BEHAVIOR OF VRLA CELLS ON LONG TERM FLOAT: PART 2

The effects of temperature, voltage and catalysis on gas evolution and consequent water loss.

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1.0 Abstract

After more than 18 months on float, production AGM cells continued to emit gas (ie: lose water) at rates too high to permit a 20 year life. The rates did not appear to be declining with time. Gel cells on the same test, but at a lower float voltage, had lower gas emission rates. Catalysts placed in the gas space of AGM cells reduced gas evolution very significantly, mainly by keeping the negative plates from discharging.
In a second experiment the effects of voltage and temperature were studied in more detail, both with and without catalysts. The results indicate that AGM cells in their present form are ill suited to high temperature applications. The effects of catalysts in AGM cells gave very encouraging results: a reduction in float current, an increase in negative polarization, a lowering of positive polarization, a reduction in gas emissions by a factor of 2 or more, and the ability to float safely at lower voltages with consequent beneficial effect on positive grid corrosion and growth.
Our results point to the conclusion that a central problem with VRLA cells in general, and our AGM test cells in particular, is that their negative plates tend to discharge, even on steady-state float, due to the oxygen cycle itself.

2.0 Introduction

This report focuses on VRLA cells designed for 20 year telephone service. The first part is an extension of the paper given at INTELEC 95 [(1)] and records the behavior, a year later, of the same three pairs of AGM cells and one pair of Gel cells. The test was continuous float at a temperature of 80º F (27º C) at a voltage of 2.27 V for the AGM cells and 2.24 V for the Gel cells. The purpose of the test was to see if these cells could sustain the low gas emissions required for them to achieve a 20 year life. The target emissions figure, 20 ml/day/100 Ah, was based on two assumptions:

- that a typical 100 Ah cell contains 1000 ml of water
- that 10% water loss defines the effective end of life.

The second part of this paper describes a special experiment intended to explore the effects of temperature and float voltage and also the benefits of catalysts in AGM cells.

3.0 Instrumentation and controls

The cells, with reference electrodes installed, were floated at constant voltage in water baths at controlled temperatures.

Several gas collection methods were used with mixed results until we understood fully that accurate collection of hydrogen from VRLA cells is an extraordinarily difficult task - especially at low rates. The final evolution of our apparatus used thick walled PTFE chromatograph tubing swaged into stainless steel fittings which were cemented into threaded holes in the cells with epoxy resin; precision pressure relief valves were located at the other end of the tubing, inside the gas collection vessels.

Conductance readings were taken with a Midtronics CCT-20 meter. To improve repeatability of readings, special "hard wired" connections were added during the test.

A portable hydrogen sensor was used to scan cells for leaks. It proved to be invaluable even though care had to be taken to avoid false readings (eg: from solvents on cemented joints). Inward leaks, caused by negative pressure in the cells, cannot, of course, be sensed by this instrument.

A confusing aspect of VRLA cells is that their transient gassing characteristics can be unpredictable. For example, during initial setup, some cells did not gas at all for several weeks (apparent total recombination) while their physically identical peers gassed steadily. *Industry standards for gas emissions will be meaningless unless such irregularity is taken into account by the use of multiple cells and long stabilization periods.*

4.0 Results of long term test

In the following discussion, when a cell is said to have a certain calculated life to dryout, it does not preclude earlier cell failure from other causes. Indeed, in some cases it appears that negative sulfation will limit capacity well before dryout occurs.

4.1 Cells 3 and 4; 140 Ah AGM; Target gas rate 28 ml/day; typical float current 185 mA.

Cell 3 was delivered in a rather wet condition. During its first 8 weeks on float, it reached a relatively high gassing rate corresponding to a dryout life of about 10 years (Figure 1). From Week 8 to Week 18, a catalyst was installed in the cell resulting in an apparent gassing rate of zero. *Note: It is quite typical for a catalyst installed into an operating cell to cause negative pressure for an extended period.*

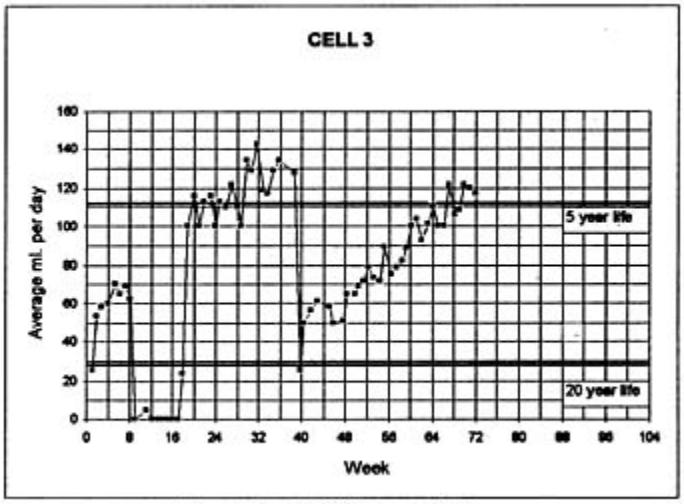

Figure 1: Cell 3 gas emissions

When the catalyst was removed on Week 18, the gassing rate continued its earlier climb to a level corresponding to a life of about 5 years. Gas analysis showed a relatively high oxygen level of 10% which may indicate excessive electrolysis.

The cell was boost charged on Week 38, which resulted in a major reduction in gas emissions to a 10 year life equivalent. However, as the weeks went by, the gassing rate increased steadily again until, by Week 70, the rates were back to the earlier 5 year life level.

The negative polarization graph **(Figure 2)** shows the effects of these changes quite clearly : the placement of the catalyst on Week 8 to Week 18 is matched by an increase in the negative polarization to a peak of 12 mV above open circuit. Following the removal of the catalyst, the negative polarization subsided back to open circuit levels. The boost on Week 38 raised it again a few mV above open circuit. That rise, however, was a temporary effect and the polarization again declined back to open circuit values within a few weeks with a simultaneous increase in gas emissions. *These data strongly suggest that negative polarizations above zero correlate with low gas emissions.*

