# ACCELERATED LIFE TESTING: DOES IT SATISFY VRLA USER AND DESIGNER NEEDS?

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## ABSTRACT

It is universally accepted that the Arrhenius equation relating temperature to reaction rate can be used to determine VRLA life. To this end normal room temperature life is determined from extrapolation of the high temperature life times.

A prerequisite to this test method requires that the reactions occurring at the elevated test temperatures are common to all those at room temperature. Without prior knowledge one cannot possibly know if this requirement is satisfied. It is now known that elevated temperature testing did not determine life or identify a room temperature failure mode. Because of this, negative plate failures were first identified in field applications, which is not the place where they should be found. The opposite of not finding room temperature failures are those cases where failures identified at high temperature are not found in room temperature battery operation. Water loss is an example of this life test problem. These problem areas are evaluated and are reported on herein. Unfortunately such test errors have resulted in user skepticism and doubt about the VRLA battery being a viable product.

This work also questions the ability of Arrhenius type testing to determine positive plate life at $25^0$C using the suggested test procedures. Based on the above, can one justify accelerating life testing of the VRLA battery by employing elevated temperatures? The answer we believe is a limited yes and that only if one is educated as to the limitations of the test.

## INTRODUCTION

In the 2003 Battcon Conference[i] frustration was expressed because VRLA battery had not attained the advertised life. This disappointment has in part been due to Accelerated Life Testing (ALT) wrongly assigning positive plate growth as the primary failure mode when in fact few batteries ended their life due to this mechanism. By not identifying the correct room temperature failure modes the calculated life times based on positive plate growth were grossly in error.

**We suggest that the appropriate standards committees address this and other problems associated with ALT. It is of concern that at this time there appears to be no plans to do so. It then is the primary goal of this work to motivate VRLA battery standards groups to review present ALT procedures. This can only be accomplished by presenting the arguments for doing so, which is the basis for this paper.**

At Power Battery, life testing was performed at room temperature so as to determine by comparison the ability of elevated temperature testing to predict room temperature battery life and failure modes. Parallel testing of many VRLA products was performed at Lucent Bell Laboratories in their search to qualify VRLA batteries for back up power in wireless communications.

Battery manufacturer identification was not exchanged between the two test laboratories. Both tested independently and collaborated only when the solution to a technical problem would benefit all including the battery manufacturer whose product was under test. Some of these instances include the following,

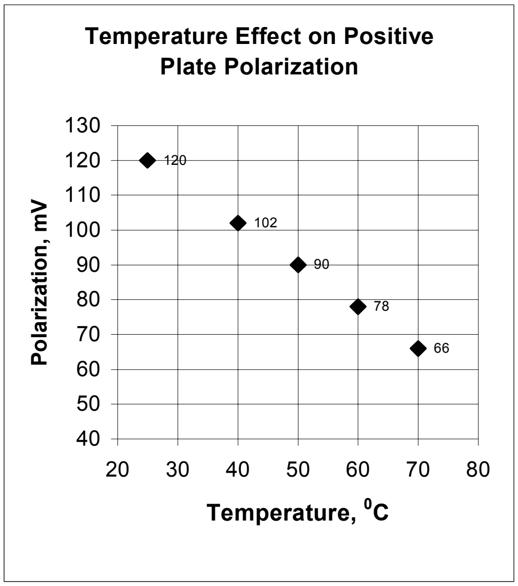
1. The evaluation of positive plate life tests at elevated temperatures.
2. The evaluation of testing for negative plate and negative structure failures.
3. Water Loss predictions from life testing.
4. Accelerated cycle life testing.
5. Attempts to arrive at realistic and meaningful life tests.

