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# Mitigating the Effects of High Humidity on Nicd Batteries Used in Power Plants

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## Abstract

As the proliferation of power plants have been on the rise to cater to the energy needs of a rising population so are the auxiliary systems that are required to support the operation of a power plant. One of the most important systems which are also very essential for the electrical protection is DC power, with which most of the relays and the breakers operate. Several standard voltage levels are used such as 48V, 110V, 220V etc. and most commonly used batteries are Nickel Cadmium, Lead Acid Batteries and Lithium Polymer Batteries. The NiCd batteries and Pb-Acid batteries are more suitable because of their robustness and the relative ease of maintenance; moreover most power plants normally do not have space constraints as selection criteria, for example an electric car. Due consideration has to be given while setting up battery banks in areas with harsh conditions. This discussion contains a case study involving a NiCd battery bank located in a very humid area; the conditions resulted in ground faults in the battery banks. A number of factors contributed to the spillage of electrolyte from the cells and lead to the ground faults. The leakage currents caused severe damage to some of the cells, reduced their capacities drastically. A point to reckon is that, there was no structural damage or crevices in the bodies of the cells; the spillage was entirely from the gas vents on top of the cells.

***Keywords:*** Nickel Cadmium; Power Plants; Battery Banks; Gasification Voltage; DC; Fick's Law; Evaporation Rates.

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## 1. Introduction

Vented Nickel Cadmium batteries are used in large industries such as power plants; it is because they are economical, robust and have a long life, some are operational for more than 25 years (1000-4000 cycles). The vented cells allow in for the large capacities required typically in power plants (often greater than 1000AH). During the events of fast discharging or charging, the gases so produced are allowed to move out, the vents also allow the electrolyte to expand during the higher temperatures encountered during its life cycle. NiCd batteries are more compact and lighter, have longer shelf/storage time as compared to Lead Acid batteries. They have a have higher charge rates as compared to their Lead acid counterparts. The loss of electrolyte is also very marginal, the electrolyte does not take part in the charging or discharging reactions, topping up with distilled water once or twice in a year is all that it takes to maintain permissible electrolyte levels. The maximum water consumption during overcharging is approximately, 0.336 cc/Ampere-hour.

The net reaction for NiCd battery is:

$$2Ni(OH)_2 + Cd(OH)_2 \rightleftarrows 2NiO(OH) + Cd + 2H_2O \qquad [6]$$

The gases formed are mainly because of the electrolysis of the water component seen in the above reaction.

Nominal cell voltages:

NiCd: 1.2V

Pb-Acid: 2.00V

Float charge voltages:

NiCd: 1.4V

Pb-Acid: 2.25V

The loss of electrolyte can be in the form of evaporation, gases formed during electrolysis during high charging and discharging rates and due to the structural leakages in the cells.

## 2. A Case Study

During the events of fast discharging and fast charging, the temperatures of the cells may increase because of the heat produced due to the charging current passing through internal resistance ($q = i^2r$, r is the internal resistance of a cell). NiCd batteries however have a negative temperature coefficient i.e. the internal resistance decreases as the temperature rises. The increased temperature causes the electrolyte to expand which may eventually cause the electrolyte to spill over through the gas vents, this scenario can provide a conducting path for current to flow out and may discharge the cell below its end cell voltage (typically around 1.2V for NiCd cells).

A NiCd cell whose voltage falls below its end cell voltage may be damaged and rendered useless. A typical NiCd battery may consist of tens or hundreds of cells connected in parallel or series depending upon the required voltage levels or capacity. Any damaged cell in a series will provide an open path in the circuit which may cause the entire battery to fail; even one malfunctioning cell can seriously hamper the functioning of the battery and put the protection systems in a power plant at severe risk.

### 2.1 *Gassing Voltage*

The gassing voltage for NiCd battery starts from 1.45V/cell at 25$^{o}$C [2, 3], this voltage is also temperature dependent which can increase by 0.0025V per degree rise in the electrolyte temperature [2, 3]. This indicates that the nominal float voltage and the gassing voltages are not separated by much, and in the absence of individual cell voltage monitoring it is possible that the voltages across some cells are beyond the gassing voltage. Thus gas formation can take place even during float charging conditions.

