New Life for Sulphated Lead-Acid Cells?

Richard Perez

Over the years I have tried many chemical treatments supposed to rid a cell of sulphation. None of them made any perceptible difference. A strange and devious set of circumstances has led us to the successful chemical removal of sulphation from six lead acid cells. Not only are the circumstances odd, but the chemical used, EDTA, is benign– in fact, it is used as a human food preservative.

The Patients

The sulphated Trojan L-16W lead-acid batteries numbered four and were the victims of a messy divorce. The pack was less than two years old when its owners had a parting of the ways. The husband took off for parts unknown. The wife left the house vowing never to return. And she left ALL the lights on when she departed. This system was sourced only by an engine/generator, with no PVs to help out. After several days the batteries were totally discharged. The batteries then sat discharged, with the lights switched on, for the next three months.

The ailing pack was transported to Electron Connection for disposal as part of the whole divorce rigamarole. Upon inspecting the cells through the filler holes, we say vast amounts of white moss covering all the plate assemblies. Or at least we assumed there were plates in there somewhere because all we could see was an even blanket of moldy looking lead sulfate. Seven of the twelve cells were very low in water. Our job was to assess what these batteries were worth. In order to do this we attempted to recharge them and see how they held the charge. Open circuit voltage of the cells averaged 0.7 Volts.

We placed the batteries on a four panel Kyocera J48 PV array (≈12 Amps) and the voltage immediately shot to 15 Volts where the regulator cut in. The amount of current accepted by the four L-16Ws was 0.4 Amps. We left the L-16Ws on the array for five days, but they never did accept a charge. We then tried discharging the batteries. They (all four 125 pound batteries) ran a 28 Watt car tail light for about three minutes. This gave us an electrical capacity of about 0.05 Ampere-hours per cell that originally had a capacity of 350 Ampere-hours. A classic case of sulphation ruining virtually new, high quality batteries. We pronounced the cells toxic waste and told the principals involved that the batteries were worthless. In fact, worse than worthless because someone had to responsibly dispose of them. The original owners promptly disappeared and left us holding the batteries. They sat, forlorn and unloved, in the battery area, side by side with new cells destined for caring homes.

In another reality…

My friend, George Patterson, a battery techie second to none, ran into an article in an obscure British antique motorcar publication that described using a chemical called EDTA to remove sulphation from old lead-acid batteries. I related to him the story of the orphaned L-16Ws and, to make a very long story short, we decided to give it a try on these virtually new, but severely sulphated batteries.

EDTA, what is it?

It is an organic acid, a chemical cousin of vinegar. EDTA stands for the entire name of the compound which is, "ETHYLENEDIAMINE TETRAACETIC" Acid. EDTA is used for many chemical jobs, but perhaps the most amazing is as a food preservative. I noticed it on the list of ingredients of a can of Slice® orange pop I drank. In chemical techie terms, EDTA is a "chelating agent". That means it likes to bond to metallic ions (like lead sulfate). While EDTA is not the sort of stuff you want to eat by the teaspoon (the label carries warnings about getting it in the eyes or nose), it is a relatively innocuous chemical with which to attack the sulphated nastiness of those L-16Ws. I admit to being skeptical. I thought we were wasting our time. How could something contained in orange pop help these severely sick cells?

The Operation

George Patterson located and purchased 500 grams of EDTA from a local chem lab that specializes in the chemical testing of wine. The cost was low, under $15 for the EDTA and another ten bucks for rush shipping. George then did an essential duty in this entire process. He came up to HP Central in Hornbrook and got me off my butt to actually perform this experiment. George could have shipped me the EDTA, but he knew my faith in this project was so low that I'd get it done some time next century.

We decided to operate on two of the L-16Ws and leave the other two untreated as controls for the experiment. We had only sketchy information from the British motorcar pub. It described a teaspoon in every cell (hold the milk and sugar) and let sit for several hours. It neglected to mention the size of the cell, but George and I assumed that an antique motorcar would have a fairly small battery- about 70 Amp-hrs. So we upscaled the amount of EDTA to 2 Tablespoons to match the larger (350 Ampere-hour) L-16W cells. What follows is a step by step description of what we did:

PLEASE NOTE: These operations involve handling sulfuric acid electrolyte. We used acid resistant Norex lab coats, rubber boots, rubber gloves, and safety glasses. If you try these operations without this safety gear, then you are risking injury. Play it safe.