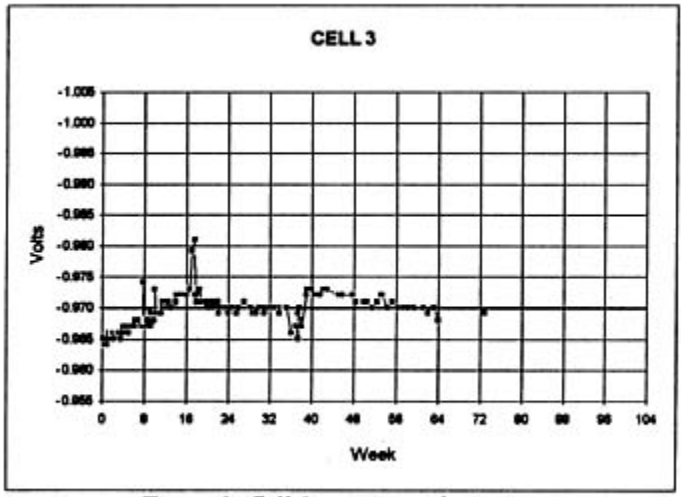

Figure 2: Cell 3 negative polarization

Cell 4 was also delivered in a similarly wet condition but was deliberately "dried out" at the start of the test by removing about 5% of the acid from the cell - corresponding to half the total water loss allowed during its life. As the gassing results for the period to Week 18 show **(Figure 3)**, the drier conditions in the cell did not reduce gas emissions to target levels but only to a 10 year life level. *This challenges the belief that gassing rates drop to insignificant levels as cells dryout.*

On Week 18, as a side experiment, a catalyst was installed on Cell 4 for long term evaluation. From that day until this writing, a period of 8 months, the cell has apparently not emitted any gas at all - except for a few weeks after Week 36 where the catalyst was removed to confirm that the gas collection apparatus was not leaking.

This odd behavior needs comment. Even with a catalyst, it is not possible, in practice, for a VRLA cell to produce zero emissions indefinitely.

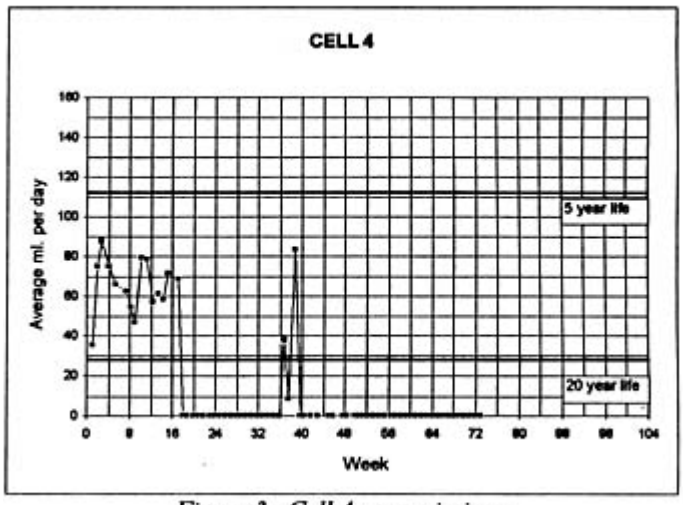

Figure 3: Cell 4 gas emissions

The explanation in this instance is as follows: The cell had a tiny leak; the catalyst caused negative pressure in the cell; air was drawn in; the catalyst recombined the oxygen from the air with available hydrogen; the cell did not vent. In time, nitrogen drawn in from the air will progressively decrease the partial vacuum and the cell will pressurize. *This mechanism was demonstrated on another cell, not in this test, which was floated for 4 months before it vented. Gas analysis showed a nitrogen content of 42%, confirming air induction.*

Normally, leaky VRLA cells will have discharged negatives, but not in this case. The negative voltage on Cell 4 **(Figure 4)** shows a healthy polarization of several mV. It appears that that a catalyst can compensate for a small leak in a cell and preserve the negative plates at a charged potential.

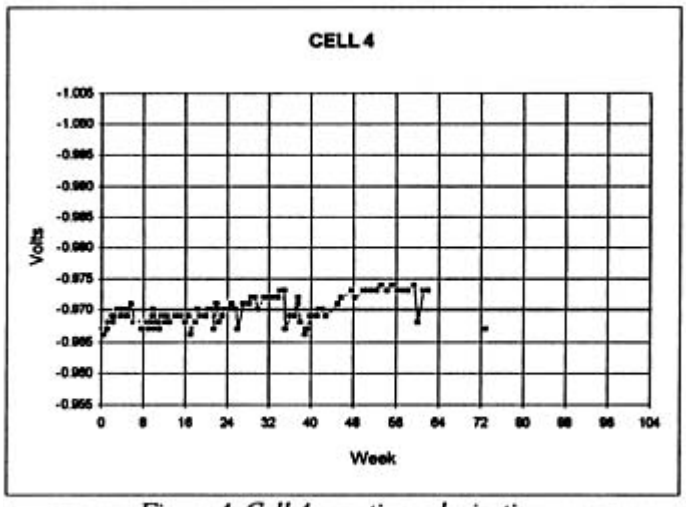

Figure 4: Cell 4 negative polarization

4.2 Cells 6 and 7; 180 Ah AGM; Target gassing rate 36 ml/day; typical float current 114 mA.

Cell 6 gassing results **(Figure 5)** shows a remarkably steady gas emission rate some 50% higher than its target -corresponding to a dryout life of about 13 years. There is no sign of a decline in this rate with time. This apparent stability may be false, however, because the float current rose a substantial 42%, from 80 mA to 114 mA, during the test. Since the gas emissions have stayed the same despite increasing current, the oxygen recombination

efficiency (ORE) of the cell has improved.

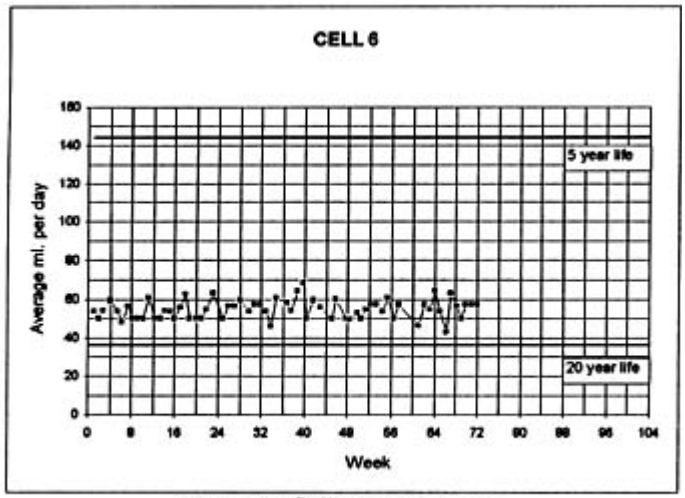

Figure 5: Cell 6 gas emissions

The negative polarization graph **(Figure 6)** shows a persistent tendency to be below open circuit, starting at 3 mV and ending at5 mV.