From this collaboration it was apparent that battery **designs were evolving mainly to satisfy ALT. As a result of this design emphasis, a trend to disregard battery performance at normal room temperature has taken place.**

## EXPERIMENTAL AND RESULTS

### Plate Life Errors

**The effect of temperature on positive plate polarization has previously been addressed**. To re-emphasis the importance of this relationship, Figure 1 was derived using the temperature coefficient (dVoc/dt) of 1.2mV/$^0$C measured by Bethune and recently by Vaccaro in the above reference. The polarization of 120mV at 60$^0$C was assigned to represent that on the positive plate of a cell on float at 25$^0$C. This positive plate polarization is typical of a cell whose oxygen recombination is such that the negative plate polarization is 5mV.




From this figure it is evident that controlling the battery float voltage will result in different plate polarizations for each test temperature. As an example the figure shows that when testing at 60$^0$C the positive plate polarization is 78mV, not the 120mv at 25$^0$C. Because it is desired to determine plate life at 25$^0$C and 120mV polarization, then the polarization should be 120mV at all test temperatures. Control of cell voltage as is instructed by the various test standards will not result in one polarization, regardless of temperature. As a consequence the calculated life for 25$^0$C operation will be in error.
To provide quantitative significance to this apparent test error Power Battery recently performed tests to determine the plate growth rate at various polarizations. The growth studies where performed at 60$^0$C with flooded lead-acid cells. Each cell contained two positive plates and three negative plates. The positive plate polarization was held constant at a pre-selected voltage above a $PbO_2$ reference electrode in the 1.300 specific gravity cell electrolyte. The reference electrodes were made from positive plates similar to those used in the growth study.

In Figure 2 is shown the relationship of plate growth to positive plate polarization at 60$^0$C.

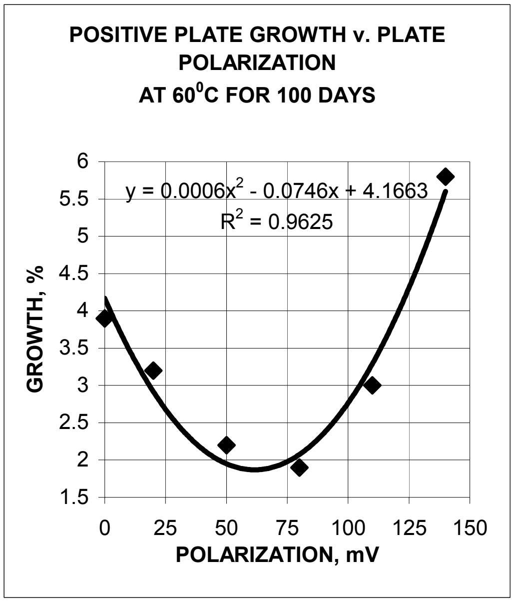



**Figure 2**

In figure 2 are experimental growth rates recently determined at Power Battery for the polarizations in figure 1. It is seen that at $60^0$C the plate growth rate at 120mV is approximately two times faster than at 78mV.

To better demonstrate this point, the Arrhenius plot (life halves for each $9^0$C rise) in figure 3 shows the difference in life when the positive plate is polarized at 120mV and 78mV at all temperatures. The projected life at $25^0$C from testing at $60^0$C and 78mV is twice that of testing at $60^0$C and 120mV.

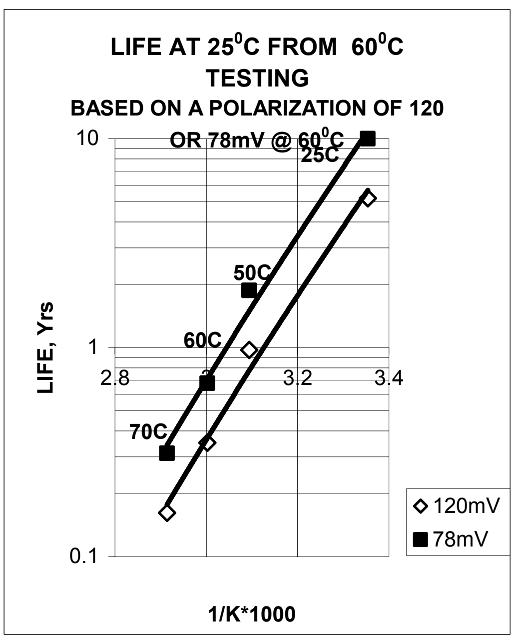



**Figure 3**

The negative plate open circuit potential decreases with increasing temperature. Thus, the result is an increase in polarization with rising temperature. The negative polarization is further enhanced by the increase in corrosion of the positive plate with increasing temperature. The dVoc/dT coefficient of the negative plate is $0.4mV/^0C$ as reported by Bethune[ii] and Vaccaro[iii].