1 We drained the old electrolyte from all six of the cells. Now this reads easier than it does. An L-16W battery weighs 125 pounds and contains 9 quarts of sulfuric acid in its three cells. Be careful not to drop the battery or spill the acid electrolyte. Reserve the old electrolyte in secure containers and dispose of it properly through your local battery shop.

2 We rinsed all the cells with water and drained them.

3 We added 2 Tablespoons of EDTA to each cell and refilled each cell with hot (≈120°F.) tap water.

4 We left the cells to merrily bubble (the EDTA/lead sulfate reaction is exothermic- it gives off heat) for about two hours.

5 We then drained the cells and repeated steps 2, 3, and 4 once again. We could see the sulphation disappearing, but one treatment had not got it all. Actually, two treatments didn't either because there was still some sulphation there after the second go

round.

6 We rinsed each cell with distilled water and drained it.

7 We refilled each cell with new (sulphuric acid in solution with distilled water- specific gravity 1.260) lead-acid electrolyte.

The Operation was a success?
After spending all day lifting and draining L-16Ws, George and I were sore and ready for a few beers. This technique is not recommended to the frail. If I were to do it again, I would build a cradle to hold and invert these heavy batteries. Doing it by hand is tiresome, risky, and invites injury.

Neither of us was convinced that we had accomplished much beside some heavy sweating dressed in kinky moon suits. We left the L-16Ws, disconnected and unused, in the basement battery area. Every time I passed by, I would wire the pack of two rejuvenated batteries into the PV array for some quickie recharging. I had no time to run any sustained recharging or testing at that point because we had another issue of Home Power going to press.

It was not until six weeks later that Scott Hening, our summer intern, hooked up the EDTA treated L-16Ws into a working system. This system is sourced by two ancient, anemic SolaVolt PV modules. The system is simple: the PVs and the two L-16Ws. This system provides power for lighting in Bob-O's spare trailer which houses dignitaries and heads of state visiting HP Central. Here the EDTA treated batteries received about 3 to 4 amps as long as the sun was shining. Since this system is seldom used, the batteries received a constant daily overcharge for about eight weeks. Bob-O kept on top of the cells' water levels and refilled them as needed with distilled water.

Since the trailer was seldom used, and no one staying there complained of dead batteries, we just left the L-16Ws alone. Since the system had no instrumentation, it was hard to tell how much improvement the EDTA treatment did.

