Real-Time Expected Life on VRLA Products
A Manufacturers' Perspective

Michael R. Moore
Frank L. Tarantino
Frank J. Chiacchio
Jaime R. Resurreccion

YUASA-EXIDE, INC.
2400 Bernville Road
Reading, PA 19612-4145
USA

ABSTRACT

In order to fully understand the life characteristics of Valve Regulated Lead Acid (VRLA) products, Yuasa-Exide, Inc. is undergoing a large project to evaluate Accelerated Aging. Following the procedures of Bellcore's Technical Reference TR-NWT-001200 "Generic Requirements for Accelerated Life Testing of Valve Regulated Lead Acid Batteries at High Temperatures," we are starting to collect data on our 20 year warranty class VRLA products as well as comparable product offerings from three other prominent battery manufacturers in the industry.

Utilizing the Bellcore small scale method to conduct our analysis, the intent is to demonstrate the predicted life performance of VRLA cells according to accelerated aging criteria. This paper discusses test results and the preliminary findings.

HISTORY

Ever since the introduction of stationary flooded batteries into the market, a typical design specification for telecommunications applications has been a 20 year life. Flooded technology has been in production for over 100 years. Over this period of time, extensive research has been conducted, allowing for design optimization. Conversely, the design of VRLA product, the newest technology, was less than ideal. As a result, the VRLA products have encountered difficulty meeting life expectations.

The evolution of VRLA batteries can be traced back to the 1930's, when Adolph Dassler was awarded a patent on an early version of a sealed cell. In the 1960's, Yuasa Corporation Japan and Exide Corporation, formerly Electric Storage Battery, were two of the companies that pioneered the development and manufacture of the first VRLA cells. Over the years, the VRLA products have improved significantly, however; they are still inferior to flooded products in regard to life expectancy.

In an effort to market these new VRLA products, manufacturers made many attractive claims to compete with the proven flooded technology. Some manufacturers claimed that VRLA batteries do not gas and require no ventilation. This led to the early misconception that VRLA products are really "maintenance free." Secondly, they claimed that the VRLA products were "sealed", which allowed for stacking the VRLA products horizontally, creating a higher energy density footprint than their flooded counterparts. Unfortunately, this configuration placed new demands on the cell's vital seals (i.e. cover seal and post seals) against leakage. Finally, the biggest misconception of all has been the claims of the cell's life. Manufacturers believed the only way this new technology could compete with the proven flooded technology was to position it in the same 20 year warranty class.

Recent papers and conferences have asked that manufacturers provide the industry with real-time life expectancy of these VRLA products. Obviously, the most relevant testing would be performed under normal operating conditions which would take years to finish and prolong manufacturer's decision on warranty and other marketing issues. In 1992, realizing this need

Bellcore issued an accelerated aging procedure for VRLA cells to allow manufacturers to evaluate their respective designs on a common standard.

SCOPE

The Bellcore procedure has provided general guidelines and methods for estimating the realizable life of VRLA batteries in service. Bellcore has addressed the problem by stressing the product, through the increase of temperature, causing it to fail much sooner than it would in normal service.

For small scale testing, Bellcore recommends using an activation energy value of 14.5 kcal/mole. This value is considered conservative because it is the lowest value of any failure mechanism present in a lead acid battery except for corrosion. In addition, this value follows closely with the industry standard that a lead acid battery will lose 50% of its life for every 10°C above 25°C.

The late physicist Arrhenius demonstrated that the rate of electro-chemical reactions as a function of temperature is expressed by the equation in Figure 1.

ARRHENIUS'S EQUATION

$$LN\left(\frac{k_1}{k_2}\right) = \frac{E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Where

k_1 = Multiplier from Actual to Projected Life (Based on T_1 temperature°K)

k_2 = 1 (Based on T_2 temperature°K)

E_a = Activation Energy (kcal/mole)

R = Gas Constant (1.987 cal/mole-degree)

T_1 = Test Temperature (°C + 273 =°K)

T_2 = 25°C + 273 = 298.15°K

Figure 1

This equation establishes the multipliers to be used to extrapolate the life at high temperatures back to a predicted life at 25°C. Plugging an activation energy of 14.5 kcal/møle into Arrhenius's equation, the following curve (Figure 2) can be drawn to show the relationship between tested temperature and the multiplier to evaluate predicted life at 25°C.

