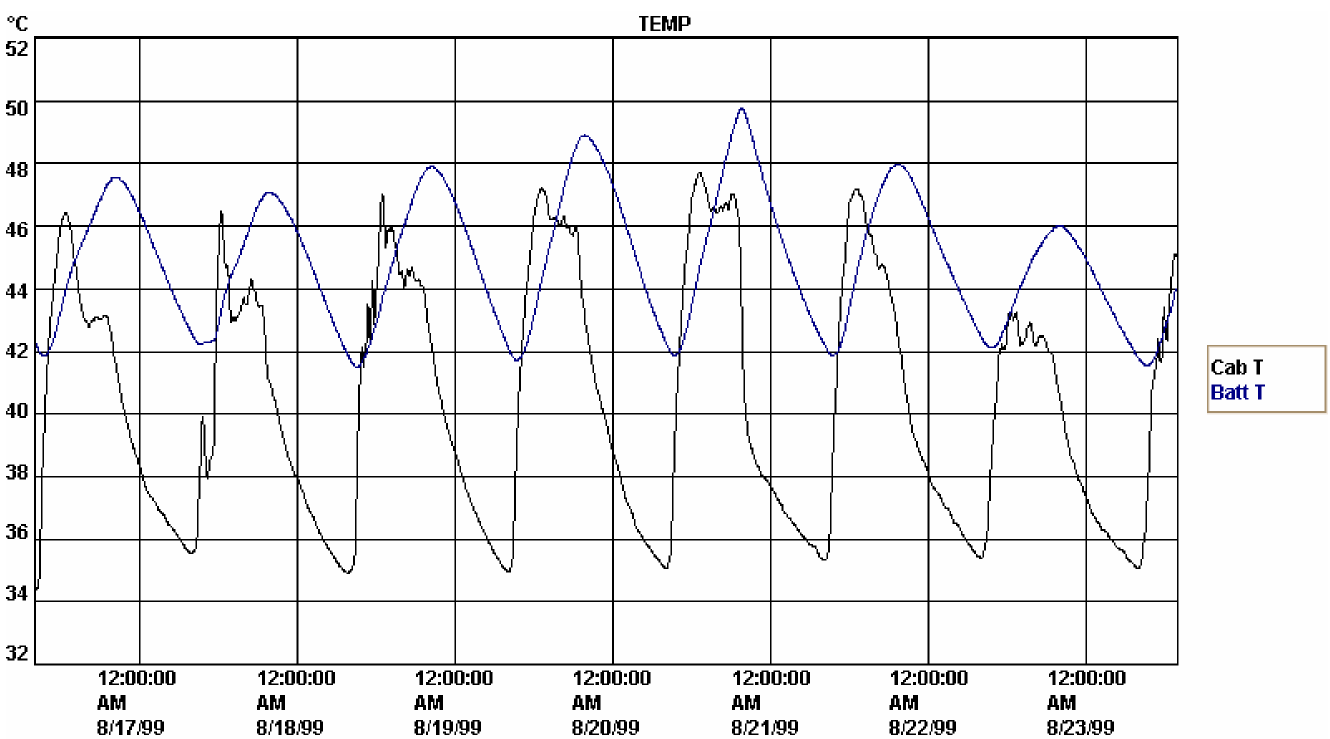

FIGURE D. The measured battery string and cabinet temperature at site H. This one week period illustrates the operating temperature during the hottest time of the year. The average battery temperature is higher since it is installed in the highest or the hottest part of the cabinet and the cabinet temperature is measured in the lowest.

