FLOAT BEHAVIOR OF VRLA CELLS: THEORY VS REALITY

Can VRLA cells last 20 years without dryout?

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1.0 Abstract:

Production VRLA cells, made by different manufacturers and designed for a 20 year life, were tested on float. Their actual water consumption rates were measured and compared with target rates based on the amount of water available in the cells. Although the tests are continuing, the data so far suggests that while some cells will achieve their 20 year goal, others may be marginal. Tafel curves and conductivity profiles are presented which show that VRLA cells of the AGM type have characteristics that are extremely variable, even in cells of the same design and batch.

2.0 Introduction

The focus of this paper is on VRLA cells designed for 20 years telephone standby float service. Early designs intended for this application failed from a number of relatively straightforward causes: grid corrosion, grid growth, internal post/strap corrosion and water loss due to leaks on cover seals and post seals. Most of these failure modes have been addressed and corrected. However, there are two much more subtle failure modes ready to take center stage: cell dryout and negative sulfation.

This paper reports on the first of these two phenomena. In particular, we were interested to see what the real gassing rates were on a variety of production cells, both initially and over time.

3.0 Establishing a water consumption target

There is a generally agreed rule of thumb that if a cell loses about 10% of its water, it will suffer a 20% decline in capacity, signifying the end of its useful life (1,2,3,). This very approximate rule is qualified by the type of construction of the cell, the wetness of the cell as delivered (very variable) and the rate at which it is to be discharged (higher rates being more sensitive than lower rates.)

There is evidence that, for some cell designs, water loss of 13% is more consistent with a 20% capacity loss (4). On the other hand, even a 10% water loss has a very substantial effect on the characteristics of a cell, as we will show. For example: it typically raises the cell open circuit voltage by 20 mV - equivalent to reducing the float voltage from 2.25 to 2.23 volts per cell - and adds yet more variability to an already complex system. So it could be argued that a 10% water loss is too severe; nevertheless, it is a useful starting point in establishing a target figure.

One way to measure long term water consumption is to weigh the cell periodically, but this method essentially weighs hydrogen loss, not water loss, and requires extraordinary accuracy. Also, it does not allow observation of short term effects. A more useful method is to measure the volume of hydrogen emitted from the cell each day, and compute the equivalent water consumption from that figure. A simple target can then be stated as the amount of gas released in mi/day. This is easily measured in a lab environment and shows clearly the effects of short term changes in the cell.
Accordingly, we calculated the target gassing rate for one of our industrial-type AGM cells and compared the result with various related published material to confirm that the target was a practical one.

3.1 Target hydrogen emission rate for 20 year life

We disassembled an AGM cell, measured how much water it contained, and converted 10% of that figure to a "maximum permissible gassing rate" in ml per day.
The calculation is as follows: The 125 Ah cell contained 2010 grams of 1.30 density acid which amounts to 1205 grams of water (9.64 gIAh). Allowable water loss is 10% of this figure, or 121

grams, which converts to 22.4 ml of hydrogen per day at room temperature or 17.9 ml per day per 100 Ah. This, then, gives the order of magnitude of the target for average emissions
over the life of the cell, recognizing that gassing rates may be higher initially and lower in the later years.

3.2 Compare published cell design

Holden (5) discusses a C&D cell design with a specification of 1.31 litres of 1.28 density acid per 100 Ah (10.52 gIAh of water). This converts, by the same calculation, to a maximum gas emission rate of 19.5 ml per day per 100 Ah. We know of other U.S. manufacturers of 20 year product who have a similar specification. Some European manufacturers use only about 1 liter of acid per 100 Ah in their designs (5), but their specification is for a shorter 10 or 15 year life.

3.3 Compare negative self discharge current

Berndt (6) states that the minimum hydrogen evolution rate on a stationary cell is the self discharge rate of the negative at its open circuit potential. He states a typical range of I to 3 mA per 100 Ah resulting in a gas emission rate of 11 to 33 ml per day per 100 Ah. Positive grid corrosion currents are typically in the same range. This practical number indicates that VRLA cells will only achieve a life of 20 years if they are on the low side of this range.

3.4 Compare positive corrosion current

Mimer (7) quotes a positive grid corrosion current of 0.4 mNlOO Ah. which converts to a gas emission rate of 4.4 ml per day per 100 Ah. However, this result was taken from flooded cells with low positive polarizations (70 to 80 mV), low specific gravity (1.210), and low stack temperatures (flooded cells). At the typical 120 mV positive polarizations found on VRLA cells, plus
1.300 specific gravity, plus higher stack temperatures, the corrosion current might be expected to increase by a factor of two or three; that is, 9 to 13 mi/day per 100 Ah. Mimer also claims a very low penetration rate of 0.12 mils/year (3x104 cm/year) but practical experience suggests that much higher rates may be the norm. (See Section 3.5). Note: This raises the question about the effect of different posftive grid alloys on the cells' minimum gassing rate. A VRLA is a water ilmited device and the choice of alloy, along with grid designs with minimum surface area, may be significant factors in delaying dryout.

