Sailing with Li-Ion batteries: Performance-Merit-Safety

By: Frederic Cosandey

Li-Ion batteries can be found everywhere in our everyday life but their use on sailboats is still lacking. There are two main reasons for their low acceptance by sailors which are their perceived high cost and safety. In this article, the performance, merits, and safety of Li-ion batteries are discussed, and the steps taken by the battery manufacturing industry to ensure that Li-Ion batteries are as safe as lead acid batteries are presented.

Design and Performance: The development of Li-Ion batteries in the 80's has revolutionized the field of energy storage, a unique achievement for which its inventors: Whittingham, Goodenough, and Yoshino received in 2019 the Nobel Prize in chemistry. Li-ion batteries are now in use almost exclusively in all portable electronic as well as in electric vehicles. By comparison, the lead acid battery is a much older technology originally invented by Gaston Planté in 1860. For applications where weight and compactness are not an issue, lead acid batteries remain very popular because they are cheap and have good reliability. Almost all sailboats, new or used, are equipped with lead acid batteries despite the overwhelming superiority of Li-Ion batteries. This superiority covers pretty much every aspect of battery performance including power density (Wh/kg) (1/4 the weight for the same power), cyclability (3000 versus 500 cycles), charging rate (5 times faster), usable capacity (80% vs 50%), constant power delivery (constant voltage during discharge) and better charge retention (<2% self-discharge per month).

A schematic design of the original Li-Ion battery is depicted in Figure 1. It consists of a graphitic carbon anode and a $LiCoO_2$ cathode separated by a liquid electrolyte. A commonly used electrolyte is $LiPF_6$ which allows conduction of the Li-ion but not the electron. During charge and discharge cycles, the Li^+ ions shuttle back and forth between the cathode and the anode, with the electron traveling on the outside closing the circuit and powering the boat electronics.

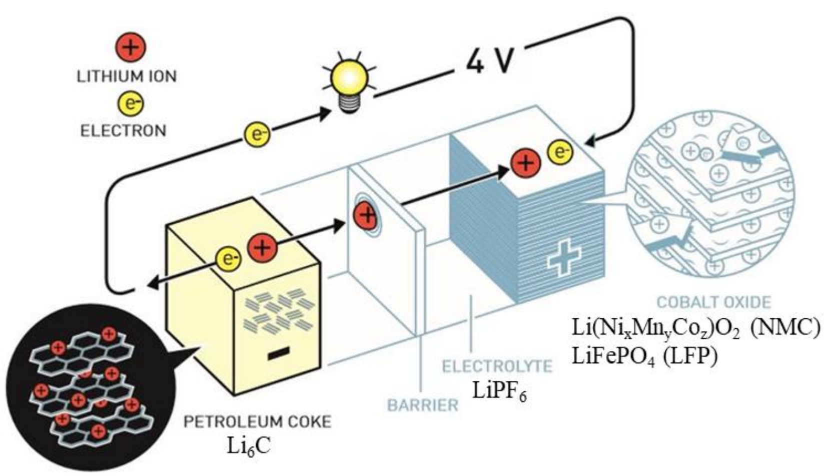

Figure 1. Schematic design of the original Li-Ion battery. (Reference 1)

It is a simple design that took years to develop. The Nobel committee noted that the inventors had developed the world's most powerful battery. The power density of Li-Ion batteries is more than four times that of lead acid batteries packed in a volume that is six time smaller. The power delivery is also remarkable as shown in Figure 2. For lead acid batteries, the voltage decreases during discharge while it remains constant for Li-Ion batteries up to 80% of discharge. By comparison, only about 50% of the nominal energy of lead acid batteries is usable. This larger usable energy of Li-Ion battery means that a 300Ah 12V lead acid battery bank can be replaced by a 200 Ah 12V Li-ion battery bank with a weight one quarter that of lead acid.

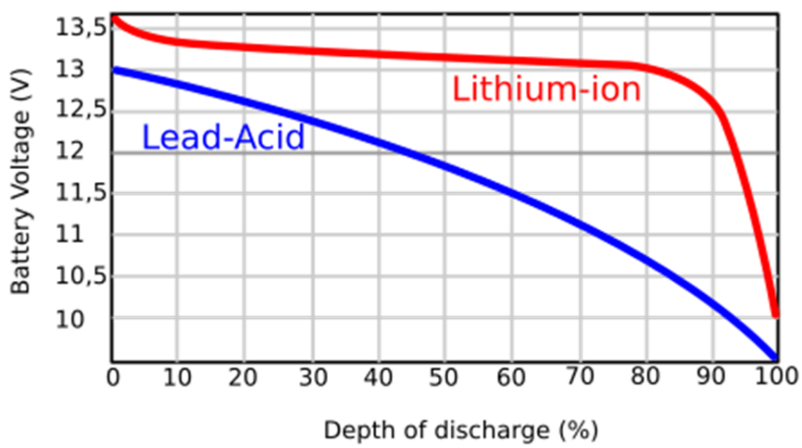

Figure 2. Comparison between LFP lithium-ion versus lead acid battery voltage as a function of depth of discharge. (Reference 2)