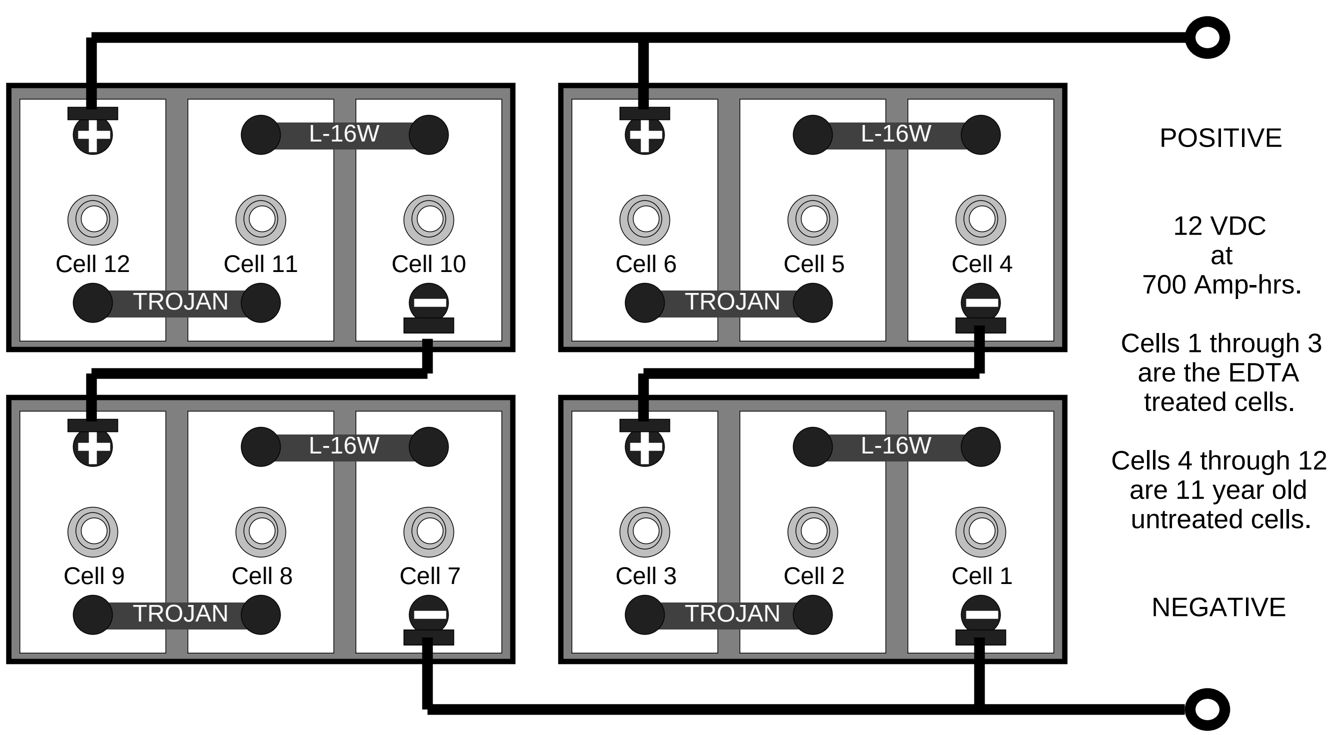
Enter a pressing need
Then all of a sudden (in the space of six days) one of the L-16Ws in the main Home Power system (4@ L-16W) at Agate Flat develop a shorted cell. As distressing as it was to lose an eleven year c L-16W battery, it was fascinating to watch and record the death one of its cells. The shorted cell dramatically unbalanced t remaining three L-16Ws in the pack. I had to do something quick disconnected the series string of two L-16Ws with the bad ce Putting a new L-16W in this eleven year old pack was out of t question. I started thinking used battery and imagined the ED treated L-16Ws. Next day, I removed one of the EDTA treat L-16Ws from Bob-O's trailer and inserted it the main Home Pow battery. I had trouble choosing the best of the two EDTA treat batteries. I went for the one that had the least voltage variati between cells.

EDTA treated L-16W performance
I had no idea what to expect. The last time I tested the sulphat L-16W it wasn't able to power up a car tail light. I inserted it into t main pack as follows in the illustration below. I gave each cell number and recorded data on the performance of the battery on cell by cell basis. The L-16W battery containing cells 1, 2, and 3 the EDTA treated battery. The remaining L-16Ws (cells 4 throu 12) are the original, untreated, eleven year old batteries.

What happened?
I'll cut to the chase here. The L-16W treated with EDTA h regained enough of its electrical capacity to function as an equ element with the battery. It works! What follows below is data fro all cells making up this battery under a variety of condition Detailed in the tables on page 25 are a variety of data, here's score card to help tell the players:

Battery Data
1. the date. 2. the battery Ampere-hour Meter reading whi indicates the pack's State of Charge (minus indicates dischar amp-hrs.). 3. the discharge or charge rate in Amperes (min indicates discharge).

Individual Cell Data
4. the voltage of each cell. 5. the absolute cell voltage deviati from the average cell voltage. 6. the average battery (that's thr



Date:	10/21/90
Amp-hrs.	-61
Amperes	-6.4

Cell #	Cell Voltage	Absolute Cell V. Deviation	Average Battery V. Deviation
1	**2.051**	**0.00058**	**0.00586**
2	**2.048**	**0.00358**	
3	**2.065**	**0.01342**	
4	2.051	0.00058	0.00325
5	2.051	0.00058	
6	2.043	0.00858	
7	2.051	0.00058	0.00125
8	2.050	0.00158	
9	2.050	0.00158	
10	2.058	0.00642	0.00714
11	2.058	0.00642	
12	2.043	0.00858	

Average Cell Voltage	2.052
Cell Voltage Standard Deviation	0.006244
Max. Cell Voltage Difference	0.022

Date:	11/2/90
Amp-hrs.	-53
Amperes	-8.4

Cell #	Cell Voltage	Absolute Cell V. Deviation	Average Battery V. Deviation
1	**2.056**	**0.00083**	**0.00594**
2	**2.054**	**0.00117**	
3	**2.071**	**0.01583**	
4	2.052	0.00317	0.00583
5	2.053	0.00217	
6	2.043	0.01217	
7	2.054	0.00117	0.00117
8	2.054	0.00117	
9	2.054	0.00117	
10	2.062	0.00683	0.00728
11	2.062	0.00683	
12	2.047	0.00817	