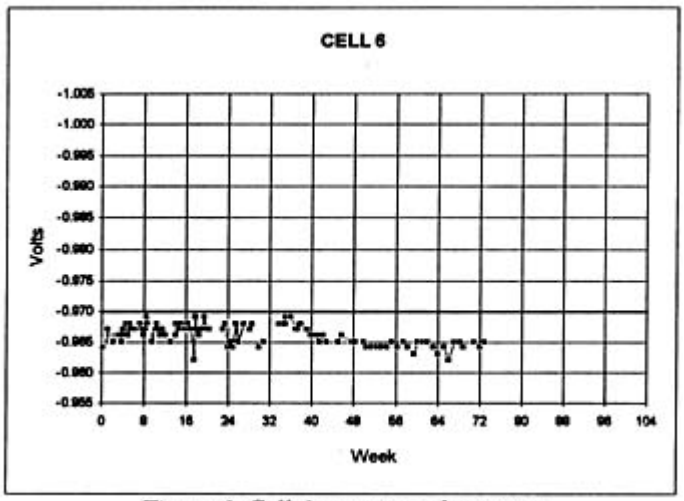

Figure 6: Cell 6 negative polarization

The conductance of this cell **(Figure 7)** shows a steadily declining value. The slope of this decline amounts to a 10% drop in conductance in about 1 year. In light of Feder's data [(2)] on similar cells, which showed that a mere 10% drop in conductance equated with a 20% loss of capacity, this looks significant if not serious. *(Note: The rise on Week 56 was due to venting the cell to replace gas collection tubing.)*

Discharge tests are scheduled toward the end of the test to confirm or refute any capacity loss.

Cell 7 shows a higher gassing rate than its twin with a rate corresponding to a dryout life of about 10 years **(Figure 8)**. In the period of Week 40, the gas rate apparently began to improve (decline) and approached the target value. The hydrogen detector found a leak at the vent seal. When the leak was stopped, the gassing rate rose again close to its original value.

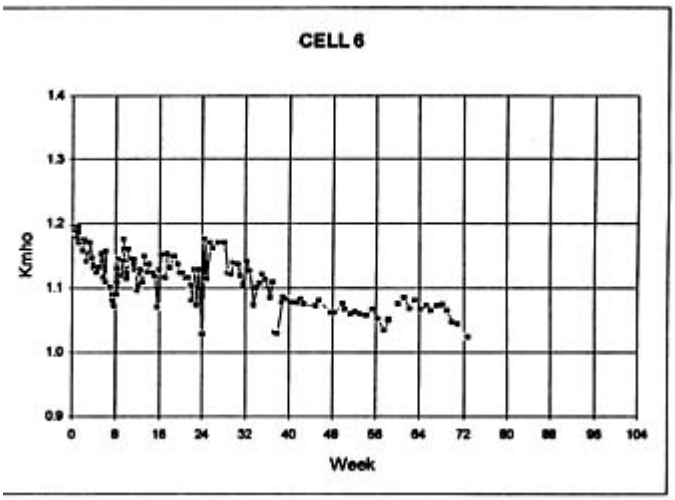

Figure 7: Cell 6 conductance

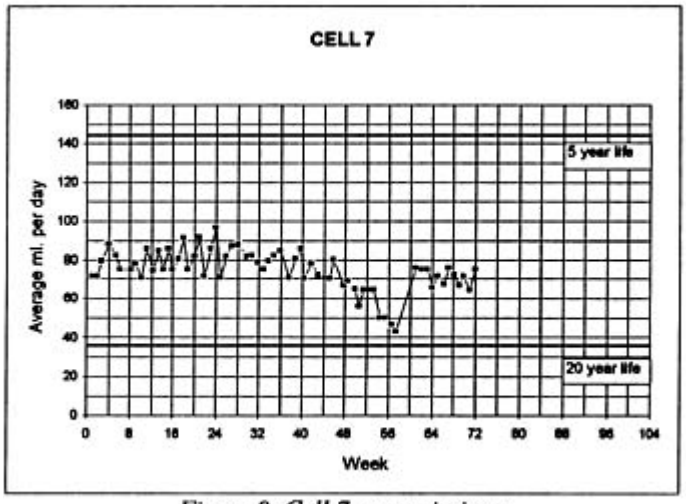

Figure 8: Cell 7 gas emissions

The negative polarization graph on Cell 7 shows the negative to be slightly below open circuit value **(Figure 9)**.

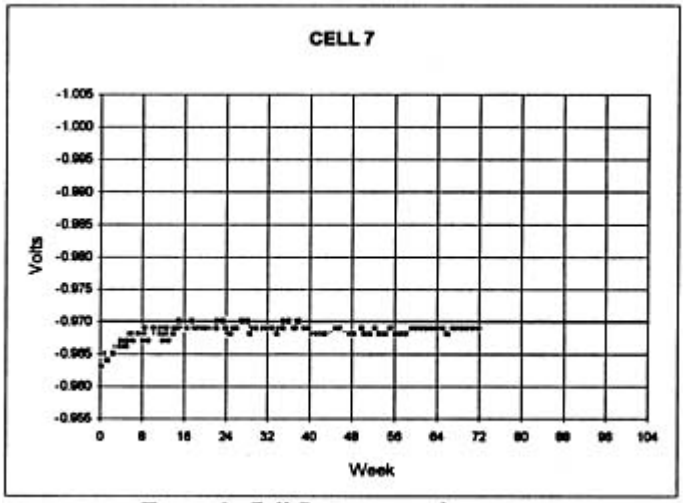

Figure 9: Cell 7 negative polarization

The conductance of Cell 7 is not only slightliy lower (worse) than that of Cell 6, it's slope of decline appears to be even steeper: a loss of 20% conductance in about one year **(Figure 10)**. Since Cell 7 had a higher emission level that Cell 6, it may be that the

conductance meter is already sensing deterioration. If so, it would not likely be from dryout since only a calculated 2% of the water would have been consumed by this time versus the 10% allowed. Perhaps the meter is measuring negative plate discharge.