It is now apparent that failures of the negative plate caused by low polarization at room temperature were not observed in elevated temperature life tests because negative plate polarization rises with temperature. For many this fact was not realized for sometime after failures in the field had occurred. Such negative plate problems include negative strap fracture and plate self-discharge. Below in figure 4 is a plot that was presented in a previous INTELEC conference. In this figure is graphed the activation energy for the failure modes of both negative strap fracture and positive plate growth. As seen the activation energy lines intersect at approximately $50^0$C. This is quite significant because this data shows that negative strap fracture will be the failure mode at room temperature, while at approximately $50^0$C and above, the failure mode is positive plate growth.

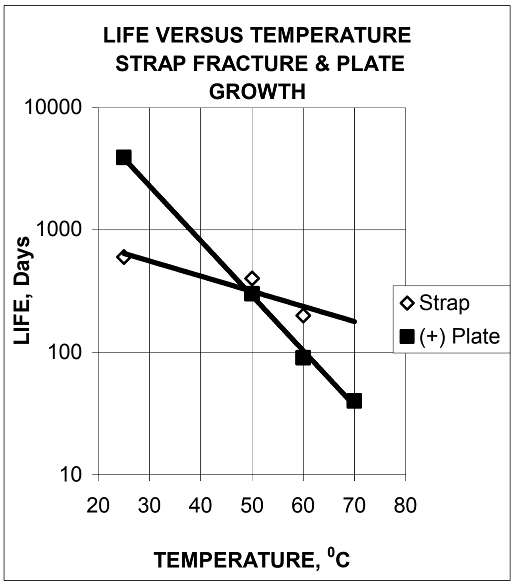



**Figure 4**

The graph in this figure was experimentally generated and of major importance in the detection and the cure of negative strap fracturing. In this example it is obvious that life testing should begin at temperatures well below $50^0$C. Self-discharge of the negative plate due to low or no polarization on this plate for the same reasons given above should not be expected to be identified at elevated temperatures. As a proof of the validity of the data presented in figure 4, room temperature life tests at Power Battery where performed. In these tests negative strap failures were readily found while at elevated temperatures rarely was this failure mode detected.

**Water Loss Errors**

The loss of water depends on many factors including seal integrity, oxygen recombination efficiency, plate polarizations, and electrolyte volume. Water loss rates due to the above factors can be of a non-Arrhenius like nature, where reaction rates vary non-predictably with temperature.

In life tests at 50, 60 and $70^0$C the weight loss of 12V-100Ah modules was measured and plotted in an Arrhenius format. The same type batteries were float charged at room temperature. Figure 5 shows the graphed high temperature data and the room temperature loss calculated from that data. Included is an entry for the water loss rate determined from the room temperature float tests.