3.5 Compare published grid corrosion data

Grid corrosion can also be used to estimate gas emissions. One major manufacturer has suggested that corrosion rates of positive grids in actual service are typically .001 inches per year, so we can estimate the total lead corroded as follows: Total surface area of a 100 Ah positive grid = 179 square inches, multiplied by
0.001 inches per year = 0.179 cubic inches of lead consumed per year = 2.928 cc/year or 33.08 grams of Pb / year/100 Ah. This equates to a hydrogen emission rate of 21.4 ml per day per 100 Ah. Note: This figure is the same order of magnitude as our provisional target and does not support the thesis that there is an ample supply of water in a typical cell for 20 years of grid corrosion - unless the corrosion rate on the positive grid is reduced.

3.6 Compare published test data

Tuphorn (8) states that, over a 10 year period, Sonnenschein gel cells consumed 70 grams of water per 100 Ah. This converts to a gas emission rate of 25.6 ml per day per 100 Ah. Tuphorn also says that 60% of the water loss happened in the first 3 years which means that the cells, per 100 Ah, emitted an average of 52 ml per day for the first 3 years and only 14.8 ml per day in the last 7 years. These cells contained an estimated I 3g/Ah of water so they should have more than an adequate supply of electrolyte for a 20 year life.

3.7 Selected target rate

Our conclusion is that a target average hydrogen emission rate of 20 ml per day per 100 Ah is a reasonable one for AGM batteries on float to aim for to achieve a 20 year life. Note: In practice, this rate amounts to about one small bubble of gas every minute.

4.0 Characterization of test cells

initially, two partially aged cells from one manufacturer were examined and put through a wide variety of experiments to define appropriate measurement techniques and determine approximate values of test parameters. Because of their age, these cells were not included in the long term gassing experiment.

For the long term experiment, three pairs of AGM cells and one pair of gel cells were tested, all of them new. All were of 9 plate design, with capacities ranging from 125 to 180 Ah. Made by different manufacturers, they reflected different design philosophies. Positive grids ranged from lead-calcium to lead-tin to pure lead. Negative grids were all lead-calcium. Some cells had been processed by jar formation,

some by tank formation.
Initially, Tafel and other characteristics of some of the new cells were determined. The cell pairs were numbered, in no particular order, as Cells 3 and 4; Cells 6 and 7; Cells 9 and 10; Cells 11 and 12. These four pairs were placed on the long term test.

4.1 Variations in cells

We were well aware that VRLA cells have a tendency to dry out as they age and that this drying out affects some of the cell's characteristics. What we had not fully understood is that this vanabie wetness" is not a minor phenomenon, but a critical complexity that lies at the root of many of the problems of VRLA cells.
The "wetter" AGM cells have characteristics that are completely different from the "dryer" ones, as we will show. Therefore, we must be able to define the degree of wetness of a cell. in practice, we can identify four distinguishable phases:

Phase 1: FLOODED. Totally wet - like a flooded cell. Both positive and negative plates will polarize like a wet cell, even on float. VRLA cells should not be shipped this way but it is probable that they sometimes are.

Phase 2: WET. Separators are almost, but not completely, saturated. The negative plates will be depolarized at float currents but will polarize steeply at higher currents. VRLA cells are often shipped like this, either accidentally or deliberately.

Phase 3: MOIST. Separators are only partially saturated for maximum oxygen transport. The negative plates will be depolarized from float currents up to about 0.7 amps per 100 Ah. (ie: they will have a "flat" negative Tafel). Some VRLA cells are shipped like this; all will become like this in time.

Phase 4: DRY. This is a mature cell which has lost 5 to 10% of its water relative to the moist condition. it will always have a fiat negative Tafel. All cells should eventually end up like this.

All of our AGM cells were received in either a wet or moist condition (Phase 2 or 3).

5.0 Experimental procedure, gassing test

For the long-term gassing test on float, the cells were placed vertically in temperature controlled water baths deep enough to immerse the cells (to facilitate checks for leaks). After initial boost charging in accordance with manufacturers instructions, the cells were put on continuous float. Each pair of cells was floated in series with its own power supply so that the cells received the same current. The AGM cells were floated at 2.27 volts per cell (4.54 volts total) and the gel cells were floated at 2.24 volts per cell (4.48 volts), each at the high end of their specified ranges.

The power supplies were Tektronix PS 282 with constant voltage capability. The bath temperatures were controlled at a nominal 800 F (270 C) initially by thermostatic tank heaters and later by Fuji PID controllers. Mercury/mercurous-sulfate reference electrodes (1.300 density.) were inserted through the covers of the cells. When necessary, some cells were equipped with digital manometers and/or pressure
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gauges. A portable Midtronics CCT-20 meter was used to measure conductance changes.

Gas was accumulated continuously in glass bell jars by means of small-bore, thick-wall, PVC tubing from modified vent plugs. We recognized the risk that a tiny amount of gas might diffuse through the tubing but we were not looking for effects this small so we ignored it. Note: Leakage or diffusion losses would mean that we were not capturing all the emftted gases so our results would look optimistic.