ACCELERATED AGING FACTORS

Based on Ea = 14.5 kcal/mole

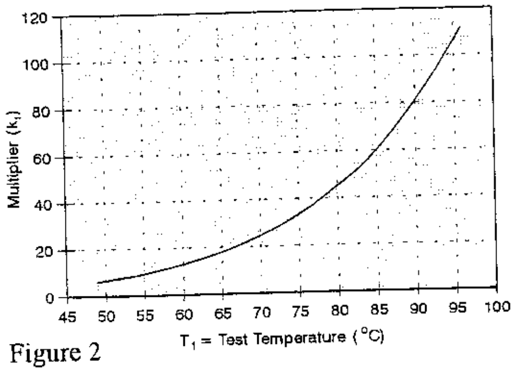

Figure 2

SET UP

The cells were selected from a common lot of cells. This required cells from a respective product type to come from the same grid casting, plate pasting, and formation. (Note: For competitive analysis this set was impossible for obvious reasons.)

PROCEDURE

1. All cells receive a freshening charge and an 8 hour capacity test.

2. The cells are placed in a thermally insulated box. All products are tested as installed for service. These cells should be placed in standard orientation, that is, plates standing on edge. All set-ups are set on float charge at 2.25vpc.

3. Daily readings are taken to measure internal ambient temperature, float current, cell voltage and cell temperature (Figure 3).

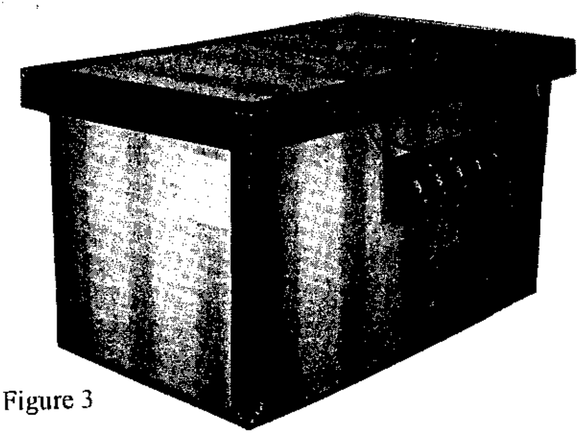

Figure 3

4. Every 28 days the heat is turned off and the cell is given time to acclimate to the ambient outside air (Figure 4). Once stable, the cell is discharged at rated nominal capacity (8 hour to 1.75vpc rate). Individual cell voltage is measured to record time to 1.75vpc.

Figure 4

5. Results are plotted on a graph. The y axis shows the cell's time to 1.75vpc and the x axis shows the number of days.

6.Repeat steps 4 through 6 until cell fails. A cell is considered to have failed when it reaches 75% of rated capacity.

RESULTS

Figure 5 depicts four different brands' performance at 60°C.

Brand A = GEL Technology - Short profile
Brand B = AGM Technology - Medium profile
Brand C = AGM Technology - Short profile
Brand D = AGM Technology - Medium profile

From the results of the above data the following life prediction table presented as Figure 6 can be created. Referring to the Temperature vs. Multiplier graph (Figure 2) the following life values can be determined from the accelerated age testing.

ACCELERATED AGING RESULTS
(BASED ON 14.5 kcal/mole at 60°C)

Brand	Technology	Days to 75% capacity	Predicted life (Years)
A	GEL	195	7
B	AGM	155	5.6
C	AGM	180	6.5
D	AGM	145	5.2

Figure 6

Example:

$$\frac{195 \text{ days}}{365 \text{ days}} \times 13.1 = 7 \text{ years}$$

Where
13.1 = multiplier at 60°C (Figure 2)
365 = days in one year

It must be noted that these predicted life values were derived using the Bellcore recommended factor when data from only one temperature is available. This is, by its nature, a conservative factor.