Safety is a big concern on a sailboat as in the case of fire, it is not possible to just walk away and instead requires an elaborate action plan. Furthermore, the electrolyte in Li-Ion batteries is flammable and does not need oxygen in the air to burn as the oxygen comes from the thermal decomposition of the cathode. Once started, a battery fire cannot be extinguished! It will keep burning until all the flammable materials inside the battery are consumed. In addition to fire, the fumes contain fluoride type gases, including HF which are highly toxic.

However, there are two existing ways to eliminate the risks of fire. This can be done firstly within the battery itself by choosing the safest cathode chemistry and secondly via a battery management system (BMS)

Cathode Chemistry: Safety is directly related to the thermal stability of the cathode since it is where the oxygen comes from in a battery fire. There are basically two types of material chemistries for the cathode that are used commercially: NMC and LFP. The first one, NMC, with a composition $Li(Ni_xMn_yCo_z)O_2$, is an enhanced version of the original $LiCoO_2$ cathode which has been optimized with the substitution of some Co by Ni and Mn. NMC cathodes have the highest energy density and are used almost exclusively for portable electronics and electric vehicles in order to pack the maximum amount of energy in the smallest volume as possible. The second chemistry, LFP with a composition $LiFePO_4$ has a lower energy density by 20 % than NMC. However, LFP is the most stable compound with a much better thermal stability than NMC because the four O atoms are strongly bonded with P. LFP is thermally stable up to 400 ^{o}C while NMC starts to decompose above 150 ^{o}C.

There have been a few spectacular fires of Li-Ion batteries that have circulated widely in the press such as Samsung notebook, Tesla car and a LG Chem storage facility that have caused some concerns, but it is vital to recognize that these industries all used the less thermally stable NMC Li-ion batteries. The safer Li-Ion batteries with LFP cathode chemistry are used exclusively for sailboats where safety and thermal stability is more critical than the ultimate energy density.

Battery management system (BMS): All Li-Ion batteries have a battery management system which is located either externally or built within the battery. The BMS system has many functions: to balance and equilibrate the charging of the individual cells, to protect the battery in the eventuality of an internal or external short circuit and finally to protect the battery in case of internal overheating or extreme low temperatures. Some advanced BMS systems might additionally have high and low voltage relays to prevent complete discharge and overcharging with voltages exceeding 15V for a 12V battery. The addition of external voltage relays is not required but is another protection in case the voltage regulator goes bust or is not part of the BMS system.

Cost: With respect to cost, Li-Ion batteries are now in a par with lead acid batteries if longevity and cycle life are considered. Over 15 years ago, a typical LFP Li-Ion battery did cost over 10 times that of a lead acid battery. However, this is no longer the case as prices have now come down dramatically with increasing demand. At the present time, an LFP Li-Ion battery with built in BMS, Bluetooth and a 10-year warranty ranges between $ 600 to $900 for a 12V 100Ah battery which is only 2-3 times that of sealed lead acid batteries.

In conclusion: I would like to propose a few recommendations for sailors, race committees and insurance companies.

For sailors, I will say: switch to Li-Ion batteries with $LiFePO_4$ (LFP) cathode chemistry as lead should be used for the keel only. It is a worthwhile long-term investment that save weight and will be cheaper in the long run. The Li-Ion battery is maintenance free, and you will have the satisfaction of owning the best energy storage system available today.

For race committees and insurance companies, I will say: do not impose restrictive rules as LFP Li-Ion batteries are as safe as sealed lead acid batteries. To guaranty safety, simply recommend that the Li-Ion battery should have the LFP cathode chemistry. All types of fire extinguishers as well as water can be used to cool down the fire and to prevent the fire from burning adjacent structures. What is already recommended for offshore sailing such as ABC type fire extinguisher and fire blanket, is sufficient.

References:

1. https://www.nobelprize.org/prizes/chemistry/2019/popular-information/
2. https://www.thepilotgroup.co.uk/lithium-ion-battery-vs-lead-acid-battery/

Frederic Cosandey is an offshore sailor with numerous Newport to Bermuda and Bermuda 1-2 races to his credit. He has sailed happily for the last 15 years with LFP Li-Ion batteries. He is also an Emeritus Professor of Materials Science with over 20 years of research experience in Li-ion batteries.

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