Guidance Note

Fire Industry Association

Guidance on Li Ion Battery Fires

1. INTRODUCTION

This document has been prepared by the FIA Li-ion battery SIG, which comprises FIA members and other interested parties and organisations.

The SIG is open to FIA members and others with an interest in increasing the understanding of the issue of lithium-ion battery fires and protecting people and property from consequences of these fires.

This document represents the current understanding of the industry and will be updated as more information becomes available.

2. SCOPE

This FIA guidance paper provides information on the issues related to the use of Lithium-ion batteries, how fires start in batteries and on how they may be detected, controlled, suppressed and extinguished. It also provides guidance on post fire management. Excluded from the scope are explosion and ventilation issues.

3. TERMS AND DEFINITIONS

The block plan should be located at the entrance to the building or close to the fire panel, in a location easily accessible by fire and rescue services or other interested parties.

3.1 Battery
a container consisting of one or more cells, in which chemical energy is converted into electricity and used as a source of power.

3.2 Lithium-ion Battery
a rechargeable battery that uses lithium-ions as the primary component of its electrolyte.

3.3 Energy Storage
the capture of energy produced at one time for use at a later time.

3.4 Energy Storage System
collection of batteries used to store energy.

3.5 Electric Vehicle
vehicle which uses one or more electric motors for propulsion.

3.6 Battery Management System (BMS)
electronic system that manages a rechargeable battery.

3.7 Thermal Runaway
exothermic chemical reaction generating more heat than is being dissipated,
note: this can be characterised where a self-heating rate of 10oC/min or greater occurs.

3.8 Thermal Propagation
Where a single battery cell thermal runaway spreads to neighbouring cells.

3.9 Fire Tetrahedron
elements required to sustain a fire - Fuel, Heat, Oxygen and a Chemical Chain Reaction.

3.10 Off-gassing
venting of flammable/ toxic electrolyte vapours.

4. BATTERY TYPES

Lithium-ion batteries vary widely, and continue to evolve, in terms of their materials of construction, chemistry and configuration. Lithium-ion batteries are rechargeable (as opposed to lithium batteries which are not) and all contain lithium-ions in a flammable electrolyte. They do not contain any free lithium metal.

Cell enclosures may typically be metal or polymer used to configure as cylinders (jellyroll), pouch/polymers (squashed jelly roll/ books/sheets) or prismatic. Cathodes are an oxide coated lithium, such as lithium cobalt oxide with an anode, such as graphite, in an electrolyte with a poly film separator.

The batteries vary in size and configuration depending on their use and application. Larger batteries may be found in Energy Storage Systems (ESS) and vehicles whilst smaller batteries are used in laptops and mobile phones with lots of intermediate applications. Batteries are arranged in series to increase voltage, and in parallel to increase capacity.

5. FIRE ISSUES

As Lithium-ion batteries do not contain any free lithium metal (as stated above) they should not be regarded as a 'metal' fire threat.

Ways fires can start:

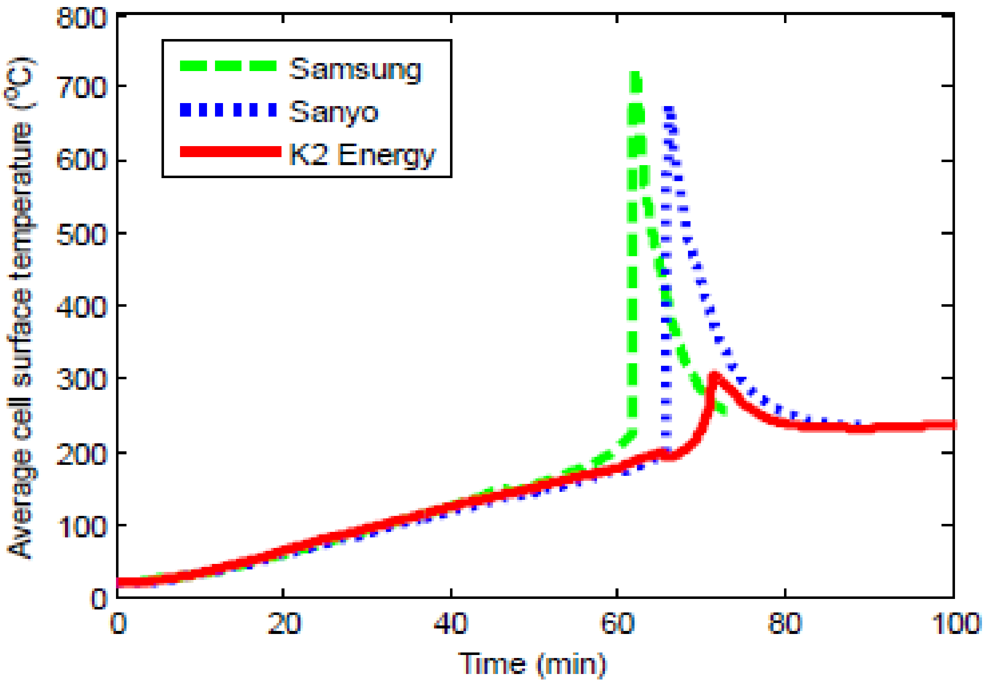
- Internal manufacturing defects (material defects, construction, contamination).
- Physical damage (during assembly, shipping, handling, waste disposal, accidental during product use).
- Electrical abuse (overcharging, over - discharging, short circuit).
- Thermal abuse (exposure to high temperatures).