The spill overs of electrolyte due to gasification are rare, batteries are designed and markings are present to indicate permissible limits of the electrolyte levels. In the events of fast discharging or fast charging (e.g. Boost charging), batteries are often checked in as a part of protocol in most locations.

### 2.2 *Electrolyte Spill*

But the problem arises when during normal charging conditions the electrolyte spills over the vents and provides conducting paths allowing the cells to slowly discharge, often at a higher rate at times, than it’s charging rates. The case at hand is of a similar nature, it was found that a few cells were damaged because their voltages fell below their end cell levels. Moreover an earth fault was also observed, but it didn't seem to be happening at a single location. The DC system in an industry is kept 'floating', none of the terminals are at earth potential, so the first earth fault will not result in any closed circuit to allow earth fault currents to persist. But any subsequent earth faults can be dangerous, it allows fault current to flow in the faulty circuit, the magnitude of which can vary depending upon the resistance offered.

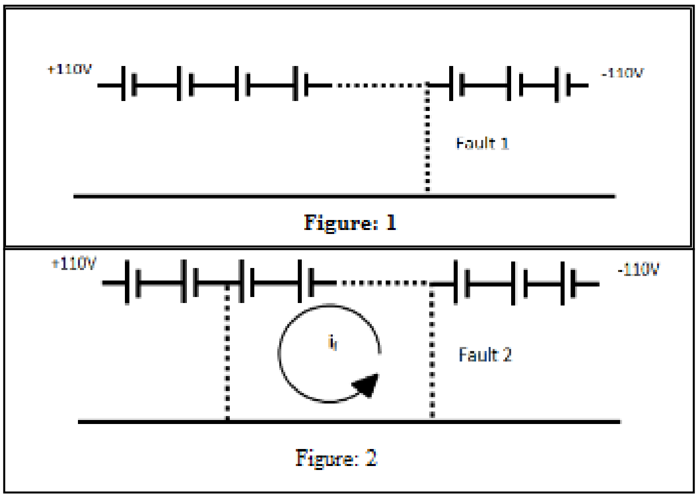


**Figure 1:** Indicates a single earth fault, but there are no paths for the current to flow, **Figure 2:** on the other hand shows a closed path for the fault current.

NiCd cells are typically made up of nylon (polyamide) and when the electrolyte spilled in streaks, it was difficult to make out as the electrolyte KOH (Potassium Hydroxide), is a clear liquid. But checking the nylon surface with a voltmeter revealed that the 'flowing electrolyte streaks' were indicating high voltages, depending upon the locations of the affected cells. Affected cells near the positive terminal showed high voltage values with respect to the negative terminal than the ones near the negative terminal, which is of course understandable given that the cells were connected is series. The presence of these voltages found on the surfaces of the cell posed serious threat to working personnel who were in charge of regular upkeep of the batteries.

**Figure 3:** A voltmeter indicates the voltages available on the surfaces the cells; voltages as high as 100VDC were observed in some streaks.

The presence of such streaks were also intriguing given that the batteries were being trickle charged and were not supplying to any load, but as mentioned before, the trickle charge or Float voltage of **1.4V** and the gasification voltage of **1.45V** are not very far apart. In the absence of individual cell monitoring system and when the cells are connected to one charger, there will be some cells whose voltages surpass the gasification voltage which eventually leads to the formation of gases *(hydrogen and oxygen)* in the electrolyte. The gassing is also dependent upon the capacity of the cells; a larger capacity cell will have greater surface area of reacting plates, thus more area for gas formation. On close observation it was found that the electrolyte was spilled due to bursting gas bubbles on the surface the electrolyte near the vents. Though the amount of electrolyte spilled by this manner was very less, the condition was worsened because of the extreme high humidity of the location *(close to 90%)*.