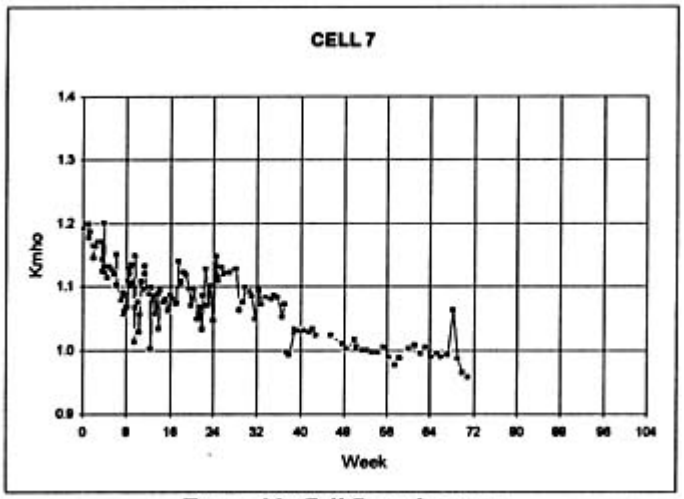

Figure 10: Cell 7 conductance

4.3 Cells 9 and 10; 125 Ah AGM; Target gassing rate 25 ml/day. Typical float current 180 mA.

Cells 9 and 10 were delivered in a rather dry condition and had a high float current of 200 mA initially. Surprisingly, the current has **declined** by 10% during the test.

Cell 9 settled to a gassing rate that was about twice its target until it was clamped to eliminate bulging; then the gassing rate rose dramatically to over 5 times the target **(Figure 11)**. A brief experiment with a catalyst placed in the gas collection tubing, brought the apparent gassing rate to near zero. After the catalyst. was removed, the cell settled to an emission rate corresponding to about 7 years life.

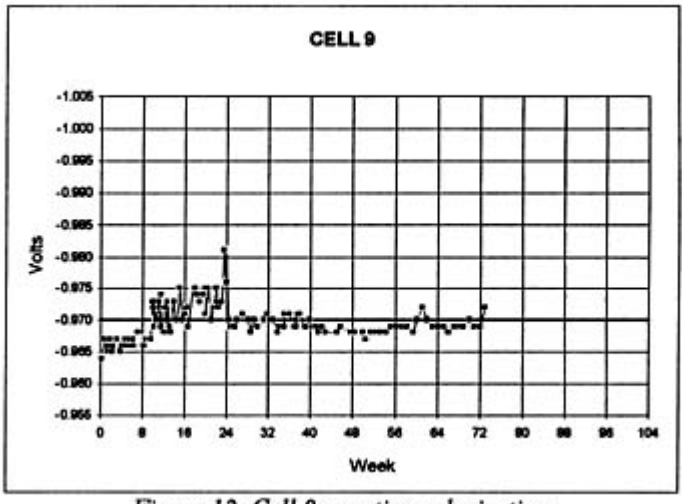

Figure 12: Cell 9 negative polarization

The negative voltage graph on Cell 9 shows that, except for the period of the catalyst experiment, the negative polarization remained at or a little below open circuit value, as expected **(Figure 12)**. Again, the catalyst caused a rise in the negative polarization - to 11 mV above open circuit.

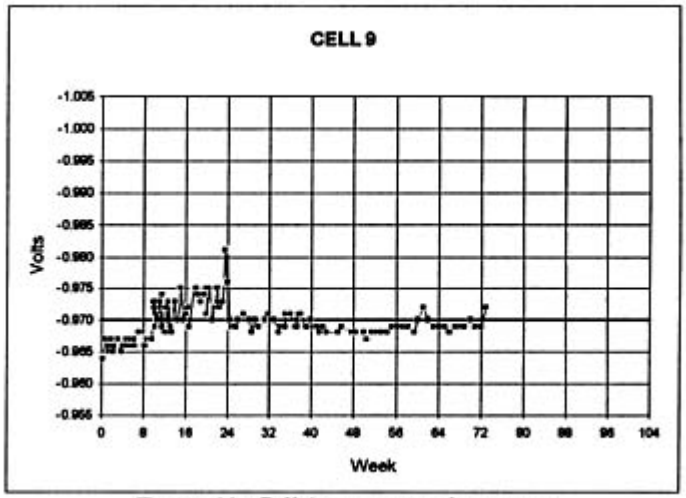

Figure 12: Cell 9 negative polarization

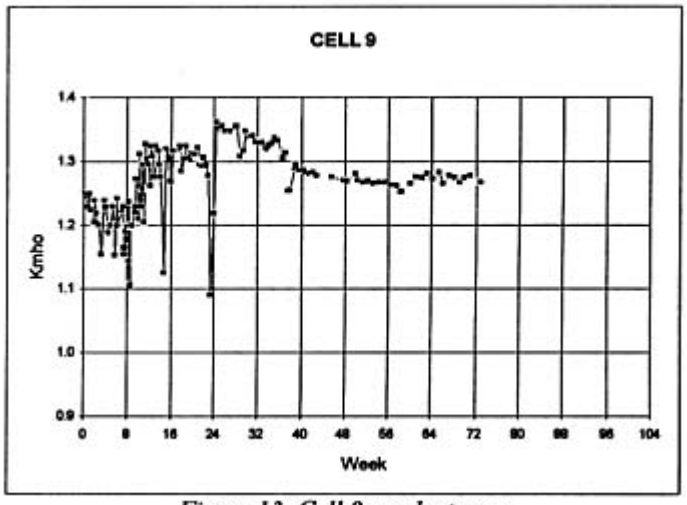

Figure 13: Cell 9 conductance

Conductance on Cell 9, after declining slowly from Week 24 to Week 48, has been fairly steady **(Figure 13)**.

Cell 10. As the gas emission plot shows, Cell 10 looks like a cell equipped with a catalyst: the gas rate was essentially zero over a period of over 40 weeks **(Figure 14)**. But this cell never had a catalyst installed. On Week 60 the gas tubing was replaced and there was an immediate increase in gas emissions to a level

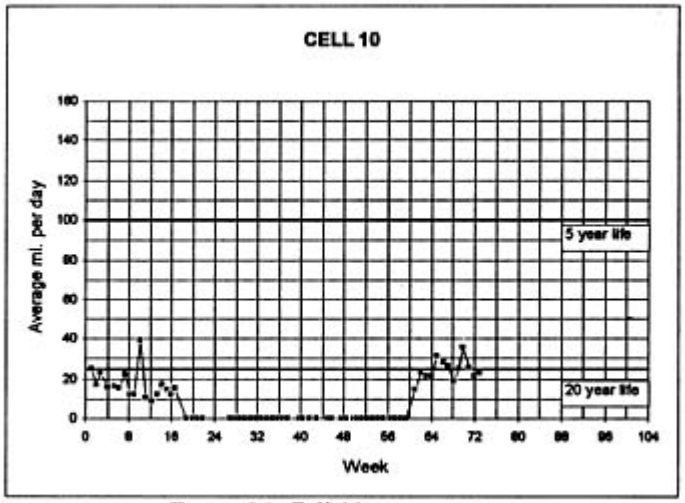

Figure 14: Cell 10 gas emissions

corresponding with the target rate; this confirms that a small leak existed but it does not explain all the observations recorded for this very peculiar cell.