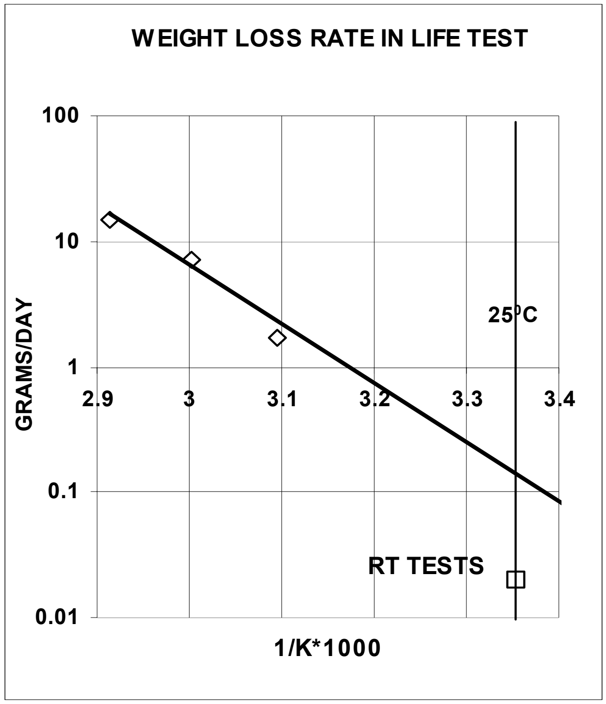



**Figure 5**

The weight loss at 25$^0$C calculated from the elevated test temperatures is seen to be approximately 6 times that of batteries float charged at approximately 25$^0$C. Considering the decrease in the efficiency of oxygen recombination and the increase in polarization of the negative plate with rising temperature this difference should not be surprising.

At the laboratories of Power Battery seventy batteries have been tested at room temperature until failure. None came close to failing because of excessive water loss. Contrary to this room temperature experience, failures due to water loss have occurred at elevated test temperatures.

**Cycle Life Tests**

The charge-discharge cycling is employed in most ALT programs to determine the number of cycles a battery can withstand. Such tests are more pertinent in motive power applications because frequent discharges are generally the life limiting factor. In rapidly repeated discharges, sulfate ion stratification is a common problem in both flooded and VRLA products. Although the cell's plates might still have the potential to provide the energy demanded it can not because sufficient sulfate ion is not available to all the plate surfaces.

The rapid cycling as currently employed is not relative to the telecommunications and most UPS plants. To satisfy all cycle concerns the test employed at Power Battery evaluates both rate of sulfate stratification and plate paste wear-out. In the Power Battery test a discharge is performed every day and a half without open circuit time. The procedure is as follows,

1. Discharge the battery with the plates in the vertical orientation. This to evaluate stratification.
2. Continue in this mode until the capacity is 80% of its original value, recording the number of cycles to 80%.
3. Place the battery so that the plates are now in the horizontal plain and continue the charge-discharge sequence. This to evaluate the plate cycle life.
4. Upon reaching 80% capacity the number of cycles is recorded and the testing is completed.

The number of cycles to 80% capacity in steps 1-2 is a track of sulfate ion stratification rate. This number yields the cycle life under the most extreme conditions, perhaps motive power applications. The number of cycles to 80% in steps 3-4 determines the plate cycle life. It more closely relates to the use mode found in telecommunications service. In this application there is normally sufficient time between discharges so that meaningful acid stratification does not occur. This can be simulated by laying the battery on its side with the plates horizontal so that gravity cannot works to keep the electrolyte distributed across the plates surface.

**Testing At Lucent**
It is our conclusion based upon the above analysis and field experience that determining battery life at $25^0$C from the results of elevated temperature tests is at best risky. As to the performance tests required by most specifications approximately two years of testing is needed to complete them. While most of the tests are important, decisions as to battery acceptance normally cannot await their completion. Because of this some prioritizing of the test schedule is necessary.

At Lucent Bell Laboratories the wireless battery forecasts were for 1 million 12-volt modules in two years. It was determined that three battery manufacturers would need to be approved to satisfy this demand. Relatively novel specifications were written at Lucent so that battery acceptance proceeded in logical steps that would result in the best battery for the intended application.

The battery capacity was required to be at least 100A-h at the 8-hour rate. It was also required that the battery terminals be front access.

After a review and selection of major telecom manufacturers, the following procedures were implemented in the order shown:

1. Does the manufacturer have an off-the-shelf solution or is the manufacturer interested in developing the needed battery?
2. Review and assess the battery's field performance, if available.
3. Review battery documentation and responses to test specifications.
4. Manufacturing and engineering technical audit.
5. Visual examination, external and internal.
6. Capacity testing at the application loads.
7. Tafel data and graphs.
8. Float charge life at $60^0$C and 20% RH with a postmortem at end of life.
9. Short Circuit test performance.
10. Negative strap metallurgical analysis.