The vent plugs originally supplied with the cells did not always meet specification (one did not open until it reached 25 psi or 1.7 bar); they were replaced by special pressure relief valves located inside the glass bell jars. These valves had a spring-loaded, 0-ring design which we pre-tested for opening pressures of 1.5 to 2.0 psi. in practice, they behaved well, releasing small bubbles of gas continually rather than large amounts intermittently, thereby minimizing pressure variations in the cells.

The results were taken at I to 3 day intervals and tabulated on Microsoft Excel in an extension of the format shown in Figure 10.

6.0 Results

The results of the gassing test are shown in the accompanying graphs. While they show only the first 6 months of the continuing test, the rates do not appear to be declining significantly. in fact, the results on some cells are rather pessimistic, and fairly large reductions in the gassing rates will have to occur for those cells to approach their targets. Further data will be reported in the INTELEC presentation.

6.1 Cells 3 and 4. 140 Ah. AGM. Target gas rate: 28mllday. Typical float current-I 50 mA.

Cells 3 and 4 were delivered in a wet condition (Phase 2). Rather than wait for months for them both to dry out, we artificially dried out Cell 4 with a mechanical technique: the cell was inverted and excess acid was removed by a vacuum. Our aim was to find out the difference in characteristics between wet and dry cells of the same construction.

The procedure was as follows: First, we physically removed 170 ml of acid which amounted to about 10% of the total acid in the cell. The conductance reading immediately dropped from 1.095 to 0.490 kiiomhos -that is, by about 50%. We then replaced acid until the conductance reached 95 % of its original value. The net effect of this procedure was that we removed 90 ml of the acid from the cell - approximately 5% of the total. Cell 3 was left in its original wet condition.

Subsequent Tafel measurements were carried out on both Cell 3 and 4 (Figure 1). The curves confirmed that we had succeeded in ~instantly" drying Cell 4. The graph showed the negative on Cell 4 to be substantially depolarized or "flat" up to 2.3 volts (ie: a Phase 3 level of wetness).

Cell 3, by contrast, had a negative that polarized rapidly, (ie: a Phase 2 level of wetness).
The Tafel curves show clearly the major change that takes place in the negative polarization as the cell dries out. They also show that the positive polarization is affected substantially.
Cell 3 was then floated with its twin at an average of 2.27 volts per cell for the first 8 weeks. The gas emissions (Figure 2) are at a rate of 60 mi/day or 2.1 times the target of 28 ml per day. The predicted life of this cell at this gassing rate is 9.4 years. However, the rate may reduce with time so the actual lifetime may increase. The other qualification is that the extra water provided in a wet condition cell (Phase 2) could, at least theoretically, add several more years to its life.

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gassing rate; the results will be published in a separate paper. After the experiment, the cell was returned to a straightforward float regime; the cell showed a much increased gassing rate.