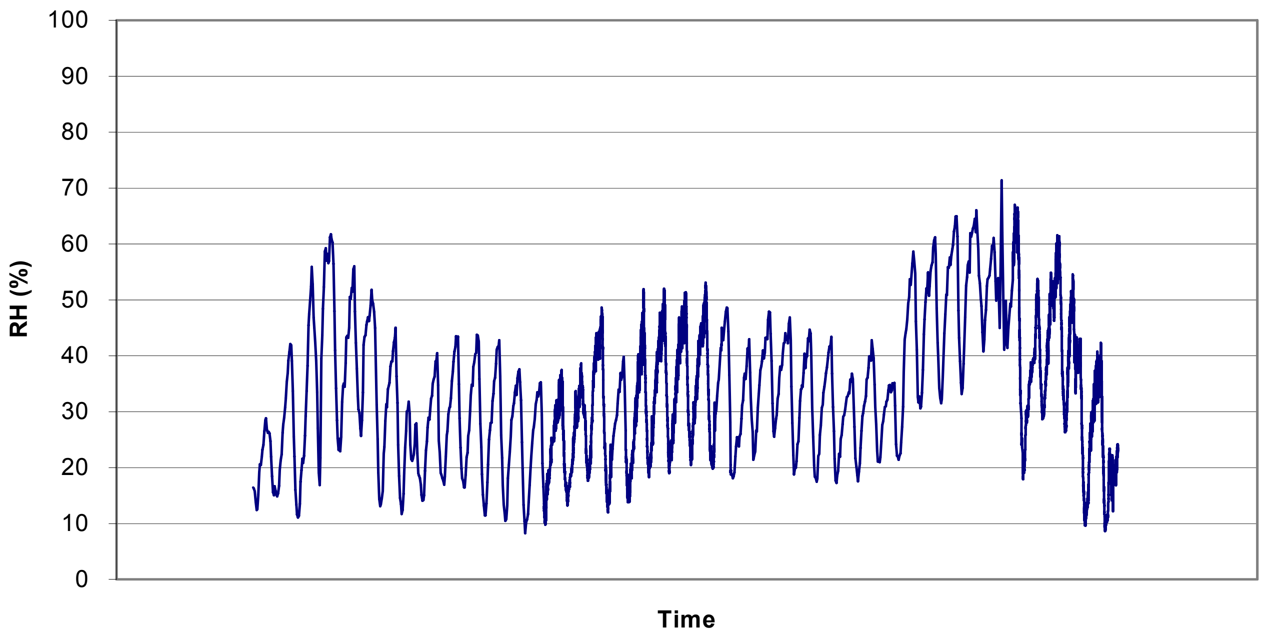

FIGURE E. The measured RH inside the battery compartment at site P. For this 3 month period, the average RH was 33%.

TABLE E. Estimated "Worse Case" Hydrogen Generation Rate Based on the Total Water Usage Rate

Site #	Usage Rate (cm^3/month/Rated Ah/cell)	Rated Ah	Hydrogen Gas Rate(Note 1) (cm^3 H_2/hour/cell)
O	0.015	100	2.6
H	0.035	125	7.5
P	0.058	125	12.4(Note 2)

Note 1 For every gram of water used through electrolysis, 1237 cm^3 of hydrogen is generated at Standard Temperature and Pressure (STP - 0°C, 1 atm).

Note 2 See discussion in **Gas Generation** about an adjusted estimate.

yearly humidity is low (approximately 29%), more frequent watering may be required (once every 3 years). Even so, the watering interval of Ni-Cd batteries *exceeds* the replacement interval of other battery technologies.

Gas Generation

Based on the measured usage rate (e.g., cm^3/month/Ah Rated/cell) shown in the previous section, the gas generation rate can be calculated. Hydrogen (H_2) is only generated when water is consumed through electrolysis (e.g., $2 \bullet H_2O \rightarrow O_2 + 2 \bullet H_2$), or, during overcharge hydrogen will exhaust from the battery string through the flame arrestor. The rate at which it will exhaust can be estimated for a specific period based on the usage rate of water during the same period. However, calculating the hydrogen generation rate based on the total usage rate will represent a "worse case" estimate since it is based on the assumption that all the water is consumed due to electrolysis. In practice, water is also used due to evaporation where water vapor is exhausted and not hydrogen gas. Table E summarizes the estimated "worse case" hydrogen generation rate for each trial site.

