FLOODED (VLA), SEALED (VRLA), GEL, AGM TYPE, FLAT PLATE, TUBULAR PLATE: THE WHEN, WHERE, AND WHY.
HOW DOES THE END USER DECIDE ON THE BEST SOLUTION?

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INTRODUCTION

In today’s world market of stationary industrial batteries, we find a large variety of battery types. Interestingly, customers in Europe, North America, and Japan prefer different battery types: Tubular low antimony batteries in Europe, lead-calcium flat plate batteries in North America, low height AGM batteries in Japan. Customers and manufacturers are used to such types over the years, understanding their advantages and sometimes disadvantages. Today, the end user of lead-acid batteries has the choice to buy globally. In this regard, this paper will show comparisons of different battery types based on technical and commercial data, life time experience, and life time testing.

The intent is to show the differences of tubular and flat plate designs concerning performance data and endurance data, for both VRLA and VLA types.

While there are customers using VRLA batteries, based on space restrictions, ventilation requirements etc, many end users have returned to VLA (flooded) after being disappointed with the performance or operational life of their VRLA solution. What are the advantages and disadvantages of using VRLA and VLA systems?

Even if the preference is given to VRLA batteries, the questions arise: GEL or AGM? What is the difference in performance and endurance? Do the different wicking heights of AGM and GEL have consequences in performance? Why do we receive valuable information with impedance measurements on AGM batteries, but far less on GEL, and VLA batteries? Experiments clearly show whether AGM or GEL batteries have a higher tendency for thermal runaway effects.

It is the theme of this paper that, by knowing the differences of the battery types, the best choice for the specific end user application can be found.

For a short identification of the different battery types, the following DIN expressions are used in this paper:

OPzS .... VLA (flooded) tubular plate batteries
OPzV .... VRLA (sealed) tubular plate batteries
OGi .... VLA (flooded) flat plate batteries
OGiV .... VRLA (sealed) flat plate batteries

COMPARISON OF VLA BATTERIES IN TUBULAR AND FLAT PLATE DESIGN

The earliest commercially successful positive plate was the Planté plate, where the active mass is formed by a corrosion process out of the pure lead grid. This type is phasing out now, because it needs 80 – 110% more lead for the same capacity and more costly production procedures than flat, or tubular plate type batteries. The flat plate type, invented in 1881 by Faure and Volckmar, has a far better lead utilization and is used now in all lead acid batteries for the negative plates and in the majority also for the positive plates.

In 1910 the “iron-clad” or tubular plate was invented. The early realization was a series of slotted hard rubber tubes, then a woven glass-polyester gauntlet and, today, a woven polyester gauntlet fixed by acrylic resin. In all versions, the tubular design keeps the active material mechanically together and presses it onto the grid. During discharge and charge, the used active mass changes in volume from 1 to 1,83 and back. This volume change is mainly compensated by the high mass porosity of around 60%, but, to some extent, the mass structure expands and particles lose contact. Gas bubbles help to distribute the free particles in the cell. The tube with the circular cross section avoids swelling of the mass and keeps the structure together. Further the corrosion speed is reduced by the tubes, because pressing the PbO2 corrosion layer onto the grid surface helps to protect the lead grid against further corrosion. To get the advantages of tubular plates, a uniform mass density is required, which can be better established by the dry filling of red lead instead of paste filling based on grey oxide. The tubular grid needs no horizontal bars, which reduces lead weight and avoids growing of the grid in the width. The normal cross section of the tube is 8,0mm. This restricts the number of plates per cell and increases the inner resistance.

The advantage of the flat plate is the variability in thicknesses from 1mm up to 9mm. A design with thinner and correspondingly more grids has a reduced inner resistance and a better active mass utilisation. For stationary batteries of high power requirements, a grid thickness down to 2-3mm is used. For automotive batteries, with their high cranking power requirements, a grid thickness down to 0,8mm is used, but corrosion restricts their life to 4-5 years.