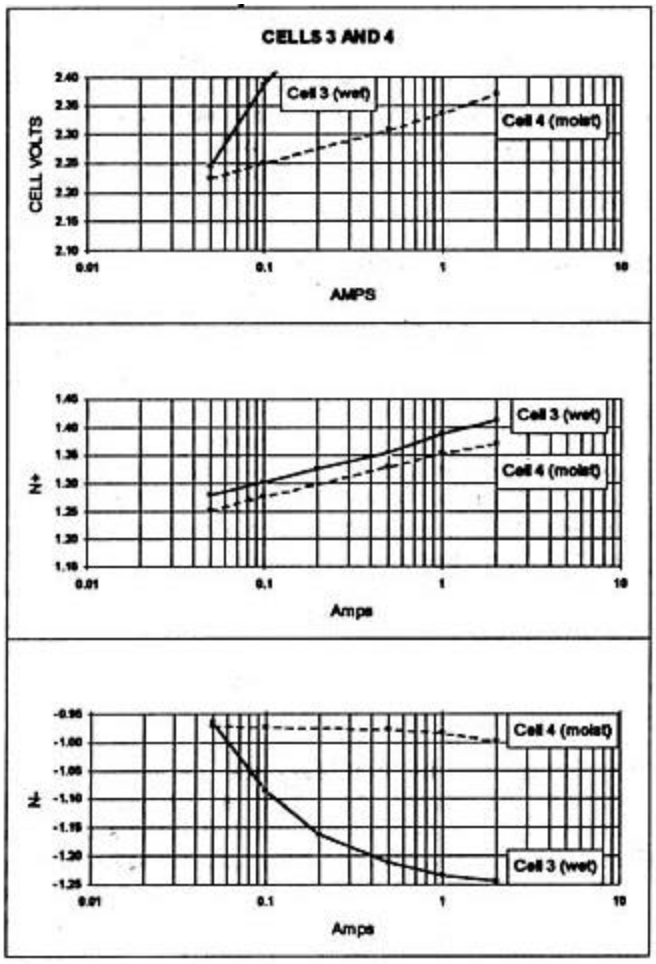

Figure 1: Tafel curves for Cells 3 and 4

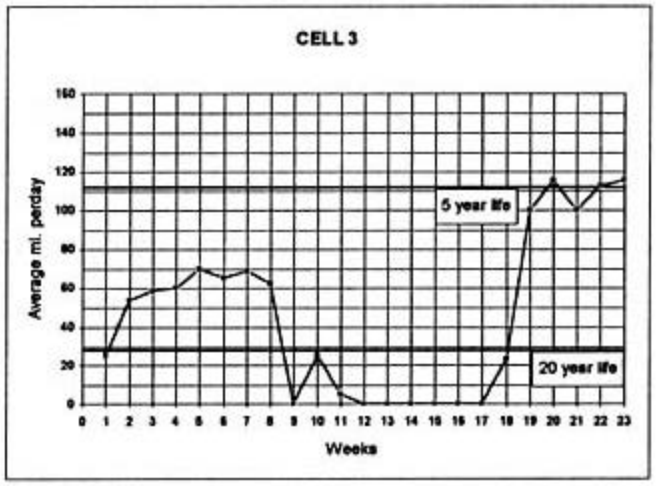

Figure 2: Gassing rate of cell 3. The experimental modification was made from Weeks 9 to 17

Cell 4, was floated in series with Cell 3 and showed a gassing rate of 60 mI/day (Figure 3) - much the same value as its wetter twin. Considering that we had removed about 5% of the water in the cell - equal to half the amount it is allowed to lose in its lifetime - and that the negative polarization showed recombination to be taking place, we expected it to be significantly less. Predicted life if this rate were to continue: 9.4 years -with the provision that the water we extracted be replaced.

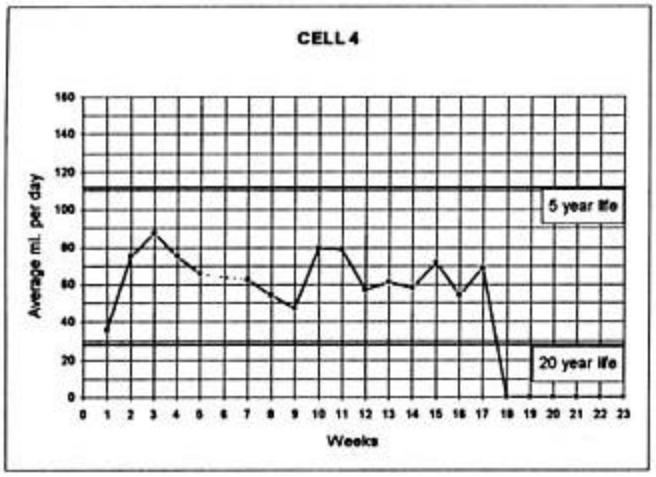

Figure 3: Gassing rate of Cell 4. The experimental modification was made on Week 17

In week 17, the same experiment was also carried out on Cell 4 to try and modify the gassing rate. The experiment continues and will be reported on at a later date.

In Week 22, Cells 3 and 4 were placed in parallel instead of in series to allow each cell to be floated at the same voltage. Otherwise, the average voltage of 2.27 volts actually became 2.28 volts on Cell 3 and 2.26 volts on Cell 4. This raises the question: will a string of cells like these, delivered in a wet (Phase 2) condition, make a safe transition to the moist (Phase 3) condition?

6.2 Cell 6 and 7. 180 Ah. AGM. Target gassing rate 36 ml/day. Typical float current- 80 mA.

Cells 6 and 7 were shipped without a steel tray for support. They had bulged and their conductance values were 0.596 kilomhos - much too low for 180 Ah cells. The cells were squeezed into steel containers to eliminate the bulging, and the conductances rose immediately to a healthy 0.921 kilomhos. This resuft shows how critical proper support is for a VRLA ceff

Cell 6 was delivered in a relatively moist condition (Phase 3) as demonstrated by the absence of negative polarization during its initial boost charge. Apart from this boost, which followed manufacturers