Cell 10 had a very unusual negative voltage curve **(Figure 15)**. In the beginning of the test the negative polarization was more than 20 mV above open circuit. After the compression of the cell in Week 8, much of this excess disappeared but the negative polarization remained above open circuit by 2 to 5 mV during the entire test period - something none of the other cells on test have done. From Week 60 onward, when the new tubing was installed, the negative polarization actually increased to 8 mV above open circuit.

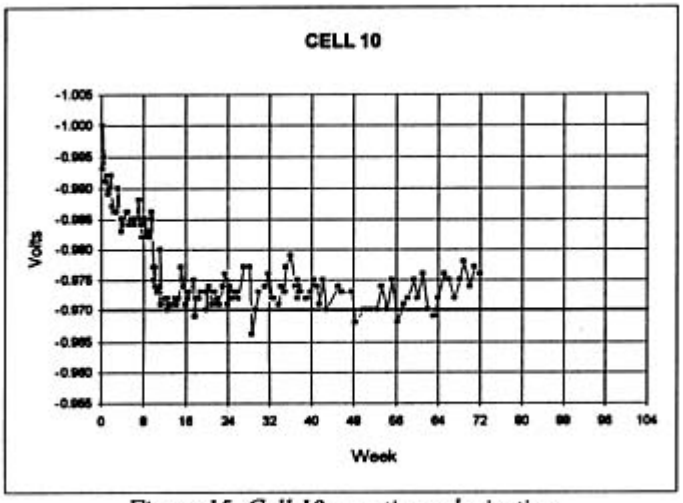

Figure 15: Cell 10 negative polarization

The conductance of Cell 10 has been fairly steady for the last 50 weeks of the test with little decline **(Figure 16)**. The conductance values have declined less than for its twin, Cell 9. The initial erratic readings were partly due to poor connections. Later, when special "hard wiring' was installed, the readings were very consistent.

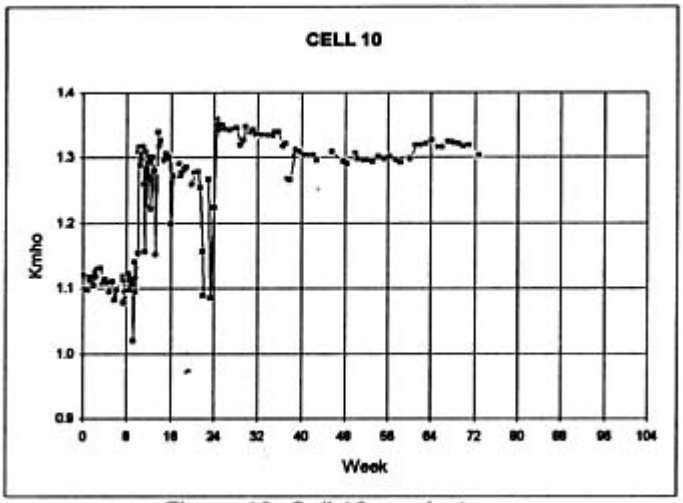

Figure 16: Cell 10 conductance

4.4 Cells 11 and 12; 180 Ah Gel cells; Target gassing rate 36 ml/day; Typical float current : 108 mA.

Cells 11 and 12 were the sole Gel cells in the extended test. Unlike the AGM cells, they were floated at 2.24 vpc versus 2.27 vpc which should give them an advantage in lower gas emissions. The float current has increased 35%, from 80 mA to 108 mA, during the test.

Cell 11's gas emission profile started at zero and climbed upwards slowly to a value close to its target rate corresponding to a 20 year life **(Figure 17)**. Then it began to decline. We found the decline to be caused by a small leak that had developed in the vent plug of the cell - again found by the hydrogen sensor. When the leak was stopped, the emissions rose again to a level corresponding to a 13 year life.

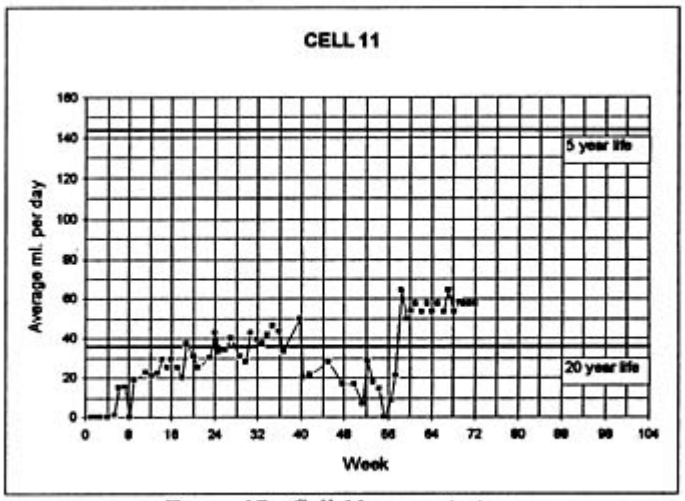

Figure 17: Cell 11 gas emissions

The negative voltage of Cell 11 stayed close to open circuit values until the cell began to leak; then the polarization **dropped several mV** below open circuit **(Figure 18)**. When the leak was repaired, the negative voltage did not recover.

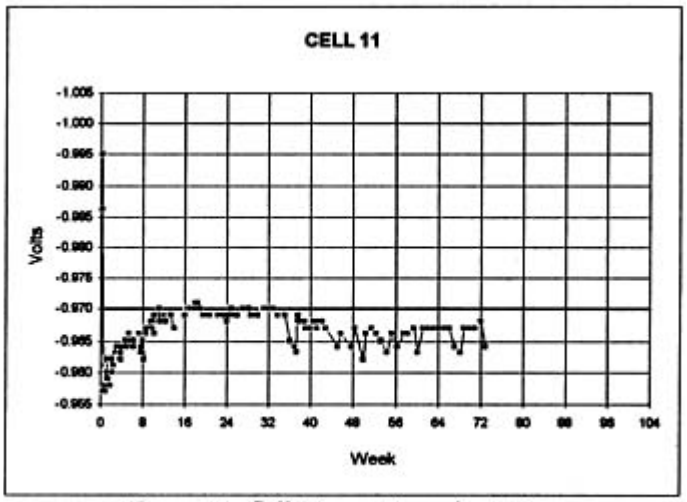

Figure 18: Cell 11 negative polarization

The conductance of Cell 11 also shows a steady decline of about 10% per year **(Figure 19)** which is similar to some of the AGM cells. The same comment applies here: the reduction looks very significant based on all known relationships between conductance and capacity.