No attempt to determine life at $25^0$C was made. Instead float performance at $60^0$C was used to differentiate individual battery performance at elevated temperatures because of Lucent's power plant requirements calling for continuous operation up to $65^0$C. End of life was defined as 80%, and at least 100 days was required. The requirement was set quite low so as not to discourage any interested party. Participants in this test program were informed that it was Lucent's intent to work with each manufacturer to make their battery acceptable. This was a rather unique user-manufacturer relationship that in many instances brought rewards to both parties.

A Tafel plot is a graph of the voltage vs. current for a battery or cell. Because of the exponential relation between the over voltage and the current, the graphs are generally plotted on semi-log co-ordinances. The Tafel data is intended to give qualitative information on the efficiency of oxygen recombination. Tafel slopes in the float region were required not to exceed 100mV/decade of current. Experience demonstrated that the battery, as new, was not Tafel stable and extensive gas collection would be timely and not indicative of the true oxygen recombination efficiency.

Negative strap fracture is a common problem to many battery manufacturers. Its origin has been traced to low over-voltage (low polarization) on the strap surface. The problem is often exasperated by the crystalline structure of the lead strap. While increasing the over-voltage or enhancing the crystalline structure may be difficult, and take a long time to test. Immediate improvement was realized by wrapping the strap with AGM separator.
Short circuit testing was performed, as per Telcordia standards to insure that the battery remained safe and did not present a hazard to personnel or equipment. Most batteries performed well, however one did open circuit at the post during the first, 1 minute short stage of the test, and could not finish. However, working with the supplier, the problem was later remedied by increasing the robustness of the post.

**Lucent Life Test Results**
Table 1 below shows the result of the float charge life test at $60^0$C. Fourteen battery models from large telecom manufacturers were included in this study and, as seen, the variation in life was quite large. Surprisingly the range of life (No. of days at 60C) was several weeks to over 400 days. Weight/water loss rates were from 0.3 to 1.5 grams/day.

Most revealing was the postmortem data shown in Table 2. While some batteries failed due to excessive water loss, most failed from loss of compression due to the high temperature test weakening the integrity of the jar walls along with plate warping. The grid thickness for the high life performers was a maximum of 0.140 inches. Where battery product could be improved changes were suggested to the manufacturer. In most instances the suggestions were accepted. Some of the failure modes seen in the table were unexpected and could not be corrected to improve battery life.

| Battery | Days to Failure | Weight loss gm/day | Impedance milliohms | AVG. Current @ 60C (mA) | Tafel Slope mv/dec. | Telcordia Short Circuit Test |
|---|---|---|---|---|---|---|
| **12V / 100AH Monobloc Front Access (2x3 cell config.) Batteries** | | | | | | |
| A | 75-90 | 1 | 3.0-5.0 | 500 | 80 | Pass |
| B | 190-210 | 0.4 | 3.6-6.0 | 300 | 80 | Pass |
| C | 150 | 0.8 | 3.0-4.0 | 275 | 200 | Pass |
| D | 125 | 1.2 | 2.9-4.5 | 200 | 200 | Pass |
| E | 188 | 1.1 | 2.8-3.6 | 300 | 80 | Pass |
| F | 117-130 | 0.9 | 3.0-5.0 | 250 | 120 | Pass |
| G | 113 | 0.7 | 3.0-4.0 | 400 | 100 | Fail |
| **12V / 150AH Monobloc Front Access (2x3 cell config.) Batteries** | | | | | | |
| H | 210-240 | 0.65 | 2.0-4.0 | 400 | | Pass |
| I | 147 | 0.3 | 2.7-3.1 | 200 | 80 | Pass |
| J | 200 | 0.8 | 3.5 – 4.5 | 150 | 80 | Pass |
| K | 110-200 | 1.5 | 3.0-5.0 | 750 | 90 | Pass |
| L | 100 | Indeterminate | 3.0-5.0 | 1100 | | Pass |
| M | 250-300 | 0.4 | 3.0-4.0 | 250 | 140 | Pass |
| **12V Monobloc Top Terminal (1x6 cell config) Telecom Battery** | | | | | | |
| N | 420-450 | 0.5 | 4.0-8.0 | 100 | 190 | Pass |