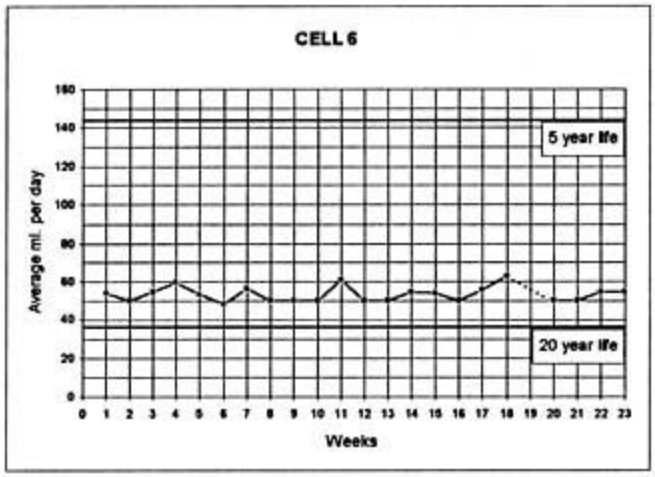

Figure 4: Gassing rate of Cell 6

instructions, nothing whatever was done to Cells 6

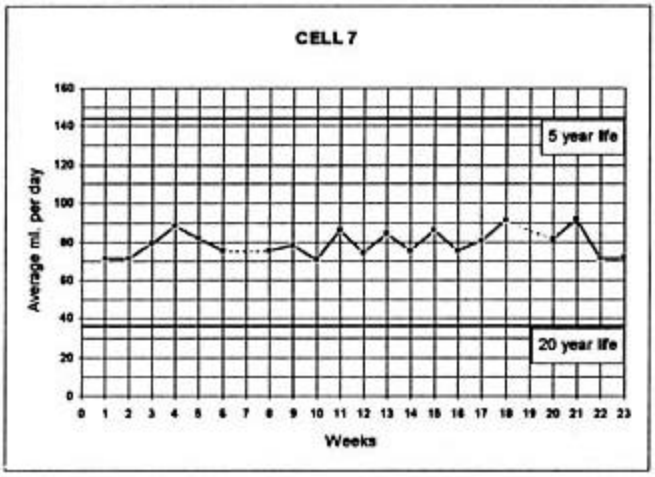

Figure 5: Gassing rate of Cell 7

and 7 other than put them on float - not even a full Tafel measurement. We wanted to ensure that we did nothing that might disturb the product and affect its stability.
The float current settled to a steady 44 mNlOO Ah. The gassing rate of 50 mi/day was 1.4 times the target rate with no decreasing trend yet apparent. (Figure 4). Predicted life if this rate were to continue: 14.3 years.

Cell 7 was almost identical in all respects to Cell 6 - voltages, plate potentials, current, etc. Nevertheless, the gassing rate was a steady 80 ml per day, 2.2 times the target rate and 60% more than its identical twin. (Figure 5). Predicted life if this rate were to con-

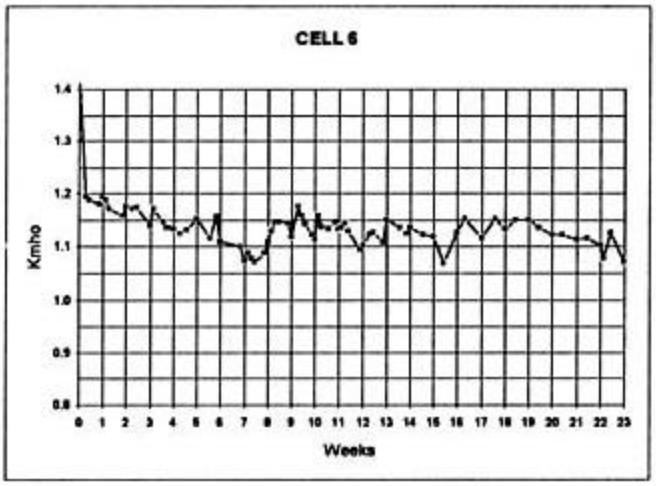

Figure 6: Conductance of Cell 6 showing gradual declining trend

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9.1 years.

6.3 Cell 9 and 10. 125 Ah. AGM. Target gassing rate 25 mi/day. Typical float current -200 mA.

Cell 9 was delivered in a moist condition (Phase 3)