Performance data of VLA flat and tubular cells in a large and a small size

Table 1. Characteristic data of VLA flat and tubular batteries

	flat	tubular	flat	tubular
Type	18 OGi 1440	12 OPzS 1200	12 OGi 300	6 OPzS 300
C10, 25°C, 1,80V	1350Ah	1340Ah	310Ah	317Ah
Weight	102 kg, 224,7lb	88 kg, 193,8 lb	26,3 kg, 57,9 lb	23 kg, 50,7 lb
Size	L x W x H = 215 x 277 x 710 mm		L x W x H = 380/3 x 205 x 380	
Plates, thickness	18 pos. plates, 4,8mm	12 positive plates, 8,0mm	12 pos. plates, 3,4mm	6 pos. plates, 8,0mm
Inner resistance	0,125 mOhm	0,23 mOhm	0,7 mOhm	1,6 mOhm

We have chosen two pairs of flat and tubular cells of large capacity (1350Ah) and low capacity (310Ah). Each pair has the same dimensions. The flat plate battery is typically 15% heavier than the tubular. It has 50 to 100% more plates, which are thinner than the tubular plates. Consequently, the flat plate battery bears higher costs. The inner resistance is nearly half for the flat plate cells. It remarkably improves the high power discharges in the region from 10 min. to 30 min., as can be seen in Figure 1.

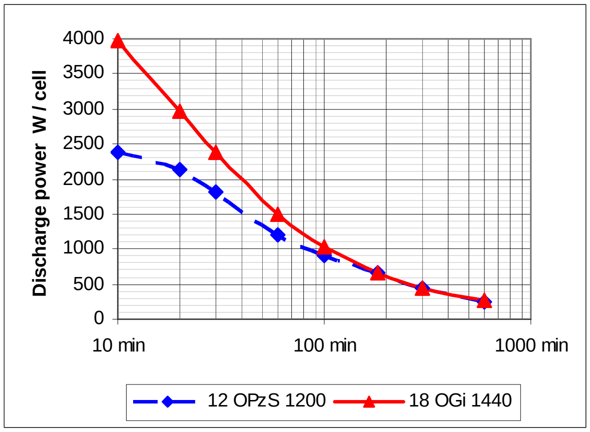


Figure 1. Discharge power per cell

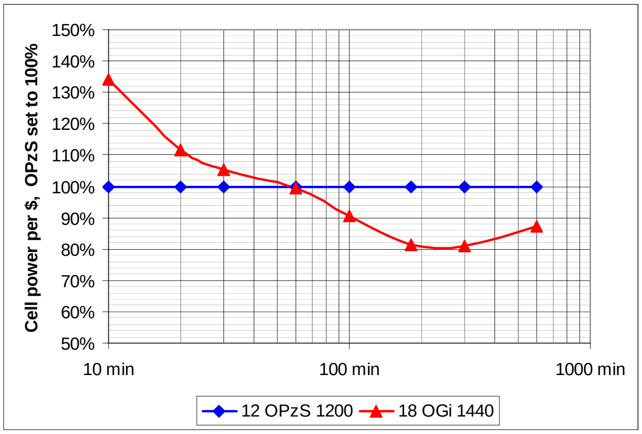


Figure 2. Cell power per cost

The discharge power at the 10 min. rate is 50% higher for the flat plate battery as the tubular. Even if we take the higher manufacturing costs into account, we get 30% more 10 min. power per $. The 60 min-rate is the crossover point. Then, between 200 and 300 min. (3h to 5h-rate), we get 20% more power per $ for the tubular cells. The results are similar for the smaller sizes (ca.310Ah). Speaking just from the performance data, it is more economical to use flat plate batteries of the above design for bridging times of 60 min. and shorter, while for bridging times of 1h and longer, tubular plate batteries are more economical.

Life time comparison of VLA flat and tubular plates

For nuclear power plants, lead acid batteries have to be qualified according to IEEE 535-1986. The qualification was made with vented as well as valve-regulated batteries. To simulate the required life time of 15 years at 23°C, the cells had to be floated at 62,8°C (145°F) and tested every 50 days the 3h-rate capacity at room temperature.

			
	OPzS vented	*OPzV* valve-regulated	*OGi* vented
type	tubular	tubular - GEL	flat
density float V	1,24g/ml 2,23V	1,24g/ml 2,25V	1,24g/ml 2,23V
samples	6 cells 200Ah	3 cells 200Ah	3 cells 480Ah
samples	6 cells 490Ah	3 cells 490Ah	3 cells 800Ah
samples	6 cells 2000Ah	3 cells 2000Ah	3 cells 1520Ah

Figure 3. Sample cells for lifetime and seismic tests

Figure 4. Heating chamber for the 62,8°C test

After 250 days at 62,8°C, the cell capacities were still well above 100%, so we did a real time history seismic and an airplane crash experiment with accelerations up to 12m/s²: There was no damage afterwards and capacities were unchanged.