Average Cell Voltage	2.055
Cell Voltage Standard Deviation	0.007259
Max. Cell Voltage Difference	0.028

Date:	11/7/90
Amp-hrs.	-29
Amperes	-2.5

Cell #	Cell Voltage	Absolute Cell V. Deviation	Average Battery V. Deviation
1	**2.114**	**0.00508**	**0.00903**
2	**2.110**	**0.00908**	
3	**2.132**	**0.01292**	
4	2.120	0.00092	0.00164
5	2.121	0.00192	
6	2.117	0.00208	
7	2.117	0.00208	0.00142
8	2.118	0.00108	
9	2.118	0.00108	
10	2.125	0.00592	0.00697
11	2.126	0.00692	
12	2.111	0.00808	

Average Cell Voltage	2.119
Cell Voltage Standard Deviation	0.006317
Max. Cell Voltage Difference	0.022

Date:	11/19/90
Amp-hrs.	-214
Amperes	-2.1

Cell #	Cell Voltage	Absolute Cell V. Deviation	Average Battery V. Deviation
1	**2.083**	**0.00075**	**0.00758**
2	**2.078**	**0.00425**	
3	**2.100**	**0.01775**	
4	2.082	0.00025	0.00258
5	2.082	0.00025	
6	2.075	0.00725	
7	2.092	0.00975	0.00575
8	2.077	0.00525	
9	2.080	0.00225	
10	2.087	0.00475	0.00658
11	2.083	0.00075	
12	2.068	0.01425	

Average Cell Voltage	2.082
Cell Voltage Standard Deviation	0.008203
Max. Cell Voltage Difference	0.032

cells in a case) voltage deviation. Note EDTA treated cells' data (Cells #1, #2, & #3) are printed in bold type.

Derived Cell Data
7. average cell voltage. 8. cell voltage standard deviation (computed via standard statistical method). 9. maximum cell voltage difference.

What the data means
What we are looking for are differences in voltage between cells. Which is why the average cell voltage and deviations from average cell voltage are computed. A maximum cell voltage difference greater than 0.05 VDC, under light discharge (<C/40) means the cells are unbalanced. This measured by subtracting the voltage of the highest cell from the voltage of the lowest cell.

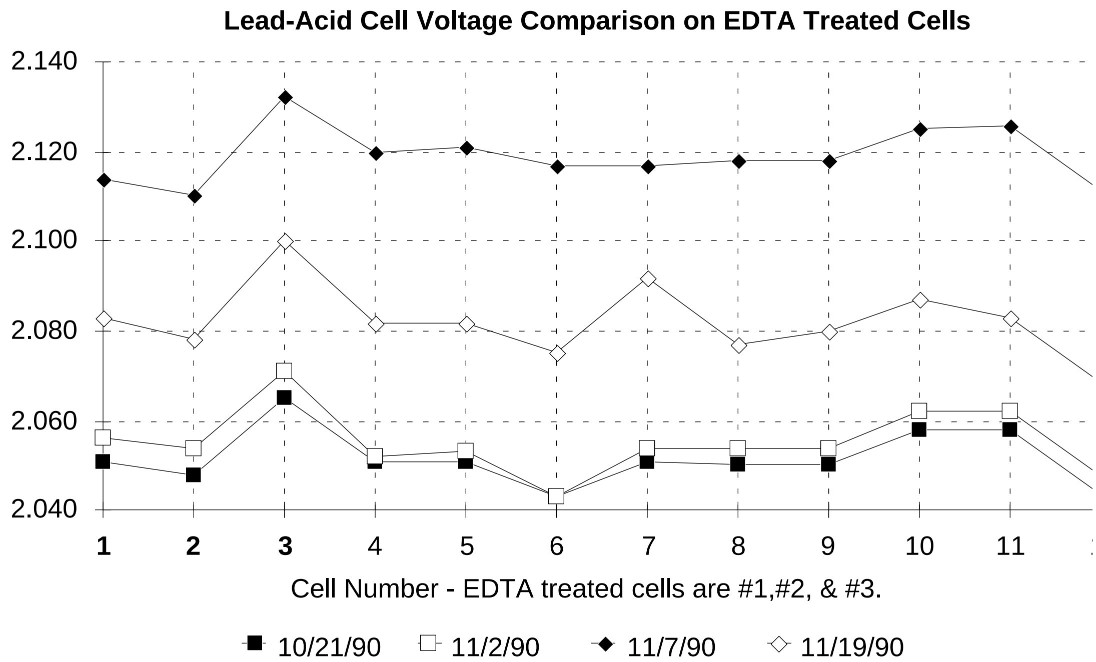
Note that on all four test discharge runs (10/21/90, 11/2/90, 11/7/90, and 11/19/90) all the cells making up the pack show about the same voltage. In fact, some of the EDTA treated cells are showing higher voltages than some of the non-treated cells.