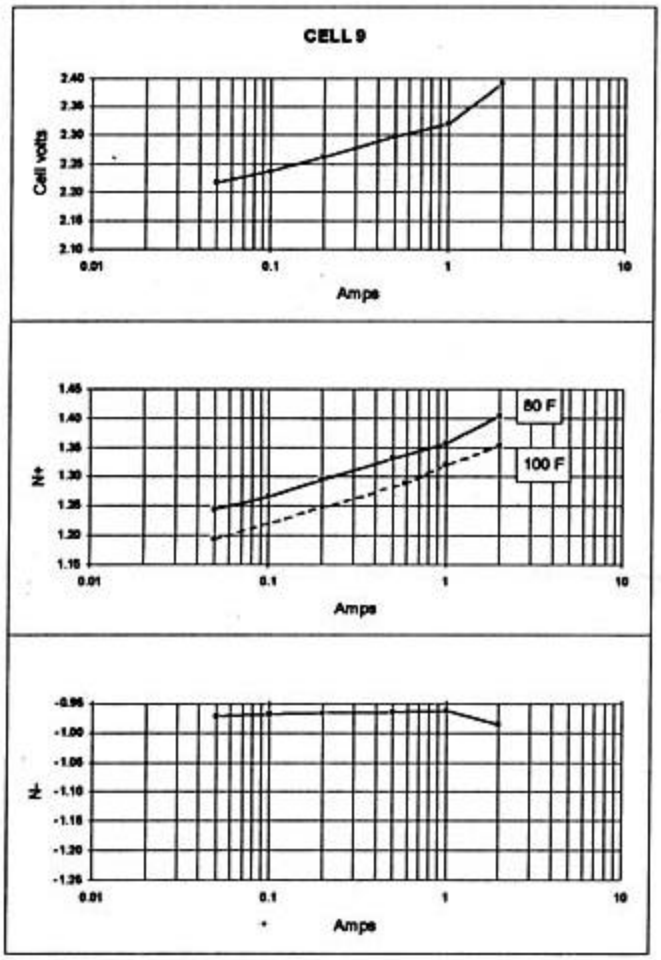

Figure 7: Tafel curves on Cell 9

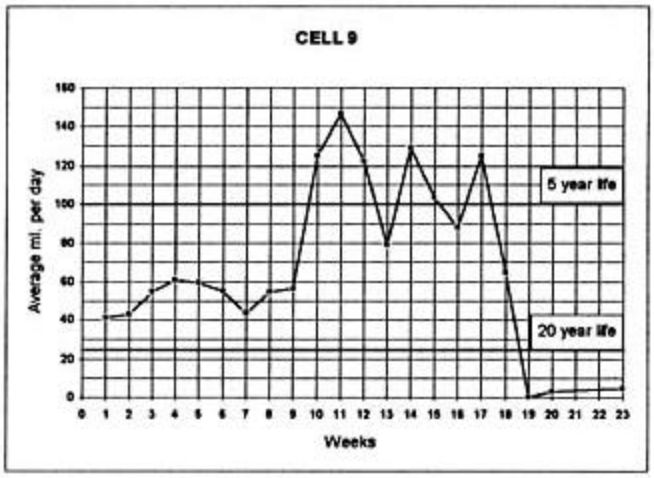

Figure 8: Gassing rate on Cell 9. Experimental modification was made on Week 17.

as shown by the Tafel curves in Figure 7. A high temperature Tafel (1000 F, 380 C) was also run to confirm that the cell current increases by a factor of about two with such a temperature rise.

The walls of the cell had a tendency to bulge and, in the 9th week, the cell was clamped between metal plates to eliminate the bulging. Note: The Ta fel curves were taken before the cell was clamped.

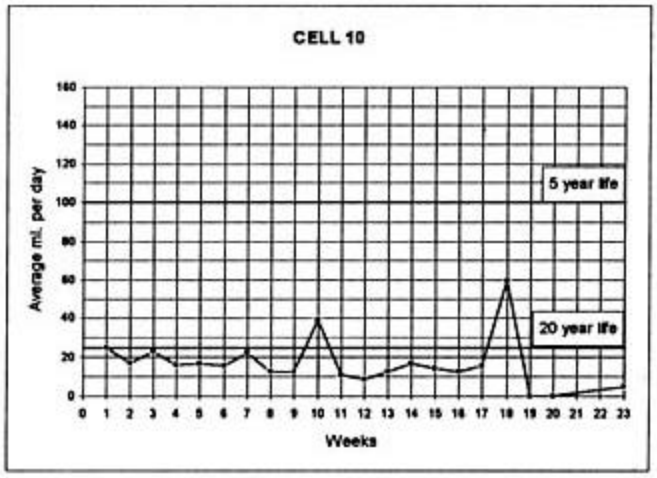

Figure 9: Gassing rate on Cell 10. The low gassing rate was a natural cell characteristic.

Gas production before clamping was about 50 ml per day, 2.0 times the target rate. (Figure 8). Predicted life at this gassing rate: 10.0 years. After clamping, gas rates rose enormously to over 100 ml/day. Presumably this effect was due to squeezing the separators, increasing their saturation level, and decreasing oxygen transport. (Note: But Cell 10 received the same treatment but responded qufte differently; so there are other variables involved here.)

Date	Volts	N+	N-	Amps	psi (nom.)	Temp.	Kmho
Feb-7	2.281	1.289	-0.992	0.220	2.0	82.0	1.116
Feb-14	2.277	1.290	-0.987	0.200	2.0	80.6	1.116
Feb-22	2.282	1.291	-0.990	0.220	2.0	81.9	1.130
Feb-28	2.278	1.292	-0.984	0.200	2.0	81.0	1.112
Mar-8	2.276	1.292	-0.984	0.210	2.0	81.0	1.109
Mar-14	2.277	1.293	-0.984	0.200	2.0	80.1	1.096
Mar-21	2.283	1.298	-0.985	0.230	2.0	80.1	1.118
Mar-28	2.280	1.296	-0.985	0.230	2.0	82.4	1.122
Apr-3	2.280	1.297	-0.982	0.210	2.0	81.0	1.106
Apr-6	2.285	1.298	-0.986	0.270	2.0	83.8	1.140
Apr-7	2.285	1.300	-0.985	0.250	2.0	81.5	1.094
Apr-8	2.271	1.293	-0.977	0.210	2.0	81.9	1.115
Apr-10	2.271	1.296	-0.975	0.220	2.0	81.3	1.154
Apr-17	2.275	1.300	-0.974	0.250	2.0	81.3	1.316
Apr-24	2.275	1.302	-0.972	0.220	2.0	78.6	1.301

Figure 10: Format of data collection; Cell 10. Note the high negative polarizations (.972 is zero).

Conductance, which had been decreasing gradually, rose instantly about 9% due to the clamping. T~e effect was to change the cell from moist to wet condition (Phase 3 to Phase 2).

The float current on this cell was a steady 200 mA (160 mA per Ah) which we considered unusually high - even for a VRLA cell. Surprisingly, the float current was not significantly affected by the clamping.