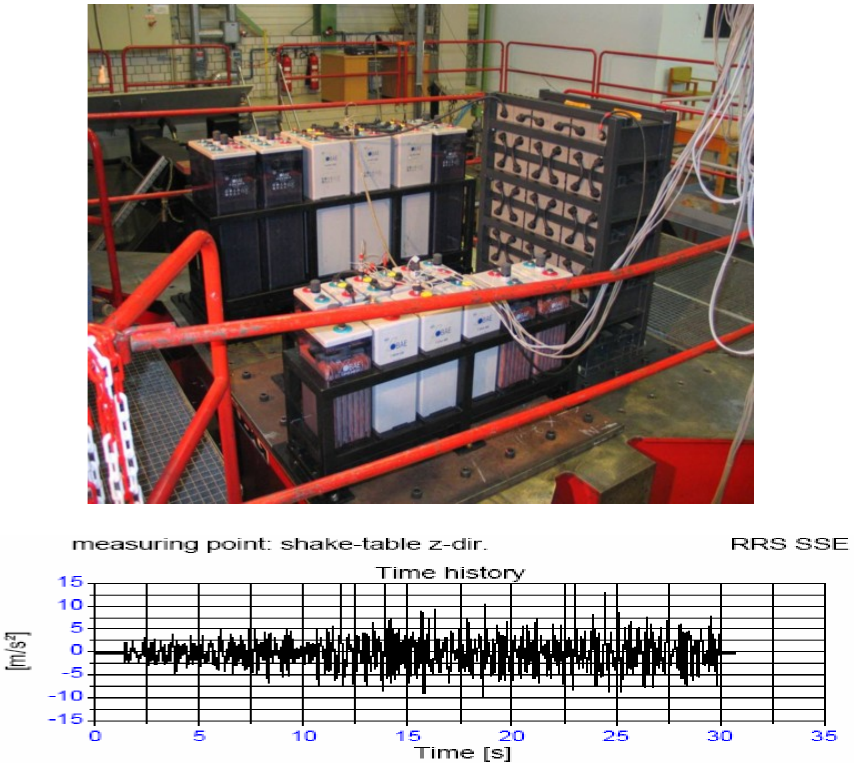


Figure 5. Seismic test with VLA tubular and VRLA tubular batteries

The capacities of the flat plate battery as well as the tubular plate battery were still above 100% after the seismic tests. Therefore, the lifetime test at 62,8°C was continued and finished after the cell's capacity started to decline.

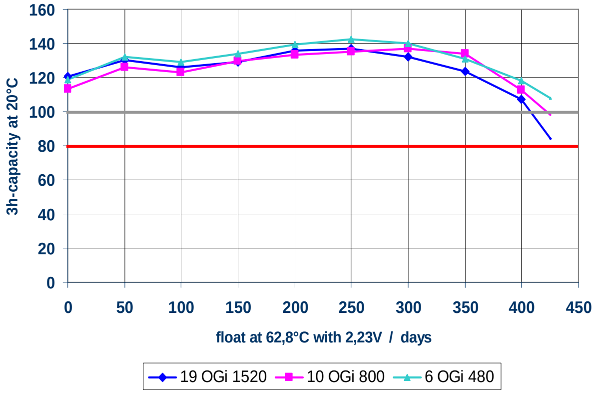


Figure 6. Life time test of flat plate batteries

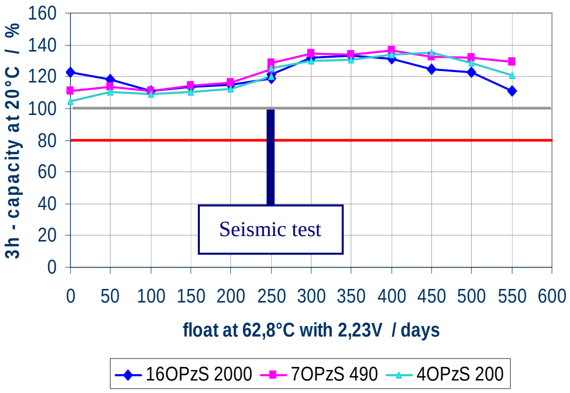


Figure 7. Life time test of tubular batteries

The IEEE 535-1986 requires 20 days at 62,8°C for one year at 25°C. The 425 days RE: Flat plate battery, corresponds to 425 / 20 days/year = 21,3 years at 25°C. The 550 days RE: Tubular battery was equivalent to 550 / 20 days/year = 27,5 years at 25°C.