As expected and as shown in Table E, site **P** was estimated to have the highest hydrogen gas rate. Given the high evaporation rate assumed at site **P**, it is reasonable to adjust this worse case estimate based on a few other assumptions. It

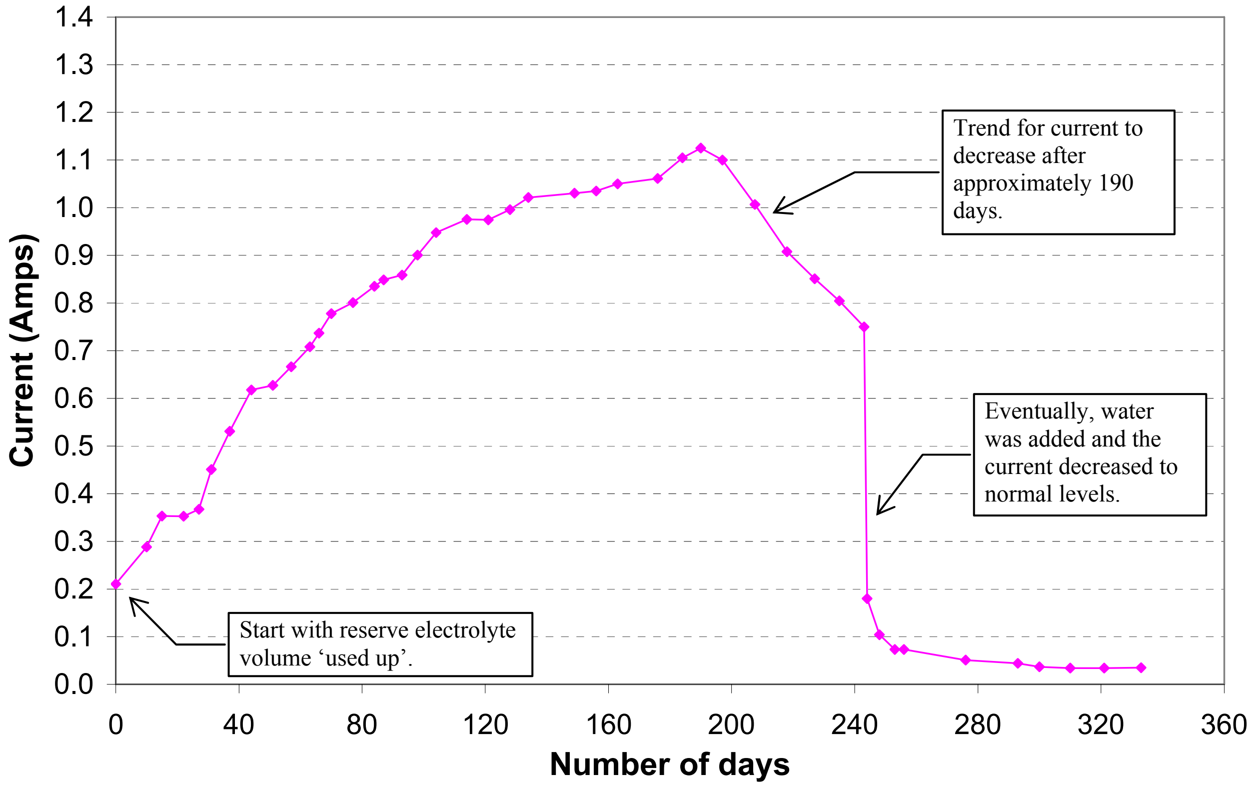

FIGURE F. The current evolution of a Ni-Cd while under 'starved' electrolyte conditions. The test was conducted at 50°C (122°F) and with a fixed voltage of 1.43 V/cell (54.4 V for a 38 cell string typically used for a 48V telecom application).

can be assumed that the average usage rate of 0.035 cm3/month/Ah Rated/cell at site **H** is largely due to electrolysis and not evaporation, given the high average yearly humidity. Given the same operating conditions and temperatures at both sites, it is reasonable to then assume that the difference in usage rate at site **P** (relative to site **H**) is largely due to evaporation. Based on these assumptions, the adjusted estimate of hydrogen gas rate at site **P** would be approximately the same as site **H** in spite of the higher water usage rate at site **P**.