Cell 10, the twin of Cell 9, was a very unusual prod-

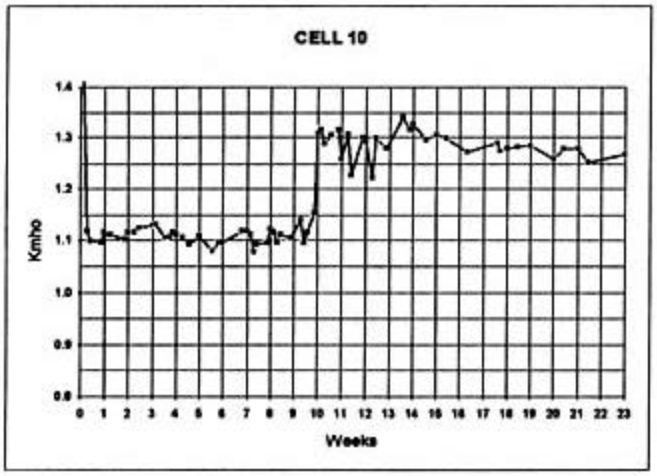

Figure 11: Conductance profile of Cell 10 showing effect of compression in mid term

uct by any standards. To begin with, while it was delivered in much the same moist condition as Cell 9, it had a very different gassing performance. Almost from the first day of the test, the cell met or beat its target gassing rate of 25 ml per day - a value of 15 ml per day being typical. (Figure 9). Predicted life if this rate were to continue: over 30 years.

The other peculiar characteristic of this cell was its negative polarization. Unlike every other cell in the test, including its twin, the negative polarization on this cell was well above open circuit values. Figure 10 shows the actual readings. Negative polarizations were typically 20 mV above open circuit for a period of several weeks. All the while, the cell was emitting gas at a very low rate. When, like its twin, this ce was clamped to eliminate bulging, the overvoltage on the negative largely disappeared without any significant change in the gassing rate.

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The conductance reading on Cell 10 was consistently lower than Cell 9 (1.10 vs 1.20 kilomhos) up to the time of clamping. Then both rose to 1.30 kmho instantly, reflecting lower impedance between the plates. FIgure 11 shows the rather dramatic change in the conductance of Cell 10.

Cell 10 was placed on brief boost charge, after the clamping, to see if it's negative would polarize. It did; showing that the clamping had shifted it from a moist to a wet condition (Phase 3 to Phase 2).

6.4 Cells 11 and 12. 180 Ah. Gel cells. Target gassing rate 36 ml per day. Typical float current -80 mA.

Note: Gel cells contain more water than do AGM cells so target gassing rates can theoretically be higher yielding an additional safety factor. However we did not know how much of the water residing in the remote reaches of the cell would be available for reaction. So, for the sake of simpilcity, we held the gel cells to the same low target as the AGM product.

Cell 11 had a conductance in the same class as the AGM cells of the same capacity (Cells 6 and 7); we expected it to be lower due to the effect of the micro-porous separator in the gel cell.

The gassing rate behavior was very different - it stayed at zero (no gassing) for a period of 5 weeks which may have been due to inadequate formation or some other transient effect. Then the rate rose slowly to about 25 ml per day. (Figure 12). This is below the target of 36 ml per day and the predicted life of the cell if this rate
should continue is 28.8 years. No experiments were done on this cell or its twin in case such experiments might disturb the results.

Cell 12 behaved in a similar way to its twin. The negative on cell 12 polarized immediately on float, accompanied by a burst of gassing - perhaps due to

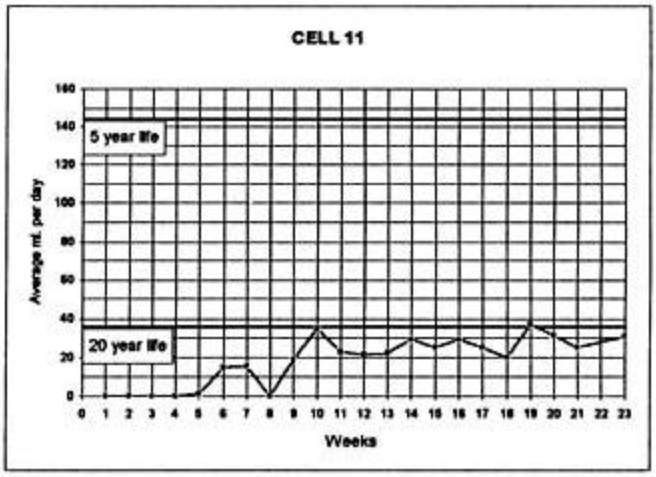

Figure 12: Gassing rate on Cell 11

absence of cracks in the gel. By the fourth week, the negative depolarized completely and the cell gassed not at all for a further 4 weeks. Subsequently, the gassing rate rose gradually to a level of about 20 ml per day - well below target. (Figure 13). Predicted cell life if these rates continue: over 30 years. The current increased during the period for both cells from 28 to 44 mNlOO Ah - which is similar to that drawn by the AGM cells of the same capacity (Cells 6 and 7).