Both batteries are qualified for a 20 year period. The tubular battery has a 30% longer service life. This is also confirmed by the float current measurements. For the tubular batteries, the float current at 2,23Vand 62,8°C doubled from 220mA/100Ah to 443mA/100Ah in 20 years, while the float current of the flat plate batteries tripled under these conditions from 193mA/100Ah to 567mA/100Ah, which allows in both cases a yearly watering period over the whole lifetime. In both cases, the low antimony alloy PbSb1.6Se0.04 has selenium as a grain refiner in it. The lower corrosion behaviour of the tubular batteries is due to the tubular design and also due to the different casting technique: The tubular grids are made with a 110 bar pressure unit, thus avoiding voids and cracks nearly completely.

The positive results of the accelerated lifetime test are confirmed in practice: In European central telecom stations, low antimony tubular plate batteries are normally 20 years or more in service, depending on the brand.

Cycle life experiments according to IEC 60 896-1 were made with both types. The results are summarized in the table below.

Table 2 Endurance data of VLA flat and tubular batteries

	Flat plate OGi	Tubular plate OPzS
On float with 2,23V at 62,8°C	425 days	550 days
IEEE 535-1986	21,3 years at 25°C	27,5 years at 25°C
	33 years at 20°C	42,7 years at 20°C
Float current increase in 20 years	Factor 2	Factor 3
Cycles according to IEC 60 896-1 80% DOD	1200	1800

COMPARISON OF VRLA AND VLA BATTERIES

Besides performance and endurance data, the VRLA batteries provide characteristics which may be of interest in some cases:

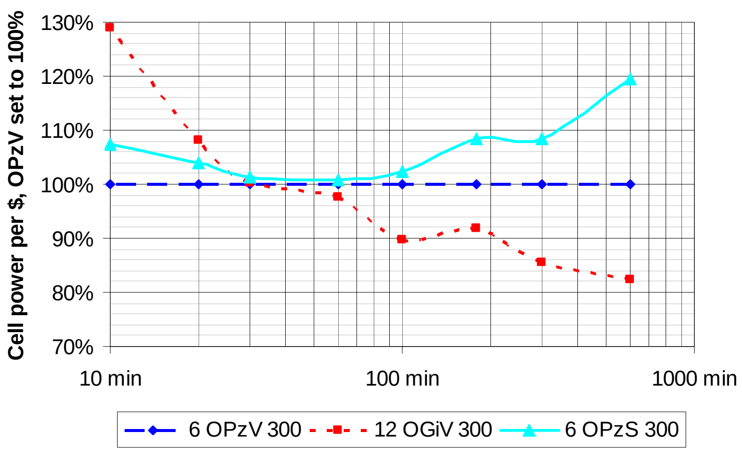
- The hydrogen gas evolution during float is reduced by a factor of 10. The ventilation of the battery room may be reduced by a factor of 5 according to the safety standard EN 50 272-2.
- No acid protection of the floor and other surfaces in the battery room is required. But acid bins underneath the VLA battery solves the request.
- Handling acid during density measurements is not required.
- Procurement of purified water and potential impurity problems are avoided.
- No cell failures, like short circuits between the plates, due to mud reduced to lead (“mossing”).

Other characteristics of VRLA designs bear significant disadvantages:

- Oxygen ingress through leakages in the container, lid or pole bushing discharges the negative plate.
- The polarization of the negative plate is reduced due to oxygen recombination on the negative plate. In unfavourable cell designs, the negative polarisation is lost and the negative plate discharges (PCL 3 effect), although the float voltage is above open-circuit.
- To avoid drying out, the maximum operation temperature is reduced from 55°C to 45°C.
- VRLA cells do not allow the same inspection possibilities such as acid density measurements and visual inspection, so the awareness of a full functioning battery is reduced.