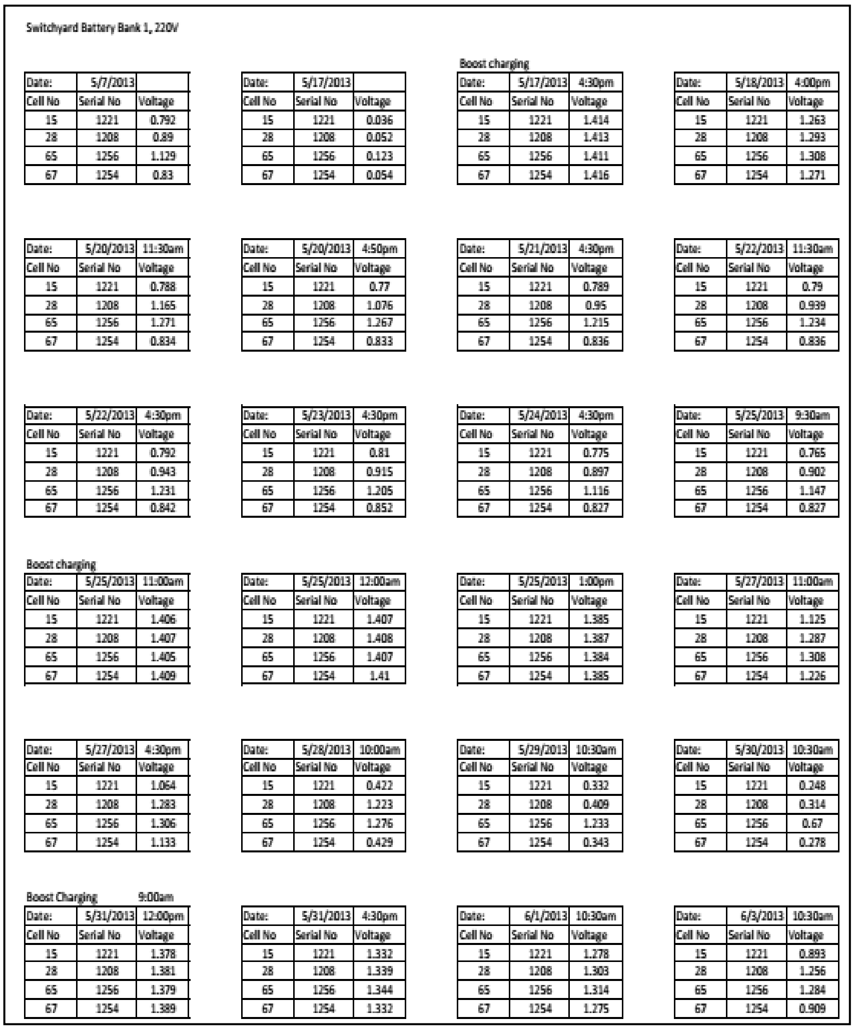
The humidity did not allow the spilled electrolyte to evaporate causing a gradual accumulation of the electrolyte and its subsequent trickling down along the surface of the cells. The cells are typically placed on a metal frame painted with an epoxy compound or at times just with thick enamel paint. The spilled electrolyte accumulated on the support frame and when the electrolyte trickling down from two or more cells met, a closed circuit was formed. If unattended this closed loop current can discharge the cells down to harmful levels. One of the easiest ways to predict such a condition is to detect the presence of a persisting earth fault, however minor. Many a times small voltage offsets are ignored or are rectified by adjusting a balancing resistor generally provided in the distribution boards.

**Figure 4:** Droplets of Electrolyte can be seen below the cell seats, the seats are basic L-sections made up of steel coated with enamel or epoxy paint.

There can be hundreds or even thousands of battery cells in a power plant, monitoring each and every cell may not be economically feasible on a regular basis, minor spillage will be present. The battery rooms must be kept as dry as possible, though easier said than done, battery rooms are some of the most neglected areas in a power plant. It is also necessary to note that during fast discharging or charging hydrogen and oxygen gases are also formed, this can lead to explosive mixtures which might result in a conflagration. To keep safety measures uptight, it is very essential that brushless motors in the exhaust fans are used, all the lighting fixtures conform to operations in very hazardous conditions (IP 65 and above) and strict restrictions must be adhered against any open flame in the battery room area. Due diligence should be given out to the choosing of the space for the battery room, it is very essential that the room has a cross ventilation, the air should keep on moving in and out. Even if dehumidifiers or air washers are used it is required that fresh air is brought in the room from outside, internal circulation of the air can result in dangerous conditions. Explosive composition of Hydrogen and Oxygen Gas is: 4% $H_2$ and 96% $O_2$ at 1 Atm pressure [4].