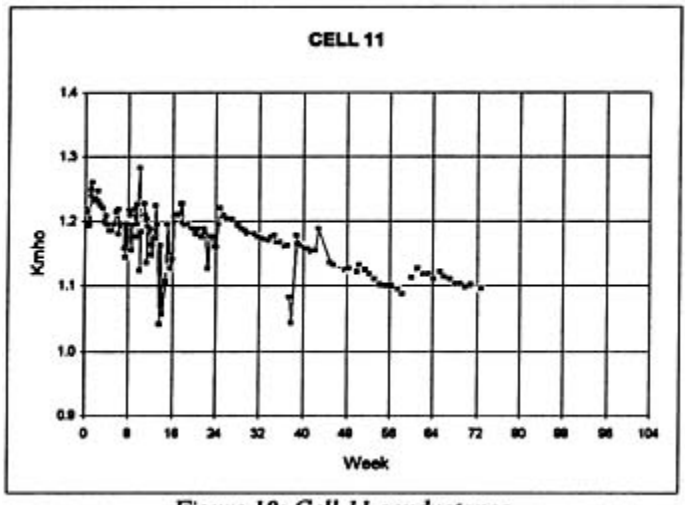

Figure 19: Cell 11 conductance

Cell 12 likewise shows a gassing rate that is exceptionally low over the test period **(Figure 20)**. However, some of this good performance is due to a yet another leaky vent which was discovered by the hydrogen sensor. After correcting the problem, the gas emission rate rose to a value close to its target.

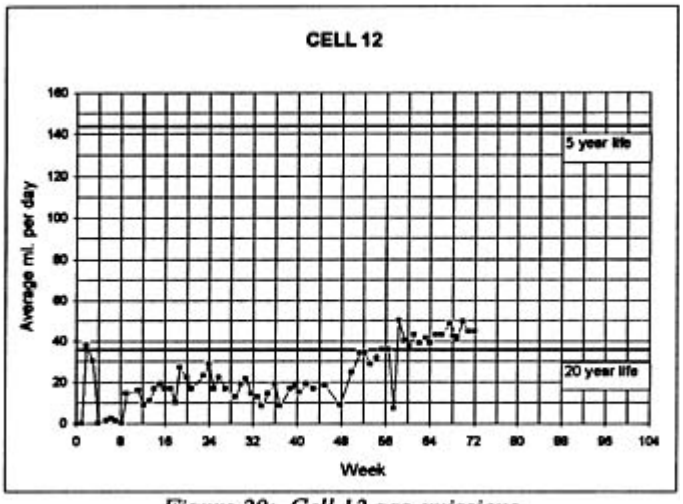

Figure 20: Cell 12 gas emissions

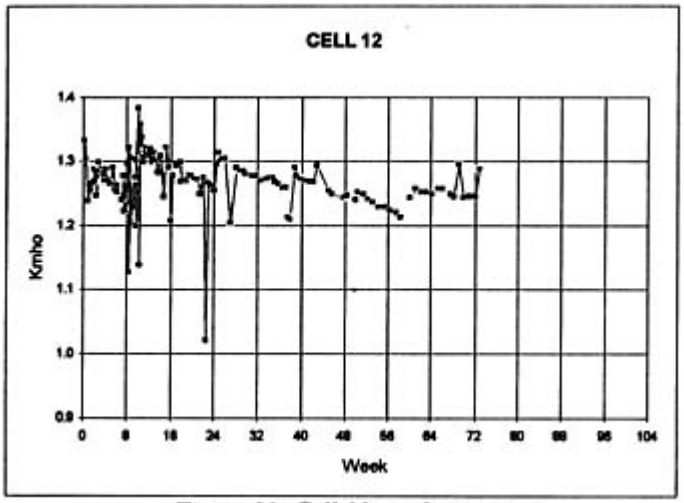

Figure 21: Cell 12 conductance

Unfortunately, no negative polarization figures are available for Cell 12 during most of the test due to a faulty reference electrode. However, when the electrode was replaced in Week 72, the negatives were 5 mV below open circuit.

The conductance of Cell 12 declined steadily from Week 24 to Week 56 and then recovered somewhat when the cell was vented. It has declined only very slightly since. **(Figure 21)**. The earlier rate of decline was quite severe - faster than 10% per year.

5.0 Discussion of results

The most significant result of this long term test is that VRLA cells on steady state float at relatively low temperatures continue to produce more gas than they should to meet their projected 20 year lives and that these gassing rates are variable from cell to cell. This is sobering considering that (1) the data is being taken at relatively low temperatures and that higher temperatures will make the situation **much worse**; (2) any measurements are optimistic rather than pessimistic due to additional loss of hydrogen though cell walls etc.; and (3) that these lifetimes are based on dryout whereas the actual mechanism of failure may be negative sulfation which could produce even shorter lives.

Analysis of the gas emitted from these cells usually shows over 85% hydrogen with less than 5% oxygen. There are two possible sources of this excess hydrogen: either the positive grids are corroding faster than they should (and with great variability) or the negative plates are discharging.

A variety of data, published and unpublished, indicates strongly that **negative discharge is the main culprit**. For example: gas emissions reduce when a cell is boosted or when the negative plate is otherwise polarized; failed cells recover capacity when water is added (and the negatives polarize); research on cycling VRLA batteries show failure due to negative limitation[3].

A probable model of behavior of most VRLA cells on float emerges from these studies:

- the oxygen cycle depolarizes the negative plate slightly below open circuit values
- this depolarization will often cause a gradual discharge of the negative plate with an attendant release of hydrogen
- the more exposed the negative plate is (ie: the dryer the cell) the faster the rate of discharge will be
- this rate of discharge will decrease with time as negative active material is removed from the reaction through discharge
- additional discharge of the negative can take place each time the cell goes on discharge because any free oxygen in the cell atmosphere is rapidly absorbed by the negative plate.

What happens next is critical to the survivability of the VRLA cell. There are two possibilities:

1.The negative plate continues to discharge until it limits the capacity of the cell.

2. The negative plate continues to discharge until the discharge reaction is balanced by the float current and the negative can be sustained by the float current. This second option has been verbally proposed by Berndt.