Performance comparison

Here we refer to the VRLA GEL design. In the next section, we will compare VRLA GEL with VRLA AGM.
We use VRLA batteries in the 310Ah region having the same size as the small VLA batteries in Table 1. So we can easily compare the performance data.

<table>
<tr><th colspan="4">Table 3 Characteristic data of VRLA flat and tubular batteries, and VLA tubular batteries</th></tr>
<tr><td rowspan="7"> </td><td></td><td>flat</td><td>tubular</td></tr>
<tr><td>Type</td><td>12 OGiV 300</td><td>6 OPzV 300</td></tr>
<tr><td>C10, 25°C, 1,80V</td><td>308Ah</td><td>326Ah</td></tr>
<tr><td>Weight</td><td>28,3 kg, 62,3 lb</td><td>23,3 kg, 51,3 lb</td></tr>
<tr><td>Size</td><td colspan="2">L x W x H = 380/3 x 205 x 380</td></tr>
<tr><td>Plates, thickness</td><td>12 pos. plates, 3,2mm</td><td>6 pos. plates, 8,4mm</td></tr>
<tr><td>Inner resistance</td><td>0,8 mOhm</td><td>1,8 mOhm</td></tr>
</table>

The VRLA flat plate design (OGiV) has the same characteristics as the VLA flat plate design. They are preferable for short bridging times. At the 10 min-rate, the power output per manufacturing cost is 30% higher than of the VRLA tubular design (OPzV), while at longer discharge times – here already above 30min – the tubular OPzV design gives more power per $. At the 3h-rate, the OPzV gives 15% higher power per $. In the graph of Table 3, we also have included the OPzS (see table 1) performance data per $ related to the OPzV. We see that, in the region from 3h to 10h, the OPzS gives 10 to 20% more power per $ than the OPzV battery, while in the important region between 30 min and 100 min, VLA tubular (OPzS) gives the same power per $ as VRLA tubular (OPzV).

Now the question arises: How are the endurance data of the VRLA tubular GEL?

Endurance data of VRLA tubular GEL

The lifetime test, according to IEEE 535-1986, was made with the VRLA tubular (OPzV) in parallel to OPzS and OGi, as already documented in Figure 3 and 5. After 250 days at 62,8°C under float at 2,25V/cell, the seismic and airplane crash test was successfully done. In total, the accumulated test time was 450 days in average for the VRLA tubular GEL. This corresponds to a life of 450/20 = 22,5 years at 25°C or 35 years at 20°C. The float current was initially 177mA/100Ah; it even reduced to 130mA/100Ah after 20 years float. No sign of thermal runaway could be detected. No extra watering during the test was necessary. No restriction of the current was made.

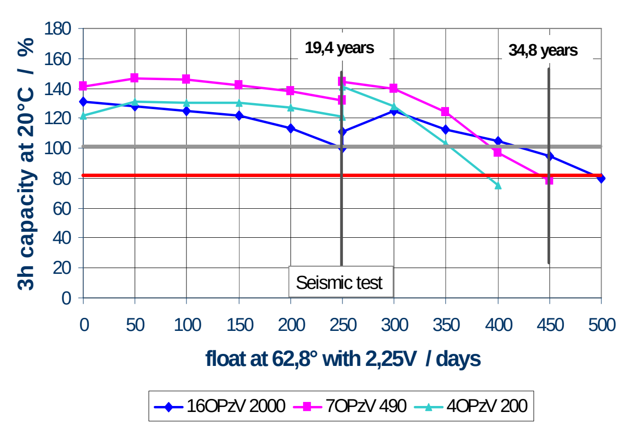


Figure 8. Accelerated life time test of VRLA tubular GEL batteries

It was interesting to see that the capacity was higher after the seismic test. It is due to extra charging and the extra cycle we did. Apparently, the float charge with 2,25V at 62,8°C could not keep both electrodes in a charged condition. Only at higher voltage could we completely charge them. Analysing the lead sulphate content in the positive and negative plates, we observed after 450 days at 62,8°C, 8,4% $PbSO_4$ in the negative and less then 2% in the positive, confirming, that the negative plate was not sufficiently polarized.

First, this tells us that, in normal battery operation, we should not float charge the VRLA GEL at 62,8°C. In the Operating Manual, the battery temperature is restricted to 45°C and requires a float charge voltage of 2,25V/cell from 10°C to 45°C. To keep the full charge at higher temperatures, we would have to ***increase*** the float voltage. Today, a lot of battery manufacturers require a float voltage reduction at higher temperatures. It is the wrong direction and it makes the PCL 3, the premature capacity loss, the sulphation of the negative plate more likely (Ref. 1 and 2).

