AVOIDING THERMAL RUNAWAY IN VRLA BATTERIES: THE PURE LEAD-TIN OPTION

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ABSTRACT

Recently there has been renewed focus on thermal runaway (TR) of batteries in general and valve regulated lead acid (VRLA) absorbed glass mat (AGM) batteries in particular. Data presented in this paper will show the difficulty of driving thin plate pure lead (TPPL) VRLA batteries with a small percentage of tin into thermal runaway. Comparative data will also establish the superiority of TPPL VRLA batteries over lead-calcium VRLA batteries when subjected to extreme overcharge conditions.

INTRODUCTION

Ever since the VRLA AGM battery was patented in the 1970s, it has been in use in a variety of very demanding applications, such as outdoor telecommunications cabinets, outdoor telemetry, weather stations and other uncontrolled ambient temperature environments. Its low maintenance feature made the VRLA battery attractive for installation in remote areas where sending maintenance crews is extremely costly.

However, since there is no way to replenish the water lost by a VRLA cell due to exposure to high temperature or overcharge or both, the VRLA design is inherently more susceptible to thermal runaway than a conventional flooded lead acid cell. Many of these VRLA batteries in outdoor applications used a lead-calcium grid alloy and were indeed prone to premature dryout and consequent failure when exposed to high temperature or high voltage or both.

This experience has quite naturally left a bad taste in the mouths of many customers who bought into the VRLA AGM technology for their outdoor battery needs. There is an abundance of literature[1, 2, 3, 4] that provide details on the premature failure of these batteries. However, most if not all of this body of literature looked at the behavior of lead-calcium VRLA batteries before reaching their conclusion that the highest quality VRLA batteries cannot last as long as their design life, even under favorable conditions.

This is an unfortunate general conclusion about VRLA batteries that ignores the vastly superior performance characteristics of VRLA batteries using pure lead with a very small percentage of tin in their grids. This paper presents laboratory test data that will demonstrate the difficulty of driving TPPL batteries into thermal runaway. Further, in separate tests (not presented here) TPPL batteries have lasted over 60 days in accelerated life tests at 176ºF (80ºC). This is equivalent to a float life of well over 15 years at 77ºF (25ºC).

Taken together, these two characteristics offer proof that with proper selection of the grid alloy, VRLA batteries with pure lead-tin grid alloys offer significantly better resistance to thermal runaway than traditional lead-calcium VRLA batteries in uncontrolled temperature environments. Further, pure lead-tin batteries can deliver on their promise of reliable long life in standby power applications.

EXPERIMENTAL SETUP

Two sets of tests were run to compare the TR characteristics of a lead-calcium VRLA battery and a TPPL battery. In the first set, two new fully charged batteries were overcharged at 15.9V or 2.65 volts per cell (VPC) until either the charge current rose to 4½ amps (roughly C_4) or the battery case temperature reached 140ºF (60ºC). The lead-calcium VRLA was a 12V, 18Ah battery and the TPPL battery was a 12V, 16Ah battery.

The first test was designed to determine the recombination efficiency of both batteries in a high overcharge environment. Less efficient oxygen recombination results in shorter battery life and higher amounts of evolved hydrogen gas.