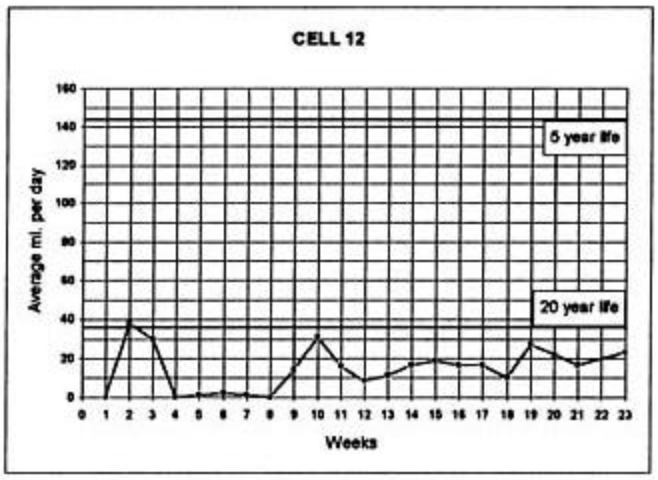

Figure 13: Gassing rate on Cell 12

The conductance of Cell 12 was somewhat higher than that of Cell 11: 1.250 to 1.300 kilomhos compared with 1.150 to 1.200 kilomhos, which is higher (better) than the equivalent AGM product.

7.0 Discussion

The most outstanding impression left by the results of the test was the variability of the cells; not just between manufacturers, but even between cells from the same production batch.

7.1 Variability of gassing rates

One pair of cells (6 and 7) were consistently close to each other on virtually all measurable parameters, including plate voltages and conductances. Yet, one cell emitted 60% more gas than the other.

Another pair (9 and 10) behaved even more variably: one cell gassed at two to three times the rate of its twin. Usually, variation in performance is put down to poor quality of manufacture. In these cases, that explanation is not supportable: these were high quality cells, made from the same batches.

7.2 Variability of Tafels

Figure 1 illustrates two major effects of cell dryout on Tafel curves. The first effect is that increasing dryness produces a "flat" negative Tafel; that is, the negative is depolarized at currents far higher than those normally seen during float. This effect is well known.

The second effect, not well known, is that drying out also shifts the positive Tafel to the "right". This effect may explain why we get variations in positive polarizations in VRLA cells that we do not get in flooded cells. That is, drying out opens the pores of the positive active material, thereby increasing the apparent surface area of the positive plate and reducing its polarization.

It should be noted that this second effect is quite a severe one at least on this cell - because the current essentially doubles for the same float voltage. The consequences to the cell performance in general, and thermal runaway in particular, are very significant. For example, there is little point in testing new, relatively wet cells for thermal runaway when it is the older, dryer cells that are most at risk.

Even after months on float, one pair of cells (9 and 10) was still drawing four times as much float current per Ah as another pair (6 and 7) with a similar AGM construction but somewhat different physical design. The reason for the high current draw is not clear. We suspect that it is either due to a larger apparent surface area on the positives plates of Cell 9 and 10, suppressing the positive voltage and causing a positive Tafel shift, as explained in 7.2 above, or to high internal element temperatures, perhaps in localized "hot spots". Note: It is informative to put this current density data in perspective: We would expect large, flooded, lead-calcium cells to draw about 7 mA per 100 Ah on float. By contrast, these two VRLA cells drew 160 mA per 100 Ah (ie: 23 times the float cur-

rent per Ah of their flooded counterparts, by inference, over 500 times the amount of heat).

Amps	Cell volts	N+	N-
0.05	2.216	1.243	- 0.972
0.10	2.235	1.265	- 0.969
0.20	2.260	1.293	- 0.967
0.50	2.296	1.331	- 0.965
1.00	2.319	1.356	- 0.963
2.00	2.390	1.403	- 0.986

Figure 14: Cell 9 polarization data showing decline of negative polarization with increasing current.

7.4 Variability in negative polarizations

We observed a phenomenon on Cell 10 that we saw nowhere else: a significant negative potential above open circuit while the cell was recombining very efficiently and emitting very little gas (less, in fact, than its twin which had a zero negative polarization). The effect seemed quite stable and lasted many weeks, disappearing only when we compressed the cell to eliminate bulging. Again the reason for this effect is not clear, but it may be that recombination is taking place locally while the reference electrode is reading average potential.

Another peculiar and troubling result, which gives insight into the problem of negative sulfation, is shown
in Figure 7 where the negative polarization of Cell 9 progressively decreased as the cell voltage was increased from open circuit. The Tafel shows the negative having 10 mV less negative polarization at a cell voltage of 2.32 volts - normally considered a boost voltage for such a cell (Figure 14). Again, this effect was not seen on any other Tafel result and could not occur on a cell in a wet condition (Phase 2).

0.05 -
0.10 -0.969

8.0 Conclusions

Although the test is relatively young at the time of writing, and final conclusions cannot yet be made, it appears that concerns about cell dryout have not been allayed by the data gathered so far. There is clearly a great deal of variability between one cell and another, some of it very difficult to explain. Some cells look as though they will meet their life targets; others look as though they will fail.

Our tests were run at cell temperatures slightly higher than room temperature, so actual gas emissions in cool climates may be a little less. However, we did no cycling at all; the usual service conditions for a cell includes discharges and recharges which will tend to increase gas emissions, not reduce them.

There is also the question of the effect of aging of the cells; will the inevitable changes in characteristics such as increased dryness, higher current draw, higher acid density, etc., make things worse, or better? Our long term results should tell.

9.0 References

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