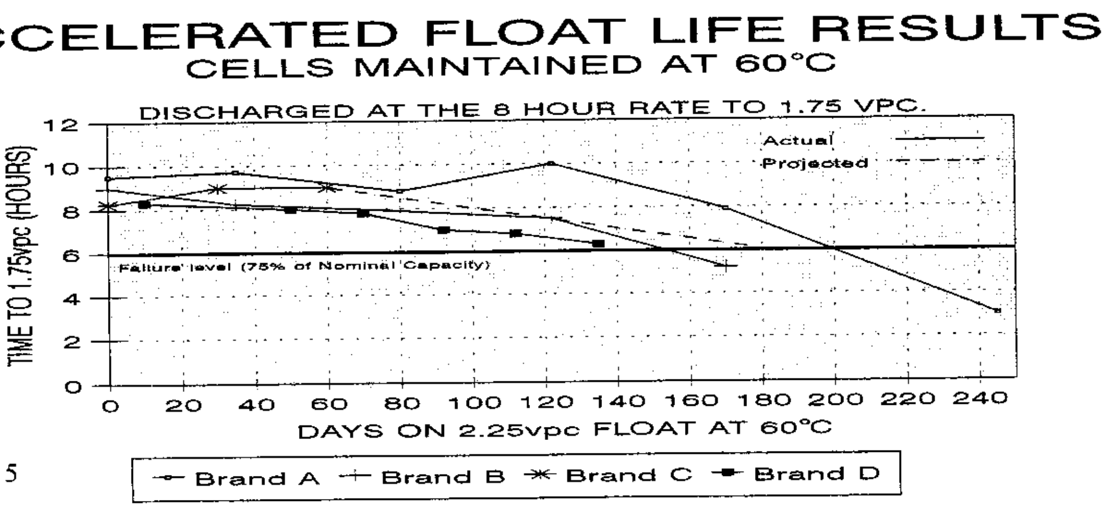

Figure 5

ANALYSIS

Once the cells have reached the failure line of 75% capacity, an autopsy is performed. This procedure requires the cell's element to be removed from the container intact. An incision is made along the cell's jar to cover interface. Then the cell's element is extracted from the jar. The positive grid is measured to evaluate corrosion and the electrolyte's specific gravity is measured with the assistance of a refractormeter.

Once the cell's vital signs have been measured, the dissection of the element starts. Each plate is removed from the strap to examine the condition of the burn as well as the luster and color of the plates. Finally, a thorough scrutinization of the separators and/or glass mat is performed to find possible internal shorts.

From our testing, the driving cause of failure in all four samples was positive grid corrosion. The rate of corrosion is dependent on many factors but the overriding one is the metallurgical properties of the grid alloy. Heat treatment and cooling rate are causes for variation in these properties.

The corrosion reaction causes the cells to draw increasingly more current which causes excessive gassing, leading to dry-out. The electrolyte concentration or specific gravity in a VRLA cell must stay within a narrow range for optimal life characteristics. During dry-out, the electrolyte loses excessive amounts of water, causing an increase in sulfuric acid concentration and thus the open circuit voltage will rise (at roughly 1 mV per point in gravity).

Bellcore has defined the driving force for water vapor transmission as the difference in the water vapor pressure inside and outside the battery case. The selection of the plastic used for the cell's container must be based on the actual intrinsic permeability and the design life of the battery system. Tests results have found Polypropylene (PP) to be one of the best materials for retaining the limited supply of electrolyte. Figure 7 shows a comparison of the three most prominent materials used in VRLA designs.

WATER VAPOR PERMEABILITY
(GMS/HR•CM)/(CM² •ΔmmHg) •10^{-8}

Material	25°C	50°C
PP	0.18	0.44
PVC	1.10	1.20
ABS	5.60	5.40

* Based on testing performed by AT&T Labs.

Figure 7

Another reason that Flooded batteries last longer than VRLA product could be explained on the basis of float current requirements. The float current in a flooded cell will polarize both the negative and positive plates, but in a VRLA cell it will only polarize the positive. This is because the recombination process prevents polarization of the negative electrode. The float current in a VRLA cell is therefore higher than a flooded cell, due to the cell's operating specific gravity (Typical 1.300 at 25°C) and the rate of recombination. The amount of current required to float the cell is proportional to the growth rate of the positive plates.

CONCLUSIONS

1. With initial results completed it becomes apparent that the projected life does not support the original 20 year warranty.