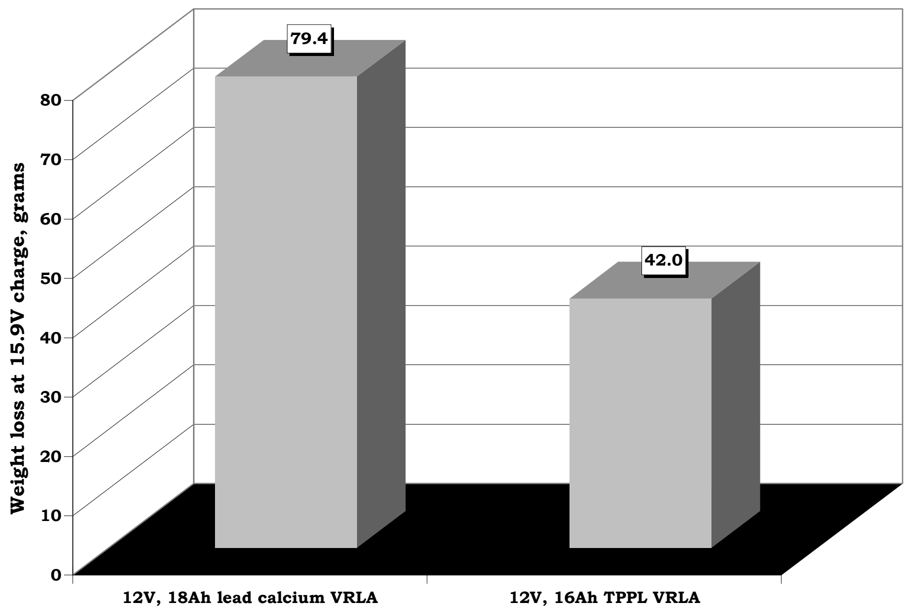

Figure 1: Weight loss comparison between lead-calcium and TPPL batteries

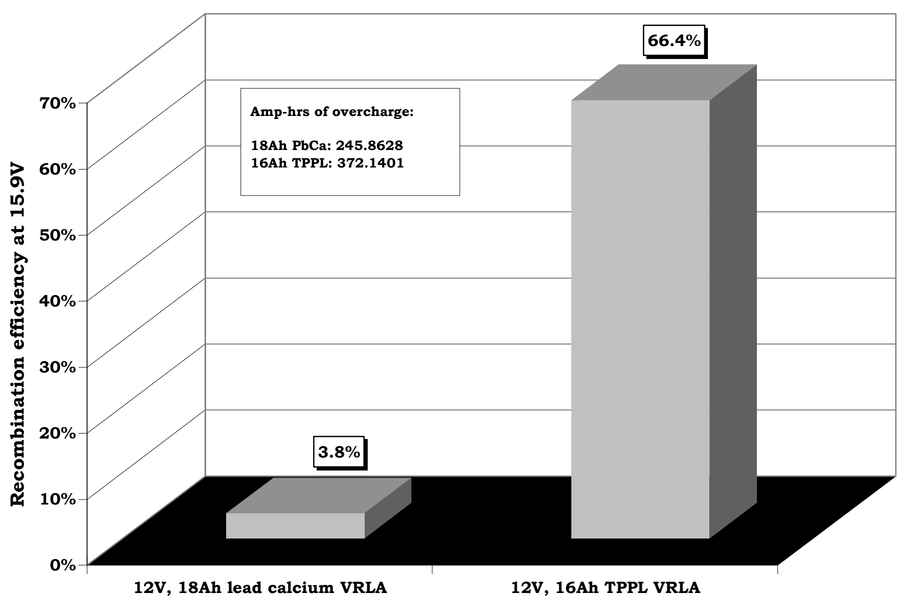

Figure 2: Recombination efficiency comparison between lead-calcium and TPPL batteries

In the second test, a 12V, 26Ah lead-calcium battery and a 12V, 26Ah TPPL battery were first partially aged by cycling them 10 times each. Each cycle comprised a 7A discharge to 10.5V, followed by a 19-hour normal recharge. They were then placed on an elevated float charge at 2.65 VPC, with the same test termination criteria of either a case temperature of 140ºF (60ºC) or a charge current of 4½ amps.

