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SAFETY INFORMATION NOTICE

No. 2 of 2019

Batteries for Racing Yachts

Issue:

Batteries used in racing yachts come in various forms. The Special Regulations do not provide any guidance on batteries other than specifying in SR 3.26 that they must be a sealed type.

Notice:

The Current Battery Landscape

Batteries used in yachts for engine and house power are currently available in various forms;

- Flooded lead acid batteries
- Sealed Lead Acid or Valve Regulated Lead Acid batteries
- Absorbed Glass Mat batteries
- Gel batteries
- Lithium Ion batteries

1. Flooded Lead Acid batteries

These batteries use lead and lead oxide electrodes immersed in a sulphuric acid electrolyte. They have traditionally been the workhorse for automotive and marine use but have now largely been superseded by sealed versions. Flooded lead acid batteries are prohibited for Race Categories 1,2 and 3

2. Sealed Lead Acid (SLA) or Valve Regulated Batteries (VRLA)

These batteries are a variant of the flooded type but are maintenance-free, leak-proof, ostensibly position insensitive and have a safety vent to release gas in case of excessive internal pressure build up during charging.

3. Absorbed Glass Mat Batteries

Absorbed Glass Mat refers to a specific variant of SLA/VRLA where the electrolyte is absorbed into separators between the plates consisting of sponge like fine glass fibre mats such that the electrolyte is largely immobilised and so the operation of the battery becomes position insensitive.

4. Gel Batteries

A gel battery is a VRLA battery with a modified electrolyte; the sulphuric acid is mixed with fumed silica, which makes the resulting mass gel-like and immobile. Unlike a flooded wet-cell lead-acid battery, these batteries also do not need to be kept upright.

5. Lithium Ion Batteries

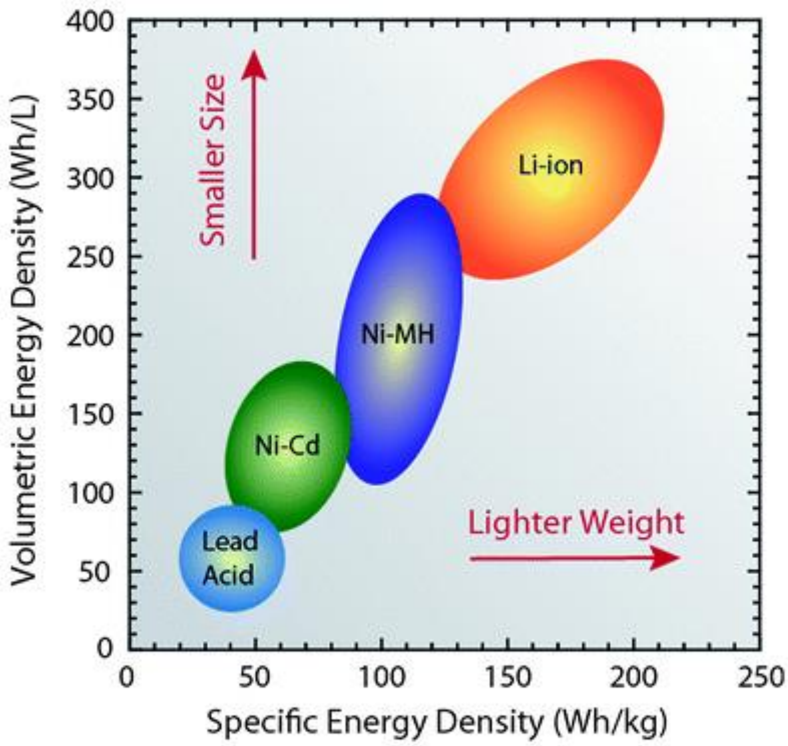
Lithium ion batteries, like its alternatives, are also composed of a cathode, anode, electrolyte, a separator and employ a variety of chemistries. Cathode materials include lithium iron phosphate ($LiFePO_4$), lithium manganese oxide ($LiMn_2O_4$), Lithium cobalt oxide ($LiCoO_2$), lithium nickel cobalt manganese oxide (also known as "NMC") ($LiNiMnCoO_2$), lithium nickel cobalt aluminium oxide ($LiNiCoAlO_2$), and lithium titanate. The anode material is typically graphite. Separators are typically microporous polypropylene or polyethylene film and the electrolyte is typically lithium hexafluorophosphate ($LiPF_6$) in ethylene carbonate. The lithium iron phosphate and NMC chemistries seem to be the most popular. It is important to point out that these batteries do not contain the very reactive lithium metal, only lithium salts.