If the first possibility were true, then the VRLA cell could not survive on float without boost charges and we would expect to see a history of early negative plate sulfation failures in service (as indeed we have). *Note: Only boost charges which* ***significantly polarize the negative plates*** *will help counter the self discharge condition.*

If the second possibility were true, it would imply that the negative plates had been over-designed and might as well have been made thinner in the first place. **It would also imply that the negative plate of a well balanced VRLA cell should always be polarized above zero, however slightly**. Berndt has shown relatively large negative polarizations up to 30 mV on German made Gel cells, but we have never seen such a phenomenon on our cells, whether AGM or Gels. Further, we are not sure that such a condition could be sustained as the cells aged and dried out.

The other major, though incidental, result of the test was that catalysts seem to have a remarkably beneficial effect on the gassing rates.

6.0 Section 2: Experiments with catalysts in series strings at various temperatures and voltages.

Our experience with catalysts in individual VRLA cells had been promising and we wanted to test their performance on strings of cells. Accordingly, a special test was set up with two strings of six 125 Ah cells, each string floating on its own separate power supply at 2.25 vpc. It was to be a direct, head-to head contest between cells with and without catalysts to see which would be the better approach.

The strings came from different production batches; one drew 150 mA while the other drew 115 mA. We tested the more severe case by installing the catalysts on the string with the higher current. The palladium based catalyst devices were of our own explosion proof design. Removable, they occupied the gas space in the cells. During this period of the test, the room temperature was 70º F (20º C). A mercury-mercurous sulfate reference electrode was installed into one cell in each string.

6.1 Initial results on series strings at 70º F (20º C).

In less than 3 days on float at 2.25 vpc the current on the catalyst string had dropped from 150 mA to 35 mIA - less than a quarter of the original float current and less than a third of the current of the control string.

The catalyst cells gassed very uniformly compared with the rather erratic control cells. Their average gas production rate was roughly half of that of the controls - and a third of that of the worst control cell.

The reference electrode showed that the negatives on the catalyst cell had polarized strongly to about 30 mV above open-circuit, with the positive voltage dropping by the same amount. The cell voltages on the catalyst string were quite uniform, suggesting that voltage spread will not be a problem.

The polarization data is summarized in the table in **Figure 22**. Both strings had an overvoltage of 100 mV.

	CONTROL CELL	CATALYST CELL
NEGATIVE VOLTS	0 mV	30 mV
POSITIVE VOLTS	100 mV	70 mV

Figure 22: Effect of catalyst on plate polarizations.

In short, under the same float conditions, there were three simultaneous improvements in the catalyst cells: the negatives were more polarized, the positives were less polarized, and the cells were gassing at a uniformly lower rate. The obvious question now was: could the overvoltage be reduced further?

6.2 Reducing float voltage on series strings

To anyone familiar with flooded cells, particularly the large Stationary lead-calcium cells used in the United States, the current practice of floating VRLA cells at positive polarizations of 100 to 150 mV seems illogical. This is true both from **grid growth** and from **grid corrosion** considerations.

Grid growth is minimized in Stationary service at positive polarizations between 40 and 70 mV. Anything more is too high. Grid corrosion, we believe, is also minimized at the lower polarizations. Unfortunately, the longterm relationship of grid corrosion rate to positive polarization is not well documented - Lander's short-term experiments are now suspect and subsequent data is widely scattered. Our own results suggest that lower positive polarizations almost always produce less gas emissions so it makes sense to reduce the float voltages as far as possible consistent with a stable field performance.

On standard VRLA cells, this conflicts with the reasons for having high float voltages on VRLA cells, namely:

- to prevent negatives from discharging
- to minimize the recharge time
- to allow for rise in acid density over time

But while higher float voltages will certainly counter the second and third items, it will not necessarily counter the first. It should be evident that is not the **float voltage of the cell** that recharges a negative plate, but the **voltage of the negative plate** itself. In fact, the authors have already published data showing that higher float voltages can actually **suppress** negative potentials on VRLA cells rather than raise them[(1)].

6.3 Results on series strings at 90º F (32º C).

We therefore extended the test to lower float voltages. At the same time the temperature of the test was raised to a more severe but, in operation, more practical level of 90º F (32º C). The two strings were installed in a controlled water bath and stabilized at 2.25 volts per cell.

The float voltage of the catalyst string was then reduced to 2.23 vpc (80 mV overvoltage). The result was a drop in current to 25 mA - nearly five times less than the controls which were still at 2.25 vpc . The polarizations settled at 55 mV (positive) and 25 mV (negative). All these factors should be improvements over standard cells and very acceptable for long cell life.

After the cells had stabilized for another two weeks, the float voltage was reduced yet further to 2.21 vpc (60 mV overvoltage) - well below the level normally deemed practical for AGM cells. The results, again, were, excellent: the current fell further to 18 mA (over 6 times less than the controls at 2.25 vpc) while the polarizations settled at 45 mV (positive) and 15 mV (negative).

The resulting gas emission figures are shown in **Figure 23**, comparing the standard control cells at 2.25 vpc - *its lowest recommended voltage* - and the catalyst cells at 2.21 vpc. The difference in results were quite stunning:

- The catalyst cells at 2.21 vpc had an average gassing rate equivalent to a reasonable 13 year life. Furthermore, all the catalyst cells had similar gas emission rates.
- The control cells at 2.25 vpc, by contrast, averaged less than 3.6 years life to dryout, with much more variance. The worst cell had a calculated life of just 3 years!

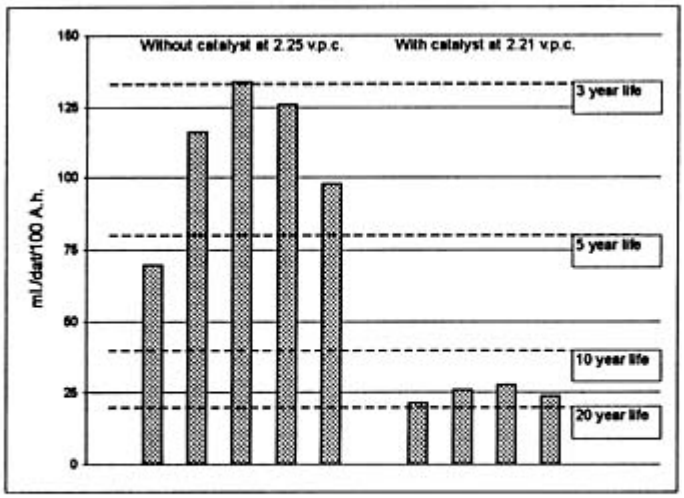

Figure 23: Comparison of gassing rates of standard cells at their lowest recommended float voltage of 2.25 volts per cell vs. catalyst cells at 2.21 vpc. The temperature is 90 F (32 C).