Bottom line is that the EDTA treated cells are functioning in as a series parallel element in a battery pack. Before treatment these very same cells couldn't store enough power to operate a small light blub for five minutes.

To date I have discharged the test battery to the depth of 214 Ampere-hours (indicated by the Cruising Equip. Amp-hr. meter) from the test battery. The EDTA treated cells are continuing to function within the pack with less than 0.02 VDC difference from untreated cells.

An alternative to the dump and refill method
The British motorcar publication recommended just adding the EDTA to the cells and that's all. We went into the dump and rinse madness on our own. Now, EDTA is supposed to work by just adding the compound to the cell. No draining, no rising and no electrolyte replacement. We are trying this technique with the remaining two sulphated L-16Ws and will publish the data when we get it.

How you can help…
This experiment seems to have worked. We would appreciate verification from anyone else who tries it. After all, if you are sitting on top of a heavily sulphated lead-acid pack, what do you have to lose? EDTA is cheap and it may restore lost electrical capacity to sulphated lead-acid cells. We would appreciate any feedback from those trying our dump and flush technique or those simply adding EDTA to the cells and just leaving it there. As a very general rule of



thumb, use 1 to 2 teaspoons of EDTA per 100 Ampere-hours of lead-acid cell rated capacity. EDTA can be ordered from any chemical supplier or from any aggressive drug store.

Conclusion

EDTA seems to work. I say again SEEMS to work. This experiment was far from scientific because it lacks enough cells to get a large statistical sample. Use of EDTA may extend the useful life of sulphated lead-acid cells by chemically stripping the sulphation from the plates' surfaces.

Really, the bottom line here is that I am sitting in front of this Mac, writing this article with electricity stored in lead-acid cells that before EDTA treatment were toxic junk. Color me amazed. And as a sidelight, the long and involved set of circumstances that led us to try this experiment is as amazing as the fact that it worked. Serendipity is an ingredient in this process.

Access

Richard Perez, C/O Home Power, POB 130, Hornbrook, CA 96044 • 916-475-3179.

George Patterson, 3674 Greenhill Road, Santa Rosa, CA 95404.

Makers of the EDTA we used: Sigma Chemical Co., POB 14508, S Louis, MO 63178 • 314-771-5750. Their stock number for EDT is 48F-0104.

Suppliers of the EDTA we used: Vinquiry, 16003 Healdsburg Ave Healdsburg, CA 95488 • 707-433-8869.

Preliminary Notes From the EDTA Trenches

by Stan Krute

I was quite excited by the articles in HP #20 on using EDTA to rejuvenate lead-acid batteries. I've done some experimenting of my own the past few weeks, and want to share the early results.

About My Battery Pack

I have eight Trojan L-16 batteries in my pack. Each battery consists of three cells. Each cell has a voltage a bit over 2 volts. The cells are connected in series, so each battery has a voltage a bit over 6 volts. A pair of batteries is then connected in series, to produce a voltage a bit over 12 volts. The four battery pairs are then connected in parallel, which keeps the voltage at 12 volts while upping the amperage.

My battery pack has been in use for 6.5 years. Much of that time has been rough. During the first 5 years, I was working away from home for extended periods. I didn't have solar panels. I didn't have Hydro-Caps. Though I'd leave the batteries well-charged, they'd slowly discharge and get low on electrolyte while I was gone.

For the past 1.5 years, things have been better. I've been home, have a roof full of solar panels, and have Hydro-Caps installed. I'm able to make sure the voltage and electrolyte levels stay healthy.