1. <u>The Allure of Lithium Ion Batteries</u>

For ocean-going yachts, gel or AGM batteries have been the preferred option and, operated correctly, perform well. However, they do have some significant limitations that are effectively addressed by the ongoing developments in Li Ion technology.

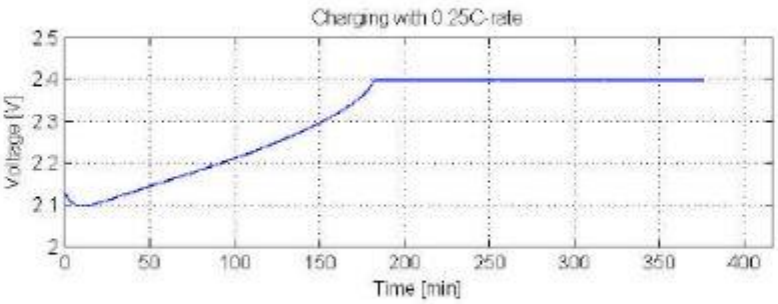
a. Energy Storage

Li Ion batteries are way more efficient at storing energy in a given volume or for a given battery weight compared to all other technologies and by a significant margin.

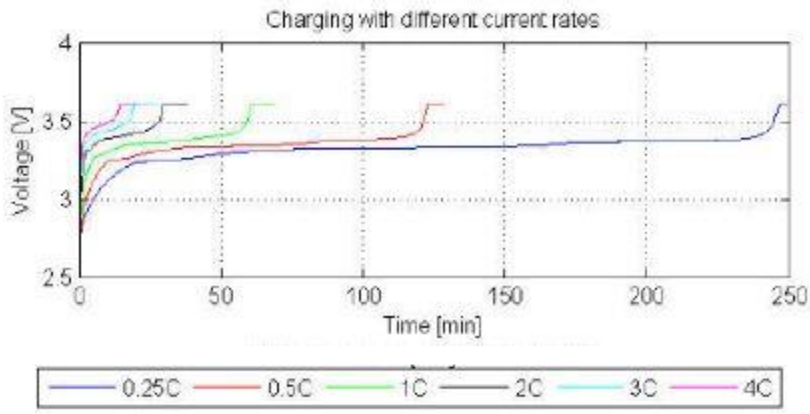


b. Charging

VRLA batteries are limited in how quickly they can be charged and is generally limited to a maximum 0.25C for flooded battery (that is a charging rate of 25 amps for a 100Ah battery), though can be higher for AGM batteries. At this same charge rate, Li ion batteries, controlled properly, reach full charge much faster. However, the conditions under which a VRLA battery can be charged are quite forgiving whereas the Li Ion batteries need to be carefully controlled (see below). There are some nuances between the optimum charging regimes between the various forms of lead acid batteries, but these differences are more to do with obtaining the best performance and lifetimes from the batteries rather than safety issues so will not be dealt with here



Charging of an AGM battery

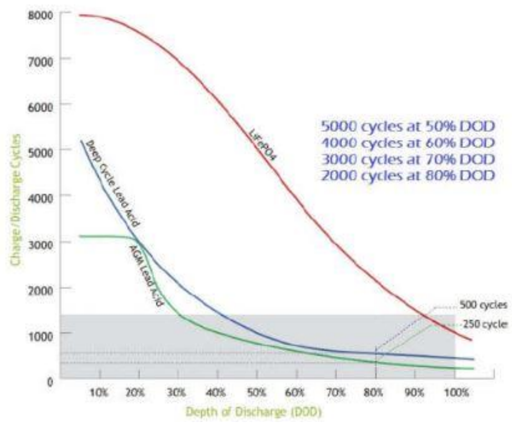


Charging of an Li Ion Battery

Note that for the same charge rate (0.25C), the Li Ion battery reaches full voltage in about 1/3 of the time of the VRLA battery.