**Figure 5:** Electrolyte can be seen on top of the covers of the terminal links.

**Table 1:** The following table contains the voltage profiles of some defective cells in a battery bank. The surges in the voltages in the graph provided were during the boost charging of the battery.



Switchyard Battery Bank 1, 220V

| Date: | 5/7/2013 | |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.792 |
| 28 | 1208 | 0.89 |
| 65 | 1256 | 1.129 |
| 67 | 1254 | 0.83 |

| Date: | 5/17/2013 | |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.036 |
| 28 | 1208 | 0.052 |
| 65 | 1256 | 0.123 |
| 67 | 1254 | 0.054 |

Boost charging

| Date: | 5/17/2013 | 4:30pm |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 1.414 |
| 28 | 1208 | 1.413 |
| 65 | 1256 | 1.411 |
| 67 | 1254 | 1.416 |

| Date: | 5/18/2013 | 4:00pm |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 1.263 |
| 28 | 1208 | 1.293 |
| 65 | 1256 | 1.308 |
| 67 | 1254 | 1.271 |

| Date: | 5/20/2013 | 11:30am |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.788 |
| 28 | 1208 | 1.165 |
| 65 | 1256 | 1.271 |
| 67 | 1254 | 0.834 |

| Date: | 5/20/2013 | 4:50pm |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.77 |
| 28 | 1208 | 1.076 |
| 65 | 1256 | 1.267 |
| 67 | 1254 | 0.833 |

| Date: | 5/21/2013 | 4:30pm |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.789 |
| 28 | 1208 | 0.95 |
| 65 | 1256 | 1.215 |
| 67 | 1254 | 0.836 |

| Date: | 5/22/2013 | 11:30am |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.79 |
| 28 | 1208 | 0.939 |
| 65 | 1256 | 1.234 |
| 67 | 1254 | 0.836 |

| Date: | 5/22/2013 | 4:30pm |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.792 |
| 28 | 1208 | 0.943 |
| 65 | 1256 | 1.231 |
| 67 | 1254 | 0.842 |

| Date: | 5/23/2013 | 4:30pm |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.81 |
| 28 | 1208 | 0.915 |
| 65 | 1256 | 1.205 |
| 67 | 1254 | 0.852 |

| Date: | 5/24/2013 | 4:30pm |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.775 |
| 28 | 1208 | 0.897 |
| 65 | 1256 | 1.116 |
| 67 | 1254 | 0.827 |

| Date: | 5/25/2013 | 9:30am |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.765 |
| 28 | 1208 | 0.902 |
| 65 | 1256 | 1.147 |
| 67 | 1254 | 0.827 |

Boost charging

| Date: | 5/25/2013 | 11:00am |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 1.406 |
| 28 | 1208 | 1.407 |
| 65 | 1256 | 1.405 |
| 67 | 1254 | 1.409 |

| Date: | 5/25/2013 | 12:00am |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 1.407 |
| 28 | 1208 | 1.408 |
| 65 | 1256 | 1.407 |
| 67 | 1254 | 1.41 |

| Date: | 5/25/2013 | 1:00pm |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 1.385 |
| 28 | 1208 | 1.387 |
| 65 | 1256 | 1.384 |
| 67 | 1254 | 1.385 |

| Date: | 5/27/2013 | 11:00am |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 1.125 |
| 28 | 1208 | 1.287 |
| 65 | 1256 | 1.308 |
| 67 | 1254 | 1.226 |

| Date: | 5/27/2013 | 4:30pm |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 1.064 |
| 28 | 1208 | 1.283 |
| 65 | 1256 | 1.306 |
| 67 | 1254 | 1.133 |

| Date: | 5/28/2013 | 10:00am |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.422 |
| 28 | 1208 | 1.223 |
| 65 | 1256 | 1.276 |
| 67 | 1254 | 0.429 |

| Date: | 5/29/2013 | 10:30am |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.332 |
| 28 | 1208 | 0.409 |
| 65 | 1256 | 1.233 |
| 67 | 1254 | 0.343 |

| Date: | 5/30/2013 | 10:30am |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.248 |
| 28 | 1208 | 0.314 |
| 65 | 1256 | 0.67 |
| 67 | 1254 | 0.278 |