Cell failure results in a voltage drop and increasing heat release and signals the start of 'thermal runaway'. This typically develops through the following events:

1. Temperature increase
2. Venting/gassing off of flammable/toxic electrolyte vapours
3. Flare
4. Steady burn
5. Flash fireball
6. Explosion

Thermal Runaway starts in a single cell before thermal propagation creates a domino effect through the adjacent cells.

Defects and physical damage can create internal short circuits leading to cell failure. Other events which could lead to cell failure arise external to the cells and so may be detected. The thermal runaway phase exhibits increasing temperature and heat release plus venting/ gassing off of flammable/ toxic electrolyte. This accelerates as cell failure approaches.



The battery cell surface temperature during external heating (oven) abuse test, showing the temperature rise upon external heating and the rapid temperature peak due to thermal runaway for two types of cobalt based cells (Samsung and Sanyo) and for a lithium iron phosphate cell (K2 Energy). All three cells are of the 18650 type. Reprinted with permission of F. Larsson [3].

Lithium-ion batteries, for example those used to power electric vehicles are in fact many hundreds, even thousands of individual cells, which may look similar in some respects to a packaging of regular AA battery and the issue is that, if they overheat and catch fire or even explode, the reaction quickly passes to the next cell and so on. This can happen due to short circuits, faulty design, physical damage, poor manufacturing processes etc; Battery manufacturers introduce safety devices/controls that aim to detect abnormal conditions developing and shutting down the batteries before it gets to thermal runaway. Monitoring of off-gases is also used to detect abnormal conditions developing.

6. FIRE SOLUTIONS

6.1 General

This section considers the various fire solutions available which are

• protection,

• detection,

• suppression and extinguishing.

It describes how the various options function and where data is available provides examples of where the solution has been used on a lithium-ion battery fire.

6.2 Protection

6.2.1 Containment

One method of handling fires in Lithium-ion batteries is to contain the battery and fire to prevent it spreading to other cells or materials.

This can be a solution for small portable battery powered devices.

At this time, most commercial airlines issue a fireproof bag to aircraft crew which have been successful in containing small battery fires on aircraft. Examples from FAA reports[1]) include:

"On SWIA flight 5598 from Los Angeles (LAX) to Mammoth, CA (MMH), after push back, a flight attendant's electronic flight attendant device (EFAD) battery caught on fire. The fire was extinguished quickly and the EFAD was placed in the fire containment bag. The crew declared an emergency with ground control and the fire department met the flight at the gate. The fire containment bag was removed from the aircraft and the aircraft was cleared. The flight deplaned through the jet bridge normally. The flight attendant reported that prior to the incident, he had dropped the device but it did not appear to be damaged so he placed it in his apron when it subsequently caught fire"

"During flight, approximately :45 minutes prior to arrival into Cleveland, OH (CLE), a passenger gave the Flight Attendant a cell phone battery charger with flashlight that was hot and began to smoke. The device was placed in the on-board fire containment bag."

As the size of the battery increases, selecting the methods of containment become more complicated.

For example, when looking at vehicle systems, containment will add weight to the vehicle which might not be the best solution, but protecting the battery pack from mechanical damage is being used as a compromise.

For large Energy Storage Systems, the use of fire walls between the cell packs and housing them in separate ISO containers can mitigate the spread of fire from one to another. Using fire rated containers (typically 90+ minutes fire resistance) with explosion relief can be used for large systems and even for vehicles after a crash. These containers can also be fitted with a suppression/extinguishing system.

6.3 Gas detection

Off-gassing occurs early in cell/battery failure. Some battery cells provide vents specifically intended to release the over-pressure that may develop within individual cells as a result for abuse or failure, others (such as pouches) may expand to accommodate a degree of off gassing but at some point these may burst – perhaps along a seam or pre-designed weak point. Systems that can detect off-gases in low concentrations can provide an early warning of an impending thermal runaway – and trigger shut down systems to electrically isolate the individual, or bank of, or rack of battery cells – and thus avoid thermal runaway occurring in a single cell. Such systems generally rely on a degree of enclosure around the batteries, such as an ESS container or a room housing large banks of batteries. It is not uncommon for effective off gassing detection, specifically tailored to be sensitive to the concoction of gases (predominately H_2, CO_2, CO, Hydrocarbon gases and battery electrolyte solvents) being generated by off gassing, to detect it within 30 seconds of it's initial release from the cell.