Lead-acid batteries are unforgiving, however. Those first 5 years did some damage. Though I don't have fancy instrumentation, I could tell that the pack had lost its snap. It discharged too quickly, and woke up too slowly in the morning as the sun and panels started pouring energy in. The voltage variance between cells was growing.

A Modified Plan of Action

Then came the EDTA article. I was excited. I decided to act.

Richard Perez mentioned that the technique he and George Patterson used was not only radical, but difficult. They had flushed and drained their experimental batteries several times. These L-16s are big, heavy batteries. So he suggested a treatment modification: just add the EDTA to the batteries. No repeated flush and drain. I asked what would happen to the crap the EDTA would form when it combined with the trouble-making lead sulfate it was removing. Richard said that this chelate should settle to the bottom of the battery cases, and there was plenty of room for it there, since the battery plates only come within an inch or two of the case bottoms.

Rounds One and Two

I purchased 1 kilogram of EDTA, which by the way stands for ethylenediamine-tetraacetic acid. The kind I purchased is a Tetrasodium Salt: Hydrate manufactured by the Sigma Chemical Company of St. Louis, Missouri. Its chemical formula is $C_{10}H_{12}N_2O_8Na_4$. On December 20th I added 24 tablespoons of the chemical to 36 ounces of warm distilled water. I shook it up, then set it next to the wood stove. After 10 minutes the solution was clear and fully dissolved. I added 1.5 ounces of the solution to each of my batteries' cells. Thus, each cell received 1 tablespoon of the chemical in solution.

Two and a half weeks later, on January 7th, I repeated the procedure, adding another 1 tablespoon of the chemical in solution to each cell.

Some Non-Numeric Observations

I'll get to numbers in a moment, but first want to share a fe qualitative observations.

First: The battery pack feels perkier. Its voltage rises faster in t mornings. It doesn't go so low at night, as I sit draining it with r big evening load: computer, printer, large computer screen, co television, and fluorescent light (20 amps all told).

Second: the cells in two of my batteries had an especia noticeable reaction when the EDTA solution was added on Janua 7th. There was immediate bubbling, and within an hour a lar amount of white material coated the tops of the plates. It looked li a small snowstorm had occurred in those cells. Two weeks late the material is still there, although there is less of it. This wh material, which I assume is a product of the EDTA reaction, al formed in the other battery cells, but to a much lesser degree. I a keeping a careful eye on these two batteries; so far there is major voltage degradation.

Third: there are white deposits on the tops of each cell around t HydroCaps. I assume this is also the EDTA chelate. It is greate on the two cells noted in the previous paragraph.

Why Cell Voltage Data

In a healthy battery pack, the voltages of the individual cells a equal. In a sick pack, the cell voltages vary. Since I currently la the instrumentation required to take direct battery pa performance data -- the ratio of watts in to watts out -- I rely on c voltage data as a health indicator.

I've taken cell voltage data on four occasions: just before ED treatment 1, just before EDTA treatment 2, two days after ED treatment 2, and twelve days after EDTA treatment 2. We' printed the first, second, and fourth data samples.

About the Data

I have eight batteries. Each data sample shows the measur voltage of each of the three cells in each battery.

Beneath each battery's voltage I derive seven statistical measure These help analyze the raw cell voltage data.

First is the difference between a cell's voltage and the avera voltage of all cells in the pack. This is given as a positive numb for each cell in the battery. We want this to be as small as possibl

Second is the average of these cell::pack deviations for the thr cells in the battery. We add up the three cell deviations and divi by three. We want this to be as small as possible.

Third is the difference between a cell's voltage and the avera voltage of all cells in the battery. This is given as a positive numb for each cell in the battery. We want this to be as small as possibl

Fourth is the average of these cell::battery deviations for the thr cells in the battery. We add up the three cell deviations and divi by three. We want this to be as small as possible.

Fifth is the average voltage of all cells in the battery.