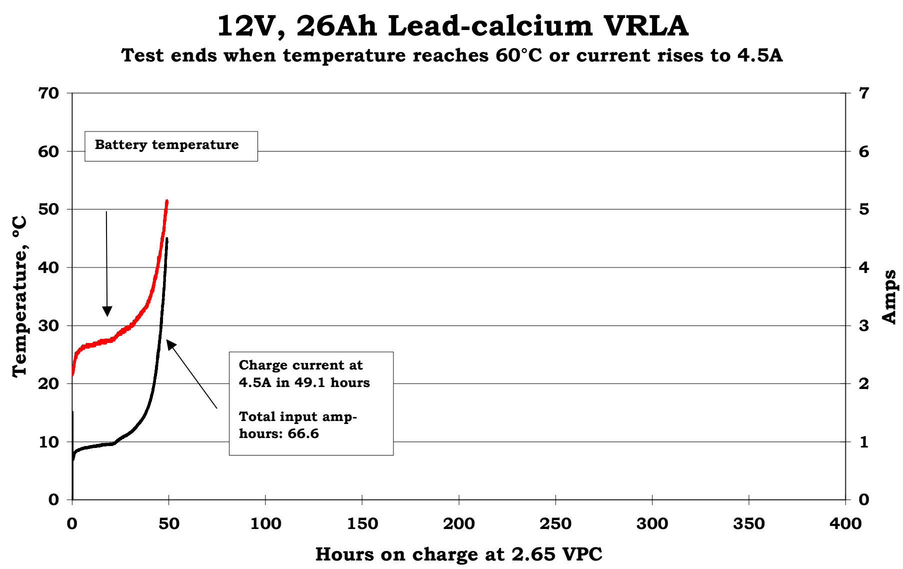

Figure 3: TR characteristics of partially aged lead-calcium VRLA battery

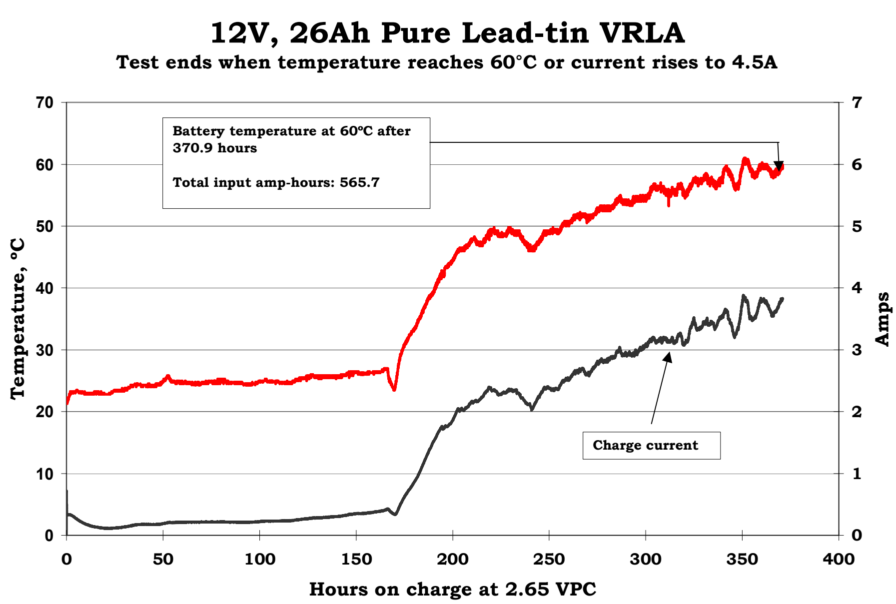

Figure 4: TR characteristics of partially aged TPPL VRLA battery

DISCUSSION OF THE EXPERIMENTAL RESULTS

As shown in Figure 1, the lead-calcium battery lost 79.4 grams or 1.34% of its initial weight, while the TPPL battery lost 42 grams or 0.67% of its initial weight. Figure 2 shows that the oxygen recombination efficiency of the lead-calcium battery was only 3.8% while the TPPL battery had a corresponding oxygen recombination efficiency of over 66%. From a practical user's standpoint, this difference in recombination efficiency indicates a higher gassing rate under extreme overcharge conditions for the lead-calcium VRLA when compared with the gassing rate of the TPPL battery.

Since a higher gassing rate implies a quicker rate of water loss, a lead-calcium battery will dry out faster than a TPPL battery during overcharge conditions. Because of this higher gassing rate, as the battery ages the lead-calcium VRLA battery is more likely to be forced into a TR situation than a TPPL VRLA battery under similar extreme conditions. The second set of tests was designed to either prove or disprove this assumption. To simulate batteries that have been in service for a while, the two batteries used for the second test were first cycled ten times under normal conditions of temperature and charge voltage before charging them at 2.65 VPC.