c. Depth of Discharge (DOD)

Starting from a fully charged state, any battery will have a longer lifetime the less it is discharged before charging is recommenced. In this regard, Li Ion technologies outperform all other battery options by significant margin.



An AGM battery is best operated at not more than 50% DOD while a Li Ion battery can be run to 80% DOD and the Li Ion batteries are able to be cycled many times more than VRLA batteries.

So, in summary, a Li Ion battery allows a given amount of energy to be stored in a significantly smaller volume, weighs much less for the same amount of stored energy, can be charged faster, discharged to a higher level and will do so over many more cycles compared to traditional lead acid equivalents.

1. <u>And the Bad News?</u>

a. Cost

Though Li Ion battery costs continue to fall, their initial cost is significantly higher that other technologies and is enough to dissuade their purchase in spite of their clear advantages. Only those who really value or need the weight savings and higher electrical performance will likely be prepared to make the significant up-front investment. However, after considering the total lifetime cost of ownership, given the higher discharge levels possible and the significantly higher number of available cycles, the financial picture moves well towards the Li Ion battery and it may well win. Prices will continue to fall as the use of Li Ion batteries in electric cars and solar storage systems continue to increase.

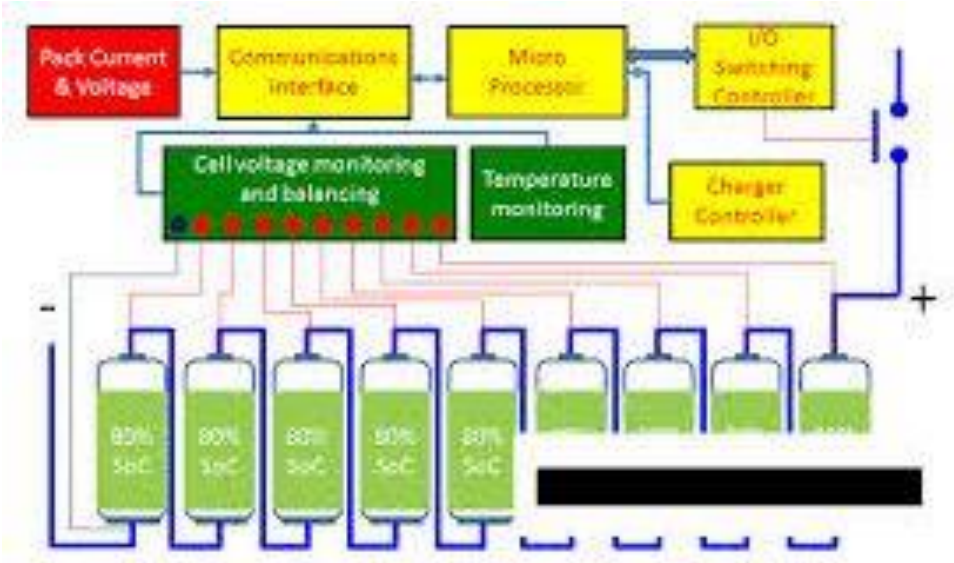
b. Safety

This is the area that has attracted plenty of media attention of late due to some impressive failures. So what are the problems and how are they managed?

- Thermal Runaway: If one individual cell gets hot from overcharging or over discharging it initiates a process of self-heating, which then causes the cell temperature to continue to rise, even if the charge/discharge process is stopped. If a single cell overheats, it may overheat an adjacent cell, which overheats the next cell and so on. This is called thermal runaway, and once begun it is very difficult to stop. Pressure builds up within the cell; the case may swell, rupture or explode, releasing highly flammable gases and electrolyte. Both lead-acid and lithium-ion cells are capable of going into thermal runaway, but the likelihood and consequences of this happening are higher for lithium as it has a greater amount of energy confined to a smaller volume.