Sixth is the standard deviation of cell voltages. This is figured applying the standard deviation formula you'll find in any statistic

Data Sample #1

date:	12/20/90
time:	11 am

system voltage:	12.58 volts
system amperage:	9 amps
system temperature:	25° Fahrenheit

notes: Data taken before adding 1 Tablespoon EDTA per cell. Each Tablespoon of EDTA was dissolved in 2 ounces of distilled water.

back row of pack	battery 1			battery 2			battery 3			battery 4		
	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3
	2.04	2.05	2.04	2.07	2.05	2.07	2.07	2.06	2.07	2.06	2.07	2.07
Absolute Cell Deviation From Pack	0.028	0.018	0.028	0.002	0.018	0.002	0.002	0.007	0.002	0.007	0.002	0.002
Average Absolute Cell Deviation From Pack		0.024			0.008			0.004			0.004	
Absolute Cell Deviation From Battery	0.003	0.007	0.003	0.007	0.013	0.007	0.003	0.007	0.003	0.007	0.003	0.003
Average Absolute Cell Deviation From Battery		0.004			0.009			0.004			0.004	
Battery Average Cell Voltage		2.043			2.063			2.067			2.067	
Battery Cell Voltage Standard Deviation		0.005			0.009			0.005			0.005	
Battery Maximum Cell Voltage Difference		0.010			0.020			0.010			0.010	

front row of pack	battery 5			battery 6			battery 7			battery 8		
	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3
	2.07	2.08	2.07	2.08	2.06	2.08	2.07	2.09	2.08	2.07	2.08	2.07
Absolute Cell Deviation From Pack	0.002	0.013	0.002	0.013	0.007	0.013	0.002	0.023	0.013	0.002	0.013	0.002
Average Absolute Cell Deviation From Pack		0.006			0.011			0.013			0.006	
Absolute Cell Deviation From Battery	0.003	0.007	0.003	0.007	0.013	0.007	0.010	0.010	0.000	0.003	0.007	0.003
Average Absolute Cell Deviation From Battery		0.004			0.009			0.007			0.004	
Battery Average Cell Voltage		2.073			2.073			2.080			2.073	
Battery Cell Voltage Standard Deviation		0.005			0.009			0.008			0.005	
Battery Maximum Cell Voltage Difference		0.010			0.020			0.020			0.010	

Pack Average Cell Voltage	2.068
Pack Cell Voltage Standard Deviation	0.012
Pack Maximum Cell Voltage Difference	0.050
Maximum Pack Average::Battery Cell Voltage Difference	0.014
Maximum Pack Average::Battery Average Voltage Difference	0.024
Average Battery:Pack Voltage Difference	0.006

Data Sample #2

date:	1/7/91
time:	9:30 am

system voltage:	12.25 volts
system amperage:	0 amps
system temperature:	45° Fahrenheit

notes: Data taken before adding a second 1 Tablespoon of EDTA per cell. When EDTA was added to cells in batteries 6 and 7, immediate bubbling action and precipitation was observed.

back row of pack	battery 1			battery 2			battery 3			battery 4		
	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3
	2.02	2.02	2.02	2.04	2.01	2.03	2.03	2.03	2.03	2.03	2.03	2.03
Absolute Cell Deviation From Pack	0.010	0.010	0.010	0.010	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Average Absolute Cell Deviation From Pack		0.010			0.010			0.000			0.000	
Absolute Cell Deviation From Battery	0.000	0.000	0.000	0.013	0.017	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Average Absolute Cell Deviation From Battery		0.000			0.011			0.000			0.000	
Battery Average Cell Voltage		2.020			2.027			2.030			2.030	
Battery Cell Voltage Standard Deviation		0.000			0.012			0.000			0.000	
Battery Maximum Cell Voltage Difference		0.000			0.030			0.000			0.000	

front row of pack	battery 5			battery 6			battery 7			battery 8		
	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3
	2.04	2.03	2.05	2.03	2.03	2.03	2.03	2.03	2.04	2.02	2.04	2.03
Absolute Cell Deviation From Pack	0.010	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.010	0.010	0.010	0.000
Average Absolute Cell Deviation From Pack		0.010			0.000			0.003			0.007	
Absolute Cell Deviation From Battery	0.000	0.010	0.010	0.000	0.000	0.000	0.003	0.003	0.007	0.010	0.010	0.000
Average Absolute Cell Deviation From Battery		0.007			0.000			0.004			0.007	
Battery Average Cell Voltage		2.040			2.030			2.033			2.030	
Battery Cell Voltage Standard Deviation		0.008			0.000			0.005			0.008	
Battery Maximum Cell Voltage Difference		0.020			0.000			0.010			0.020	