To achieve a long service life, VRLA batteries need a polarization of the negative plate. This can be achieved, if the materials in the cell are avoided, which reduce the hydrogen over voltage.

Did the growth of the positive plates and the poles restrict the life? No. A considerable growth was observed of 3 - 14mm for OPzS, OPzV as well as OGi at the end of the test, but the pole bushing tolerated it and remained acid- and gas-tight.

And how is the cycle life of the VRLA tubular GEL in comparison to VLA tubular? The test was done according to IEC 60 896-2 on 6 cells 6 OPzV 420: 3h discharge with 84A and 21h charge at 2,40V during 6/1999 till 12/2004. After 1500 cycles, the capacity was still 100%.

Table 4 Endurance data of VRLA tubular GEL and VLA tubular

	VRLA tubular GEL OPzV	VLA tubular OPzS
On float with 2,23V at 62,8°C	450 days	550 days
IEEE 535-1986	22,5 years at 25°C	27,5 years at 15°C
	35 years at 20°C	42,7 years at 20°C
Cycles according to IEC 60 896-1, 2 80% DOD	> 1700	> 1700

Apparently, the endurance time during float of VRLA tubular GEL is excellent, positioned between VLA tubular and VLA flat plate types. Leaking, drying out, and special corrosion at negative grids, etc. are apparently overcome, so that the true lifetime restriction, dependent on the corrosion of the positive grid is present.

The VRLA tubular GEL battery has a similar cycle life as the VLA tubular, which qualifies it for photovoltaic applications.

COMPARISON OF VRLA GEL AND VRLA AGM

The oxygen developed on the positive plate during overcharge or float charge escapes out of the cell in VLA batteries and causes water loss. In VRLA batteries, the oxygen migrates to the negative plate, recombines there with the ionic (H^+) and electronic (e^-) current to water, which diffuses back to the positive plate. The recombination to water depolarizes the negative potential and causes a reduction of hydrogen evolution by a factor of ten. The recombination process must carry a current of 2-3 A/100Ah to be able to full charge a battery in reasonable time and to avoid an oxygen escape through the valve at higher pressure. This high current of 2-3A/100Ah requires a transport of 400 – 600cm³/h oxygen from the positive to the negative plates. This is only possible if, between the plates, gas voids are present, where the oxygen can flow through. On the other hand, the VRLA system needs a good ionic contact for all charging and discharging processes between the plates. The realization of the two phase system is made for VRLA GEL and for VRLA AGM in a different way.

In the AGM system, a glass fibre structure attracts the diluted acid via surface tension and leaves appr. 5% of the space open for the oxygen transfer. The pores in the SiO2 fibre structure are in average 5µ. The AGM separator is partially elastic to keep the ionic contact between the plates at expansion and contraction of the active masses during discharging and charging.

The GEL system incorporates the acid and water molecules in the molecular chains of the pyrogenic silica. Their “pores” are smaller then 0,5µ. Pores in the GEL with a size of at least 10 times smaller than in the AGM system attract the diluted acid very much higher, causing a lot of different characteristics as listed below. The oxygen transfer happens through cracks in the GEL. Further a microporous separator is needed for giving support to the plates.

Differences in battery characteristics:

- The height of AGM cells is restricted to plate heights of ca. 300mm. At larger heights, we get acid stratification due to the lower acid attraction or wicking height of the AGM separator. GEL, with its small pores, doesn't have such height restriction. GEL cells with plate heights of 1000mm for submarine cells were already realized.
- The tubular design is easier to realize with GEL system.
- GEL systems have higher inner resistance because of the extra microporous separator.
- GEL systems have higher costs due to the extra microporous separator.
- The stability against deep discharges is better in GEL systems, because of the extra microporous separator.
- The dry-out process reduces the capacity over life more rapidly in AGM systems then in GEL systems. In all VRLA systems, we have some hydrogen evolution, which reduces water or liquid in the cell. Keeping in mind that the pores in the positive mass are in average 0,1µ and in the negative mass 0,3µ, the GEL provides pores of the same size, while the AGM pores (ca. 5µ) are ten times as large. The smaller pores of the active mass attract the acid more than the larger pores, with the consequence that the AGM separator loses more liquid (acid) than the GEL separation. Less liquid in the AGM results in shrinkage during life. The shrinkage of the AGM separator reduces the ionic contact of the plates, which increases the inner resistance and reduces the capacity especially at high currents. No question that this is the reason why impedance measuring systems provide a better lifetime prediction for AGM cells as for GEL or VLA cells.
- Cycle life is better in GEL cells, because the higher acid attraction of the GEL cells avoids acid stratification.
- The thermal run-away tendency is very much lower in GEL cells, because the recombination current is restricted (Ref. 3).