In the second test, a 12V, 26Ah lead-calcium battery and a 12V, 26Ah TPPL battery were first partially aged by cycling each battery ten times to a cutoff voltage of 10.5V at room temperature. The batteries were then put on a 15.9V (2.65 VPC) charge, with identical test termination thresholds as for the first test – a charge current of 4½ amps or battery case temperature of 140ºF (60ºC). Results of this test have been plotted in Figures 3 and 4 above. The lead-calcium battery reached the current threshold of 4½ amps in just over 2 days (49.1 hours). The TPPL battery, on the other hand, stayed on charge for over 15 days (370.9 hours) before reaching the 140ºF (60ºC) threshold.

Based on the rapidly increasing charge current (see Table 1) it can be argued that the lead-calcium battery had entered into a TR situation after only 30 hours on charge. In contrast, the TPPL VRLA battery experienced more gradual increases in the charge current during the almost 371 hours it was on charge before it hit the temperature cutoff.

Table 1: Charge current for 26Ah TPPL VRLA and lead-calcium VRLA at 2.65 VPC

Hours on overcharge	*Charge current, amps*		*Rise in charge current*	
	Lead calcium VRLA	*TPPL VRLA*	*Lead calcium VRLA*	*TPPL VRLA*
10	0.910	0.181	---	---
20	0.956	0.114	0.046A	0.067A drop
30	1.157	0.139	0.201A	0.025A
40	1.653	0.177	0.496A	0.038A
45	2.623	0.174	0.970A	0.003A
49.1	4.5	0.185	1.877A (test over)	0.011A
60		0.211		0.026A
80		0.218		0.007A
100		0.224		0.006A
150		0.351		0.127A
175		0.619		0.268A
200		1.860		1.241A
225		2.286		0.426A
250		2.383		0.097A
300		3.084		0.701A
350		3.746		0.662A
370.9		3.828		0.082A (test over)

ADDITIONAL CONSIDERATIONS FOR OUTDOOR VRLA APPLICATIONS

While the propensity to go into TR is an important consideration for batteries in outdoor applications, another performance feature deserves a closer look when evaluating VRLA batteries for these applications. This is the battery's float life at high temperatures, which for a typical lead-calcium VRLA battery is between 3 and 5 years at 77ºF (25ºC). A TPPL VRLA battery, on the other hand can have a float life as long as 12 years at 77ºF (25ºC). Accelerated float life testing of TPPL cylindrical VRLA cells at 176ºF (80ºC) has demonstrated an equivalent float life at 77ºF (25ºC) of over 15 years before its capacity dropped to 80% of its rated capacity.

Based on the two cities' average annual weather profiles[1], lead-calcium VRLA batteries may be expected to last about 3.7 years in Miami, FL and about 2.5 years in Phoenix, AZ in outdoor float applications. Under the same conditions TPPL VRLA batteries can be expected to last for 8.7 years in Miami and 6.2 years in Phoenix. Note that average temperatures should not be used to estimate expected float life.

CONCLUSIONS

The TR test results using a charge voltage of 2.65 VPC, summarized in Figures 1 through 4, clearly demonstrate the superiority of the TPPL VRLA battery for outdoor applications in uncontrolled temperature environments. The first TR test showed the significantly higher recombination efficiency of the TPPL battery (66% vs. 4%). This would make the TPPL VRLA less susceptible to going into a TR situation than a comparable lead-calcium VRLA battery. The second TR test confirmed the above hypothesis. A partially aged TPPL battery took over 15 days to go into TR whereas a similarly aged lead-calcium VRLA battery of the same amp-hour rating went into TR in just over 2 days.

In addition to better TR characteristics, TPPL VRLA batteries also offer superior high temperature float (standby) life. At high ambient temperatures the TPPL VRLA battery will deliver about twice the float life as a lead-calcium VRLA battery.

The laboratory results on the excellent TR characteristics of TPPL batteries presented in this paper are fully supported by empirical field data. TPPL batteries have been in harsh outdoor applications now for over 25 years, and to this author's knowledge, not one of these batteries has ever gone into thermal runaway.

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[1] Annual city weather data taken from www.city-data.com/city/Phoenix-Arizona.html and www.city-data.com/city/Miami-Florida.html