Boost Charging 9:00am

| Date: | 5/31/2013 | 12:00pm |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 1.378 |
| 28 | 1208 | 1.381 |
| 65 | 1256 | 1.379 |
| 67 | 1254 | 1.389 |

| Date: | 5/31/2013 | 4:30pm |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 1.332 |
| 28 | 1208 | 1.339 |
| 65 | 1256 | 1.344 |
| 67 | 1254 | 1.332 |

| Date: | 6/1/2013 | 10:30am |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 1.278 |
| 28 | 1208 | 1.303 |
| 65 | 1256 | 1.314 |
| 67 | 1254 | 1.275 |

| Date: | 6/3/2013 | 10:30am |
|---|---|---|
| Cell No | Serial No | Voltage |
| 15 | 1221 | 0.893 |
| 28 | 1208 | 1.256 |
| 65 | 1256 | 1.284 |
| 67 | 1254 | 0.909 |

## 3. Evaporation

Evaporation of the spilled electrolyte can prevent the occurrence of the conditions discussed. The electrolyte did spill at regular intervals but during the dry seasons, this meagre spill of electrolyte caused no such trouble. Even though evaporation is desired it is very necessary to keep it in optimum levels else the loss of electrolyte from the cells may be accelerated and they might end up drying at a faster rate. A brief and a derived analysis are proposed below for the controllable parameters that can influence evaporation rates.

Evaporation of the electrolyte can be determined using any of the following methods:

**a.** Energy Balance Method

**b.** Aerodynamic Method

**c.** Combined Method

Using the Energy Balance Method,

$R = LE+H+G$ [5, 7]

Where

R: Net radiation on the surface of electrolyte

L: Latent heat of electrolyte vaporization

E: Rate of Evaporation

H: Heat flux that heats up the air

G: Heat flux stored in electrolyte (this value is very small as compared to the other terms in the equation so it can be neglected.)

Using Stefan's Law we can obtain:

$R = (1-\alpha)R_s + \varepsilon\sigma(T_a-6)^4 - \varepsilon\sigma T_s^4$ (i) [5]

$T_s$: Temperature of the electrolyte

$T_a$: Air Temperature

$R_s$= 0, as battery banks are kept indoors with little or sunlight in it. [5]

$R = \varepsilon\sigma (T_a-6)^4 - \varepsilon\sigma T_s^4$ (ii)

$H = h (T_s - T_a)$ (iii)

$h = 5.907V^{0.8}L^{-0.2}$ [5]

V: Air velocity

Evaporation is a diffusive process and it follows Fick's law.

$E = KM/RT_a[P_{vs} (T_s) - P_v (T_a)]$ [5]

Where, K (convective mass transfer coefficient) = $h/(\rho C_p)$.......{Lewis Hypothesis} [5, 7]

$\rho$ = density

$P_{vs}$= exp(25.5058-5204.9/T) {Claplyron-Clausius formula} [5]

$P_v(T_a) = H_{ur}.Pvs.T_a$

$H_{ur}$: Relative Humidity

Thus the equation (i) can be summarized as

$$\varepsilon\sigma(T_a-6)^4 - \varepsilon\sigma T_s^4 = LKM/RT_a[P_{vs}(T_s) - P_v(T_a)] + 5.907V^{0.8}L^{-0.2}(T_s - T_a) \qquad \text{(iv)}$$

In equation (iv) it can be seen that optimum evaporation rates can be obtained by regulating the air velocity and the vapour pressure of water, the surface temperature and air temperature may not be controllable variables in most cases under consideration as no air conditioning apparatus are generally installed in the battery rooms. Other methods can also be used to arrive to similar conclusions.

