A BRIEF APPRAISAL OF THE USE OF LI-ION BATTERIES IN HYPERBARIC CHAMBERS
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Li-ion batteries have become the standard for powering most battery-powered portable devices. While accidents are reported regularly, incidents are rare considering there are an estimated 5 billion people[1] carrying a mobile device with a li-ion battery. Through an understanding the risks and following the recommendations provided by both the industry and the original equipment manufacturers (OEMs), these can be considered as 'extremely' safe.

The period of highest risk occurs during re-charging and it is essential that this not be done during hyperbaric operations. Disposable Li-ion batteries are thus safer and more suitable for use; hence they are not the point of focus in this review. The use of any powered device in an oxygen-enriched operating environment, where oxygen is intentionally meant to be above 23.5[2], should only be considered where batteries are contained in intrinsically-safe, sealed housings.

This brief summary of the hazards and recommended practices will assist in assessing and mitigating many of the concerns associated with the use of rechargeable Li-ion battery powered devices in a hyperbaric chamber.

(a) Li-ion batteries can rupture, ignite or explode when exposed to high temperatures (above 140°F/60°C) and even just prolonged exposure to direct sunlight. Heat combined with humidity may stress and cause permanent damage. Many multiplace chamber environments get very hot during compression of the chamber; and some of these chamber environments are humid.

(b) Degradation and irreversible damage when charged at below 0°F/-18°C can lead to thermal runaway when in sue.

(c) Short-circuiting a Li-ion battery can cause it to ignite or explode – this may be caused by a loss of conductor insulation, incorrect installation and storage, moisture ingress and certainly submersion in water, as well as through normal equipment failure. To mitigate this, manufacturers may include several safety features in their products, including vents to release any gases built-up inside the battery containment, power-flow regulators, temperature monitors and fuses. Activation of a multiplace chamber fire suppression system can cause ingress of water into a device, hence the requirement to simultaneously deactivate all electrical equipment not designed to withstand flooding.

(d) Mechanical damage caused by dropping the device or any other impact, rough handling when installing or removing batteries, and potentially the increased external pressure during a hyperbaric session can rupture the inner separator causing an internal short-circuit.

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[1] Rydberg, J; Li-ion battery safety

[2] ASTM G 88-90; CGA G-4.1, CGA P-45-2018; NFPA 99 et al.

(e) Any attempt to open or modify a Li-ion battery's casing (to vent or allow it to vent safely in the hyperbaric chamber) is dangerous – this may negate the safety features that protect the internal cells from damage, which can cause the battery to ignite or explode.

(f) Liquid-based electrolytes in a Li-ion battery all contain some form of lithium salt in an organic solvent, which is classified as flammable. All that is required is sufficient heat to cause ignition. The presence of elevated oxygen levels, either in terms of concentration (percentage or ppm) or partial pressure, will ensure even higher combustion rates and temperatures.

(g) The period of highest risk occurs during re-charging of batteries and battery packs. Device manufacturers frequently design their chargers to prevent overcharging and this requires carefully determining the optimum voltage and then preventing further charging. These systems are not fool-proof and batteries can still be damaged during this vulnerable stage - another reason to prohibit recharging during any hyperbaric exposure. Non-OEM chargers are discouraged from being used.

Additional causes that have led to failures: these lessons have already been learned:

(a) Contaminants inside the cells can override these safety devices and this was the reported cause in mid-2006 where Sony recalled several million batteries used in Dell, Sony, Apple, IBM, Toshiba, Fujitsu and other laptops.

The reason given was the consequence of internal contamination with metal particles. Under some circumstances, these can pierce the separator, causing the cell to short, rapidly converting all of the energy in the cell to heat resulting in an exothermic "oxidizing" reaction, increasing the temperature to hundreds of degrees in a fraction of a second.

This causes the neighbouring cells to heat up rapidly, causing a chain thermal reaction.

Quality control is thus essential during the production of all Li-ion batteries.

(b) Sony were not the only ones to recall batteries although probably the largest recall to date. There have been several recalls of Li-ion batteries in cell phones and laptops owing to overheating problems during periods of intense working of the devices. Kyocera (2004) recalled cell phone batteries; Dell (2006) had a further recall of laptop batteries from the U.S. market; IBM (2007) recalled laptop batteries due to an explosion risk; Nokia (2007) recalled many millions of batteries due to overheating and possible explosion.

Recommendations to ensure safer use:

(a) Adhere to the OEM specified operating conditions. This is especially important in terms of temperatures and humidity. Any damage caused by external pressure should be evaluated during testing together with regular visual interrogation prior to each and every use.

(b) Only use OEM chargers. The manufacturer may locate the cut-out device to prevent over-charging in either the device or in the charger and this detail is often not known.

(c) Li-ion batteries operate best and with the least amount of stress if kept charged at between 65% - 75%. The device manufacturer should indicate the preferred storage level (usually not less than 40%) and minimum level at which they should be recharged (these batteries typically shut down when the charge level approaches 25%).

(d) Do not charge under hyperbaric conditions or at temperatures below freezing.

(e) Do not leave batteries unattended during charging, such as overnight.

(f) Always remove batteries from the charging circuit when charging is complete.

(g) Only use OEM-specified replacement batteries.

(h) Inspect Li-ion batteries regularly for any signs of deformation or leakage, that they are secured such that there is no movement inside the housing, and that the power leads and contacts are secure. A failing Li-ion will show signs of bulging, hissing and/or leaking electrolyte.

(i) Never tamper with any part of the battery, including the casing, wrapping or connections to internal parts.

(j) Develop, implement and practice an emergency action plan for any form of Li-ion battery failure during operations. This should include locking the device out of the chamber and managing a Li-ion fire. Foam, carbon dioxide and dry chemical extinguishers are suitable extinguishing mediums for fires occurring outside the chamber. Water may be used for the internal extinguishing/deluge medium.

Looking ahead:

Li-ion battery technology will continue to develop, providing higher capacities as well as more robust and better internally-protected products. Current new technology includes features such as the use of non-flammable, solid ceramic electrolytes.

Combined with due caution, these products should become more suitable for use in hyperbaric chambers.

References:

Buchmann, I; Cadex Electronics, Inc, Vancouver, Canada, 2007.

Personal interview: Emerson, D (CEO, Light & Motion), November 2019.

Rydberg, J (President & CEO, Ikelite); Li-ion battery safety; AlertDiver Fall 2019, pages 62 – 63

Technical specifications including:

(1) ASTM G 88-90 (1997): Standard Guide for Designing Systems for Oxygen Service

(2) CGA G-4-1 2018 Cleaning equipment of oxygen service

(3) CGA P-45-2018: Fire Hazards of Oxygen and Oxygen-Enriched Atmospheres

(4) NFPA 99: Health Care Facilities Code (2018)