- Battery Design: Li ion batteries have safety features built into the battery itself, plus additional circuitry to protect the battery during operation and charging. Individual cells in the battery pack are required to have: shut-down separators, a thin porous membrane the separates the anode from the cathode to prevent thermal runaway; a tear-away tab that shuts down the cell if internal pressure increases; a vent to relieve internal cell pressure; and a thermal interrupt which shuts the cell down should an overcurrent or overcharge occur.

- Battery Management System (BMS): The BMS is essentially the brains of the battery system. Its primary purpose is to protect the battery by preventing any cell (cells can charge differently) from operating outside of its safe operating limits. Secondarily, but also importantly, it maximizes battery performance. It does this by monitoring the state of the battery pack, as represented by voltage at various points, current in or out and temperatures. The BMS also calculates necessary data, such as state of charge or depth of discharge, maximum charge current limit, maximum discharge current etc.



- Fire Hazard: Battery management systems can fail and fires are then possible. A Li Ion battery is considered a Class B fire so the existing extinguishers as currently required in the SR's are sufficient. There is no Li Metal involved (only Li salts) which would have necessitated a Class D extinguisher. However, most Li Ion chemistries use lithium hexafluorophosphate as part of the electrolyte system and during a fire this can produce hydrogen fluoride which is very corrosive and toxic to humans.

2. <u>Conclusions</u>

- Li Ion batteries do offer significant performance advantages over other battery technologies such that despite their high initial cost deployment on racing yachts is to be expected and installed properly there is no technical reason to limit their use. With the ubiquitous use of Li Ion technology in electric car and solar energy storage applications, the cost of Li ion batteries should continue to reduce.
- The key to safe operation of a Li Ion battery system is that the batteries be made by a reputable source, installed by an appropriately qualified person, and a fully integrated battery management system be used to control both the safe charging and discharging of the batteries.
- Sailors should be made aware of the increased risk of fire and the potential for release of toxic chemicals at that time.
- A good overall summary of the various battery technologies is given in the table below (a bit technical maybe but included it here for reference).

Specifications	Lead Acid	NiCd	NiMH	Li-ion[1] Cobalt	Manganese	Phosphate
Specific energy (Wh/kg)	30–50	45–80	60–120	150–250	100–150	90–120
Internal resistance	Very Low	Very low	Low	Moderate	Low	Very low
Cycle life[2] (80% DoD)	200–300	1,000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Charge time[4]	8–16h	1–2h	2–4h	2–4h	1–2h	1–2h
Overcharge tolerance	High	Moderate	Low	Low. No trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<5% Protection circuit consumes 3%/month		
Cell voltage (nominal)	2V	1.2V[6]	1.2V[6]	3.6V[7]	3.7V[7]	3.2–3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20 typical Some go to higher V		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75V	1.00V		2.50–3.00V		2.50V
Peak load current Best result	5C[8] 0.2C	20C 1C	5C 0.5C	2C <1C	>30C <10C	>30C <10C
Charge temperature	–20 to 50°C (–4 to 122°F)	0 to 45°C (32 to 113°F)		0 to 45°C[9] (32 to 113°F)		
Discharge temperature	–20 to 50°C (–4 to 122°F)	–20 to 65°C (–4 to 49°F)		–20 to 60°C (–4 to 140°F)		
Maintenance requirement	3–6 months[10] (toping chg.)	Full discharge every 90 days when in full use		Maintenance-free		
Safety requirements	Thermally stable	Thermally stable, fuse protection		Protection circuit mandatory[11]		
In use since	Late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		
Coulombic efficiency[12]	~90%	~70% slow charge ~90% fast charge		99%		
Cost	Low	Moderate		High[13]		