In other words, the data appeared to show that our expensive, heavy duty VRLA telephone cells, floated at 90ºF at recommended voltages, might have **less service life than an average automotive starter battery!** Also, a catalyst used at low float voltages could extend battery life by a factor of 3 or 4.

6.4 Gas emissions at three float voltages at 90ºF (32ºC)

To characterize the two strings fully, they were floated at three voltages: 2.21, 2.25 and 2.30 volts per cell at a temperature of 90º F(32º C).

The gas emissions data is summarized in **Figure 24**. The normalized gassing rates are plotted against float voltage for both strings. Horizontal lines denote lives between 3 years and 20 years. The gassing rates vary slightly from those in Figure 23 but not enough to alter the overall trends. Some of the key results were as follows:

- The gassing rates of both strings increased with the float voltage; the rates at 2.30 vpc were typically two or three times those at 2.21 vpc.
- The catalyst cells continued to have a gassing rate less than half that of the controls at the same float voltages.
- At the manufacturers' lowest recommended float voltage of 2.25 vpc, the standard cells would be expected to last only about 3 years to dryout; the catalyst cells would be expected to survive for 6.5 years.
- At the manufacturers' highest recommended float voltage of 2.27 vpc, the standard cells would dry out in only 2.5 years while the catalyst cells would last a little over 5 years.

The best performance was 13.3 years for the catalyst string at the lowest float voltage (2.21 vpc).

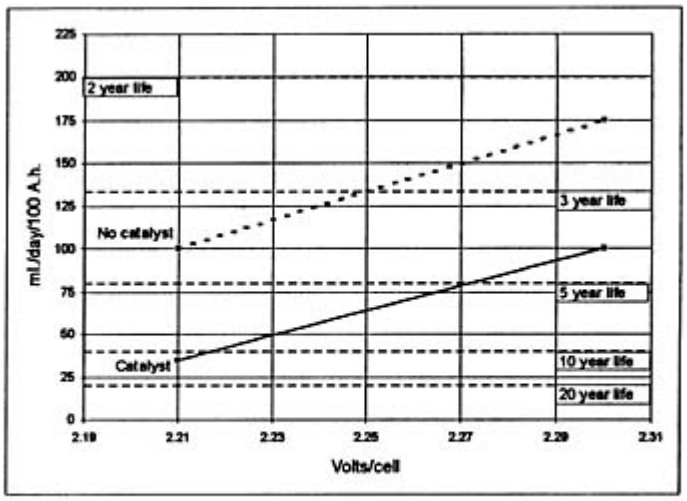

Figure 24: Variation in gassing rates with float voltage. The temperature is 90 F (32 C).

7.0 Discussion: How catalysts work in Stationary VRLA cells

The purpose of catalysts in lead acid cells in deep cycle service, such as electric vehicles, is self evident: the cells are charged at relatively high voltages which can lead to electrolysis. The catalysts merely recombine the bulk oxygen and hydrogen gases.

Catalysts in VRLA cells in Stationary service have a much more subtle effect. Analyses of emitted gas from conventional VRLA cells often show over 90% hydrogen, with less than 5% of oxygen at normal temperatures. Therefore, it is impossible for a catalyst to reduce emissions by 50% or more by simple recombination of the exhaust gas: there simply isn't enough oxygen available.

We propose that the catalyst works by a different mechanism -it reduces hydrogen by minimizing the production of hydrogen in the first place - that is, by keeping the negatives from discharging. By removing some of the oxygen in the cell atmosphere, it allows the negative plates to polarize at normal float voltages.

A secondary virtue is that it recombines any stoichiometric oxyhydrogen that happens to be in its vicinity. Therefore it can recover some of the oxygen absorbed into the negative plate during open-circuit or discharge conditions. In conventional VRLA cells, this oxygen is wasted because, during recharge, an equivalent amount must leave the cell causing permanent water loss[4].

8.0 Conclusions and recommendations

All the VRLA cells in our test (with one partial exception) have demonstrated near-zero negative polarizations at normal float voltages. As a result, they appear to suffer from negative plate discharge (sulfation), even on float, due to the oxygen cycle itself The discharging negative plates generate hydrogen, and thereby consume water, at rates that preclude a 20 year life at all but low temperatures and low float voltages.

Based on gas emissions translated to water loss, the life of the tested AGM cells, even at moderate temperatures of 80º F, is unlikely to meet a 20 year target. Gel cells at moderate temperatures may do better. Lower float voltages reduce gas emissions and can help extend life.

The life of AGM cells to dryout (10% water loss) shortens drastically with increasing temperature. For example, one of our tested designs would only last 2.3 years at 90º F and 2.30 vpc. To put the point directly: **these cells are simply not suited to high temperature operation**.

Even these short life figures may be optimistic because as the negatives continue to discharge, the cell may fail by direct negative limitation (sulfation) well before dryout occurs.

Despite these rather pessimistic conclusions, actions can be taken to improve the situation, both from the application and the design standpoints, including the following:

1. Operational procedures could be modified so that all VRLA cells which have depolarized negatives could be boost charged regularly at voltages that substantially polarize their negatives.

2. The cells should be provided with some form of cooling in hot environments. Unfortunately, users may find this an impractical solution but it would unquestionably yield the **single biggest improvement in cell life possible**.

3. From the design standpoint, AGM cells in particular would benefit from actions taken to reduce the transport rate of oxygen to the negative plate or the reaction rate at the negative plate. The target might be to have negatives that polarize slightly on float. Design changes might include re-balancing active material ratios, adding "oxygen shields" like microporous separators around the plates and using organic or other additives to the negative plate to reduce the reaction rate of the negative. The last action has already been reported on as a means of reducing float current, albeit at the expense of cell performance[5].

4. The catalyst is a design solution that also deserves further evaluation because it appears to have a special affinity for the VRLA cell. It will typically provide the following benefits without impairing the capacity or performance of the cell:

- Reduce float current and tendency for thermal runaway
- Permit reduced float voltages, reducing current further
- Polarize negatives on float and prevent negative discharge
- Reduce positive plate polarization and extend grid life
- Recover oxygen from negative plate sulfation
- Compensate for small leaks in the cell
- Reduce gas emission by a factor of 2 or 3, increasing life to 10% water loss from (say) 10 years to 20 years.

Our results indicate that a reliable catalyst in combination with low float voltages and adequate cell cooling would give the optimum maintenance free life for VRLA cells.

9.0 References

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