2. As additional temperatures are completed (i.e. 40°C and 50°C), a more accurate activation energy value will emerge to show how far away from actual life the warranty life will be.

3. If failure modes are common on all test temperatures on future tests, it will provide the way for possible design or process changes to elevate life to a true 20 year VRLA product.

RECOMMENDATIONS

Using Bellcore's Accelerated Life testing to provide the expected life on VRLA cells, users will possess a realistic life criteria to design their systems. Manufacturers may consider using this procedure to develop their future warranty statements for all their VRLA products.

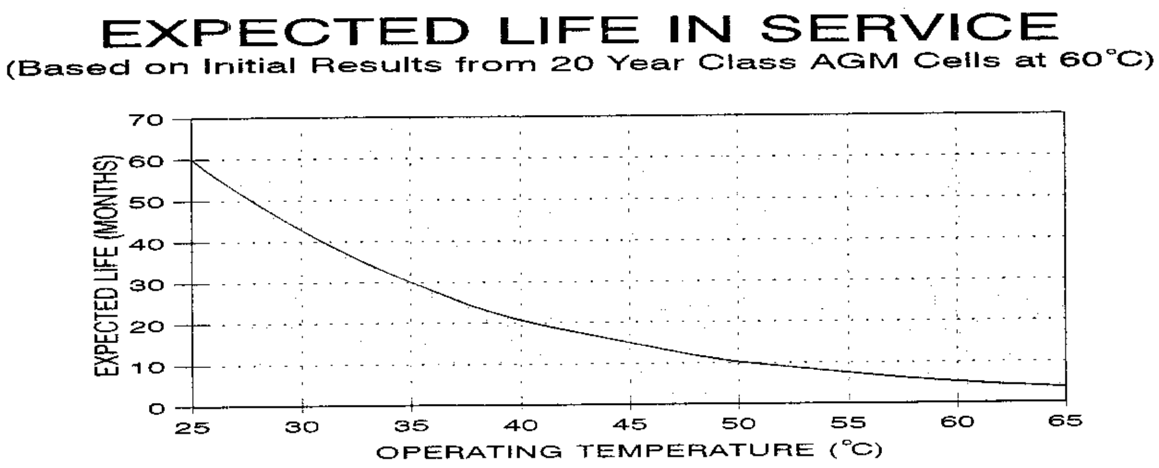

Figure 8

Typically, VRLA products come with a 1 year full - X number of year(s) pro-rata replacement policy. This ancient concept was designed to encourage repeat buying; however it left unrealistic expectations of X+1 years of use from products that our data shows won't last that long. Considering initial results Figure 8 depicts expected life of typical 20 year class Absorbed Glass Mat (AGM)cells vs. operating temperature in service.

In addition, with accelerated age testing underway, manufacturers should be able to develop an algorithm to evaluate the life of the battery system when in service (i.e. Fuel Gauge for VRLA cells). Once this information is determined, manufacturers will finally be able to focus on satisfying the two biggest concerns of VRLA customers.

1. A true "maintenance-free" battery with realistic life expectancies.

2. Monitoring (via modem) the battery's life in remote systems without human intervention.

Satisfying customer's requirements and listening to the "voice of the customer" should be the main objective to all battery manufacturers. The first step to achieving a real-time expected life on VRLA product is one back to reality. The goal is to set the high bar at a realistic level and challenge all manufacturers to raise it through design and process improvements.

MAY THE BEST MANUFACTURER WIN!

REFERENCES

[1] William F. Smith, Principles of Material Science and Engineering, McGraw Hill, 1986, ch. 6, pp.356-357.

[2] "Generic Requirements for Accelerated Life Testing Of Valve Regulated Lead Acid Batteries At High Temperature" TR-NWT-001200 Issue 1, Bellcore. January 1992

[3] W.B. Brecht, "Life expectancy of VRLA batteries", Batteries International, July 1994

[4] J. McDowall, "High Temperature Characteristics of VRLA Batteries: Translating Theory Into Reality, January 1995

[5] F. J. Vaccaro and J. A. Klatte, " Water Vapor Permeability of Plastics Used for Electrolyte Immobilized Lead-Acid Battery Containers." Intelec '89, IEEE (New York, 1989), paper 6.4.