**Table 1**

| Battery | Days to Failure | Autopsy Findings |
|---|---|---|
| **12V / 100AH Monobloc Front Access (2x3 cell config.) Batteries** | | |
| A | 75-90 | 100% Plate Corrosion & Loss of Compression, Minimum Plate Growth |
| B | 190-210 | Loss of Compression and Corrosion |
| C | 150 | Loss of Compression & Dry Out |
| D | 125 | Loss of Compression |
| E | 188 | Loss of compression due to flexible case, requires steel Jar |
| F | 117-130 | Rapid Plate Growth – Shorting & Thermal Runaway (Possibly due to plate contamination) |
| G | 113 | ABS Polycarbonate Jar material, very brittle under temperature testing (shattered) & Negative strap lead fracturing |
| **12V / 150AH Monobloc Front Access (2x3 cell config.) Batteries** | | |
| H | 210-240 | 90% Grid Corrosion, minimal Plate Growth |
| I | 147 | Loss of Compression, 90% Grid Corrosion |
| J | 200 | Loss of Compression |
| K | 110-200 | Dry Out, |
| L | 100 | 100% Plate Corrosion |
| M | 250-300 | Plate Growth & 80-100% Corrosion |
| **12V Monobloc Top Terminal (1x6 cell config) Telecom Battery** | | |
| N | 420-450 | 100% Grid & Strap Corrosion, minimal plate growth |

**Table 2**

## CONCLUSION

Corporations such as Lucent that purchase large numbers of batteries as sub- assemblies of their product often want some assurance beyond the warranty as to the expected life of the batteries. To that end they turn to life testing. Some tests such as the Short Circuit test and the room temperature Tafel Test can be carried out in a relatively short period. Accelerated Life Test (ALT) can take a year or more.

The premise of ALT is that elevated ambient temperature shortens product life. A rough rule of thumb is that every $9^{0}$C, halves the life. This is referred to the Arrhenius relation. What we have found is that even at a "modest" $60^{0}$C ALT the data can be misleading. Several examples are:

a.) At room temperature some batteries failed due to negative strap corrosion. Like batteries showed no sign of it at 60C.
b.) Batteries failed at room temperature due to negative plate discharge, but did not at $60^{0}$C.
c.) Batteries failed at 60C because of low plate compression (jar bulging), yet the problem never showed up at room temperature.
d.) The extrapolated value for room temperature water loss from elevated temperature test data was found to be ten times greater than the measured values.

The Lucent life test program was designed to be relevant to its intended battery application. The results were carefully measured against that mode. Other battery users should always consider test results in the light of their particular use mode. Most importantly, and the main objective of this work, is to emphasize that standard test specifications do not satisfy the needs of every battery, battery designer, or user.

**Accelerated life testing should not be the only criterion the industry employs to design or select a VRLA battery. As this paper points out, it is one of many tools/criteria that must be used in conjunction with one another to truly assess a battery's performance.**

**We call upon the responsible battery committees to review the existing test procedures with the inconsistencies discussed above in mind and suggest that all in the industry have a greater awareness of these pitfalls.**

## ACKNOWLEDGEMENT

The authors take this opportunity to thank the management at Power Battery and Lucent Technologies for both supporting this work and realizing its importance.

## REFERENCES

[i] McCluer S., "*Wanted: Real World Battery Life Predications*",14, Battcon, April 2003.
[ii] Bethune, "*Half Cell Potentials and Reactions*".
[iii] Vaccaro F., *"The Effect of Temperature on VRLA Reaction Rates",* INTELEC 1997.