		% change from first sample
Pack Average Cell Voltage	2.030	
Pack Cell Voltage Standard Deviation	0.008	-33%
Pack Maximum Cell Voltage Difference	0.040	-20%
Maximum Pack Average::Battery Cell Voltage Difference	0.010	-29%
Maximum Pack Average::Battery Average Voltage Difference	0.010	-59%
Average Battery:Pack Voltage Difference	0.005	-17%

Data Sample #4

date:	1/19/91	system voltage:	12.89 volts
time:	2;25 pm	system amperage:	14 amps
		system temperature:	50° Fahrenheit

notes: 12 days after last EDTA treatment. still white precipitate on battery tops & inside cells. especially in cells of batteries 6 and 7. like a light snowfall.

	battery 1			battery 2			battery 3			battery 4		
back row	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3
of pack	2.13	2.14	2.13	2.14	2.14	2.13	2.13	2.14	2.13	2.13	2.14	2.13
Absolute Cell Deviation From Pack	0.003	0.007	0.003	0.007	0.007	0.003	0.003	0.007	0.003	0.003	0.007	0.003
Average Absolute Cell Deviation From Pack		0.004			0.006			0.004			0.004	
Absolute Cell Deviation From Battery	0.003	0.007	0.003	0.003	0.003	0.007	0.003	0.007	0.003	0.003	0.007	0.003
Average Absolute Cell Deviation From Battery		0.004			0.004			0.004			0.004	
Battery Average Cell Voltage		2.133			2.137			2.133			2.133	
Battery Cell Voltage Standard Deviation		0.005			0.005			0.005			0.005	
Battery Maximum Cell Voltage Difference		0.010			0.010			0.010			0.010	

	battery 5			battery 6			battery 7			battery 8		
front row	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3	cell 1	cell 2	cell 3
of pack	2.13	2.15	2.13	2.12	2.13	2.13	2.13	2.13	2.13	2.13	2.14	2.13
Absolute Cell Deviation From Pack	0.003	0.017	0.003	0.013	0.003	0.003	0.003	0.003	0.003	0.003	0.007	0.003
Average Absolute Cell Deviation From Pack		0.008			0.006			0.003			0.004	
Absolute Cell Deviation From Battery	0.007	0.013	0.007	0.007	0.003	0.003	0.000	0.000	0.000	0.003	0.007	0.003
Average Absolute Cell Deviation From Battery		0.009			0.004			0.000			0.004	
Battery Average Cell Voltage		2.137			2.127			2.130			2.133	
Battery Cell Voltage Standard Deviation		0.009			0.005			0.000			0.005	
Battery Maximum Cell Voltage Difference		0.020			0.010			0.000			0.010	

		% change from first sample
Pack Average Cell Voltage	2.133	
Pack Cell Voltage Standard Deviation	0.006	-50%
Pack Maximum Cell Voltage Difference	0.03	-40%
Maximum Pack Average::Battery Cell Voltage Difference	0.010	-29%
Maximum Pack Average::Battery Average Voltage Difference	0.006	-74%
Average Battery:Pack Voltage Difference	0.002	-67%

text to the battery's cell voltages. We want this to be as small as possible.

Seventh is the maximum voltage difference between any two cells in the battery. We want this to be as small as possible.

After giving the data and these statistics for each cell and battery, I derive six more statistical measures for the pack as a whole.

The first of these is the average voltage of all cells in the pack. I add up all the cell voltages and divide by 24.

Second is the standard deviation of cell voltages. This is figured by applying the standard deviation formula you'll find in any statistics text to the pack's cell voltages. We want this to be as small as possible.

Third is the maximum voltage difference between any two cells in the pack. We want this to be as small as possible.

Fourth is the maximum voltage difference between the average voltage of all cells in the pack and any individual cell. We want this to be as small as possible.

Fifth is the maximum voltage difference between the average voltage of all cells in the pack and the average cell voltage of any battery. We want this to be as small as possible.

Sixth is the average voltage difference between batteries and the entire pack. We want this to be as small as possible.

On the second and fourth samples, I show the percent of change each of the last five pack statistical measures since the fi sample.

Some Interpretation

What we want to see is the cell voltages coming closer togeth We want most of the statistical measures to approach zero.

This is what has been happening. By the fourth sample, the da seems significant. The changes in the last five pack statistic measures range from 29 to 74 percent. They are going in the rig direction -- down.

I am a very happy puppy so far. I shall give further reports as t experiment continues.

Access

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