Evaporation will also be influenced by the temperature of the electrolyte which is again dependent upon the current flowing through the battery, a simple relation between current and temperature is as:

$$i^2r = c_pmdT \qquad \text{(v)}$$

Where,

i: Charging current

r: Internal resistance of the battery

$i^2r$: Electrical power dissipation

$c_p$: Specific heat (kJ/kg.K) of the electrolyte

m: Mass (kg)

dT: Temperature rise

The temperature rise can be used to determine the electrolyte temperature, which can be further substituted in equation (iv) to obtain evaporation rates.

## 4. Points to Ponder and Recommendations

One of the biggest limitations of this study is that, it may not be possible to determine exactly how much electrolyte spillage can happen due to high humidity or currents, thus it would be difficult to ascertain the required rate of evaporation, however a negative pressure with an optimum air movement must be maintained in the battery room along with the air movement to increase the evaporation of any spilled electrolyte.

Heating up the room must be avoided if the location is already hot and humid, it would only worsen the situation, the electrolyte level would decrease due to evaporation and this in turn would cause the humidity levels to increase more.

The seats for the cells must be designed in a way that the electrolyte cannot accumulate, generally the seats are shaped in an 'L' shape, so whenever there is a spill the electrolyte will stay in the corner if the angle between the two sides is acute, but on the other hand if the said angle is a little obtuse, the electrolyte would trickle down to the floor.

The cells must be closely observed during the 'Boost Charging' of the battery. The 'Boost Charging' must be carried out twice in a year in order to keep the capacity of the battery intact and also to counter some malicious conditions such as the 'Memory Effect' in NiCd batteries. However if the batteries are discharged deeply due to an operation, a 'Boost Charge' is highly recommended.

During the aforementioned boost charging the charging current is typically high such as C10, C5 i.e. 10% & 5% of the rated capacity and the cell voltages are as high as 1.7V, because of this high rate of charging gases are formed in the electrolyte inside the cells they form bubbles, come up to the surface and burst thereby splattering the electrolyte. The increased temperature swells up the electrolyte and the electrolyte may be very close to the gas vents or filler caps. The splattered electrolyte may dry up but the potassium of the electrolyte gets deposited on the nylon body of the cell. And when the humidity is very high, moisture may settle down and some parts of the surface of the cell may become conducting.

Many manufacturers provide an auto top up arrangement, this arrangement can be very beneficial because not only it can allow the monitoring and topping up of the electrolyte in each cell, it can also prevent the splattering of the electrolyte. The arrangement has all the cells connected with tubes in parallel to the filler caps of each cell. Any gas or electrolyte that has to exit may do so through the tube without falling on to the body of the cell.

In many applications individual cells are monitored separately, their charging, healthiness, capacities are taken care of individually. This arrangement is certainly more expensive than an arrangement of a single charger for a battery bank, but certainly more effective to prevent the conditions discussed.

## 5. Conclusion

This study would facilitate proper design of NiCd cells, battery chargers and also the operation and usage of such batteries. Better vent caps can be designed and manufactured to prevent spillage, and improvements can be made in the battery rooms such as the provision of an air washer, allowing dehumidified air in the battery room etc. to reduce the effects of gasification. Gasification in NiCd batteries is an issue to ponder upon especially in wet and humid areas; when overlooked can result in some unexpected but serious troubles as the one that was discussed. Spilling of electrolyte must be checked on a regular basis and though it may not be possible to produce tailor made products for every condition present, but customization should always be done wherever or whenever it is feasible. Earth fault indicators and Ampere Hour meters are a must on the chargers and if possible, each cell must be individually monitored.

Any cell whose terminal voltage is below the nominal float voltage must be observed closely or must be replaced. Apart from proper ventilation airflow in and out in the battery room must be ensured, the humidity levels must be monitored. Healthiness of battery must be ensured at regular intervals; an open cell in a battery during an emergency can be a very dangerous situation and cause severe damages but it can be avoided to a great extent with proper measures, this study should certainly lessen down battery failures and prevent loss to life or equipment. This study should also enable further research work in the development of more robust and reliable batteries.

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