THERMAL RUNAWAY

Related to battery maintenance is a phenomenon known as "thermal runaway"[6]. If specific maintenance items go un-checked, a failure mechanism potentially leads to a melt-down or, in the worse case, a fire and/or explosion in the battery compartment may result. Thermal runaway is characterized by high charge currents and high oxygen recombination rates that, both, 'feed' each other and eventually lead to a melt-down. Thermal runaway has been experienced with other types of battery chemistries in the field. Control measures, such as temperature compensated voltage (TCV) and current limiters, were deployed to minimize its occurrence.

For a Ni-Cd, watering is the only required maintenance. Adopting and implementing a required maintenance program will maximize performance and expected life and ensure safe operating conditions. However, worse case testing was conducted in a controlled laboratory environment to investigate thermal runaway risks if the Ni-Cd string is not watered as required.

Several tests were conducted at different temperatures (20°C (68°F), 40°C (104°F), and 50°C (122°F)) on the NCX125. Today, they are ongoing. The 50°C test is most interesting since it is a considered to be worse case in terms of operating temperature. Before starting the test, the reserve electrolyte in each battery was 'used-up' by continuously overcharging at C/50. Once the level of electrolyte was brought to its critical level, charging was continued at 50°C (122°F) and a fixed level of 1.43 V/cell (equivalent to 54.4 V for a typical 48V telecom application). As charging continued, the current evolution was measured.

The results of the test are illustrated in Figure F. At time zero, the level of electrolyte was at the top of the electrode stack. At this critical level, the reserve electrolyte was used up. As constant voltage charging continued, the current increased gradually and slowly for approximately 190 days. At that point, the maximum current level (approximately 1.1 Amps or C/113 for the NCX125) was reached and a gradual decrease in current followed. During this period of charging, the measured battery temperature remained at the controlled level of the environment (50°C) and unchanged. Eventually, water was added to the battery and the current eventually decreased to its normal level of float current and continued to operate at that level.

In summary, if water is not added to the Ni-Cd string as prescribed, the preliminary test results suggest a 'fail-safe' trend where the current will reach a maximum level and gradually decrease over time. Once water is added to the string, the abnormal level of charging current returns to normal. It further suggests, based on the stable temperature of the battery, that oxygen recombination is minimized, even under 'starved' electrolyte conditions, due to the separator system design.

It is important to note that the results of this investigation suggest a non-catastrophic outcome during *abnormal* operation. Even with such encouraging results, it is vital to restate that adopting and implementing a required maintenance program is essential for normal operation and to guarantee adequate performance.

OTHER MAINTENANCE

Periodic re-torque of the terminal connections are not required. All cell terminals and inter-cell links are constructed of nickel plated steel. With an additional corrosion preventative compound applied, corrosion is minimized and essentially eliminated. Additionally, steel is relatively nonmalleable and not easily deformed which may result in a high impedance connection.

Routine conductance measurements on a Ni-Cd are not required. Current studies are attempting to correlate conductance measurements with the state of charge and state of health of a Ni-Cd.

The Ni-Cd batteries are shipped from the factory either charged or discharged. Discharged batteries, when stored, should remain in this state until ready for deployment to the field. Maintenance charging of Ni-Cd batteries while in storage is not required.

The flooded Ni-Cd does not require periodic specific gravity measurements. The electrochemical reactions do not contribute to significant changes in the concentration of the electrolyte. Hence, specific gravity also remains unchanged. It is impractical to obtain state of charge information by measuring the specific gravity of a flooded Ni-Cd.

CONCLUSIONS

- Field trials to date have been deployed in many regions of the US for more than three years. Ni-Cd battery operation in the hottest climates (Zone III and Zone IV) confirms that their operation is compatible with typical 48V RT applications.

- Field trial experience, in RT telecom cabinets, confirms that periodically adding water to a Ni-Cd battery string is the only required maintenance and, in most cases, exceeds the replacement interval of other battery technologies used in uncontrolled environments.

- From usage rate data, a 'worse case' hydrogen gas generation rate was estimated. Through comparisons between the high humidity and low humidity sites, an estimation of the evaporation rate at low humidity sites was made.

- Preliminary results suggest that thermal runaway is improbable. High charge currents cannot be sustained with the normal operating voltages of a typical 48V telecom application; even if water isn't added, as prescribed, to the battery. Further tests are ongoing to reproduce and confirm the 'fail safe' nature of the Ni-Cd.

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