We can summarize this information in the spider diagram of Figure 9.

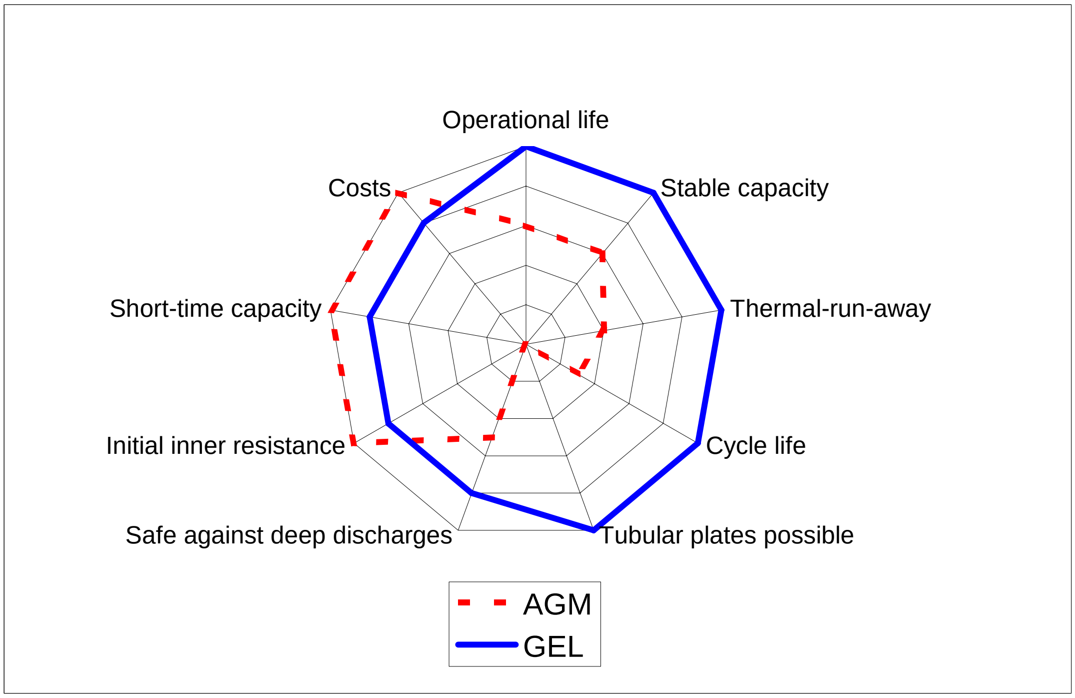


Figure 9. Characteristics of VRLA AGM versus VRLA GEL

CONCLUSION

We try to give here proposals to application engineers as to which battery type fits best to customer requirements, based on the information presented in this paper.

For electrical systems of a very high safety level, like utilities, bank data centers, military or security applications, the VLA types have advantages versus the VRLA types. Visual inspection and gravity readings give more safety. For bridging times or peak current requirements of 60min or shorter, the VLA flat plate batteries provide a better power-per $ ratio. For bridging times of more than 60 min, the VLA tubular is the preferred choice.

In systems where the advantages of VRLA systems count, we see the AGM type in front for UPS applications, as far as bridging times of 60 min and lower are required and where life time expectations are limited, because the technical innovation requires a new power supply in the next 5 to 10 years anyway.

If the electrical system has an expected usage of 10 to 20 years, VRLA GEL batteries should be preferred: VRLA GEL tubular plate batteries for discharge times of 60 min and longer and VRLA GEL flat plate batteries for 30min and shorter.

For solar applications, maintenance-free batteries with very high cycle life are required. Here, the VRLA tubular GEL is the best choice.

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