Note, the presence and build-up of significant quantities of H_2 and Hydrocarbon gases may present an explosion hazard. While such matters are beyond the scope of this document, it is worth noting that ventilation is an important feature in the mitigation of potentially explosive risks. Such hazards are traditionally associated with the slow accumulation of the gases given off during normal operation (e.g. charging of lead-acid batteries) but they may also occur relatively quickly as a result of the gases emitted during failure or thermal runaway of lithium-ion batteries. Thus, off gassing detection can play an important part in the control of ventilation systems.

It is also worth noting that early detection of off gassing is most effective when the ventilation is limited/minimal or at least fully understood. However, it is often the case that air movement is used to keep batteries cool during normal charging operations. Hence, off gassing sensors need to be strategically positioned and sensitive enough to detect the first signs of off gases before they become too diluted. Reference sensors are often used as well as off-gas sensors and are installed to monitor the ambient air conditions. Moreover, off gassing detection can provide situational awareness of the conditions within a facility; for example, providing information on where the incidence started to assist personnel responding to an event as well as more general information on any hazardous or toxic risks which may indicate that entering the facility is not appropriate.

6.4 Fire detection

As with all fires, a fire event in a lithium-ion cell/battery/installation is basically the rapid oxidation of the cell materials in an exothermic chemical process of combustion, releasing heat, light, and various reaction products, which can be gaseous or solid. Fire detection specialists have developed their products and systems to be capable of detecting one or several of these 'fire' phenomena.

A fire event starts long before flames are visible. Indeed, in certain circumstances a flame may not be produced at all i.e. if the combustible vapours and particles do not have the correct conditions, such as the equipment is contained within an inert gas atmosphere.

To detect the onset of a catastrophic fire event may require the use of several detection methods dependent on the number and layout of the cells and their positioning within their application.

Various phenomena produced throughout the stages of a cell failure event can be detected by different technologies such as: electromagnetic radiation (from IR to UV), visible smoke particles, invisible particulates, vapours, gases and light.

Early detection of a developing situation is key to preventing a fire developing.

Detection can be performed at many physical locations but may be limited by the application – e.g. within or local to the cell/battery (usually provided by the BMS), within the battery package, at equipment level, distant from the equipment, enclosure or room level. Each would have its advantages and be selected on merit to give appropriate and timely signals to other systems as required (e.g. to shut down the battery charging circuit, alert engineering or security staff, trigger the automatic suppression system, evacuation alarms for the building occupants, off-site signalling, etc.).

Detection within tightly assembled battery packaging/systems where, often bulky sensors cannot be placed, can be accomplished by extracting an air sample via a network of tubes and pipes to be analysed by an appropriate detector remotely. Detection of more accessible individual or groups of cells and batteries can be undertaken by video detection employing applicable algorithms. Individual point sensors can achieve in-cabinet and room detection.

A successful detection and prevention of a catastrophic fire event may require several of the methods mentioned above together with the appropriate extinguishing system(s) discussed below.

Significant visible smoke is generated once battery failure starts. Where battery enclosures exist, detectors sensitive to the smoke emitted by batteries may provide warning and be linked to battery management and fire protection systems. Both conventional and early warning type smoke detectors may be used.

Heat is given off once battery failure occurs. Where battery enclosures exist, detectors sensitive to the heat emitted by batteries may provide warning and be linked to battery management and fire protection systems. These may take the form of linear heat sensing cables or infra-red fire detectors.

The smoke and off-gases may be sensed by 'video' cameras with smoke obscuration algorithms and able to link to battery management and fire protection systems.

Smoke detection is unlikely to provide a warning early enough to prevent thermal runaway.

In order to avoid unwarranted release of firefighting agent, it is industry good practice to use 'coincidence' of two or more fire detection signals before initiating release of firefighting agent. A method of manually delaying the automatic release of the agent should be considered as well as a manual release method to by-pass the coincidence in order to release the agent immediately should the situation demand it.

6.5 Suppression and extinguishing

6.5.1 Fixed Systems

6.5.1.1 Gaseous Fire Extinguishing Systems

A gaseous system comprises of one or more containers containing an extinguishing agent. When the system is operated it discharges the agent into an enclosure through one or more discharge nozzles. Systems may be activated manually or automatically through a connection to an appropriate fire detection system.

When considering the protection that may be offered by gaseous fire extinguishing systems, it is important that we separate the protection of enclosures that could house lithium-ion batteries, which is certainly possible and practical in many situations. A scenario where the lithium-ion batteries enter a phase of thermal runaway, which results in a rapid progressive fire and presents a very specific scenario and where the aim is to contain that event and where currently conventional fire protection methods are not yet proven.

Protecting an enclosure where lithium-ion batteries are stored, may be treated as any other gaseous extinguishing system application, taking due account what the most likely hazards within the enclosure would be from normal combustibles that could at some stage create an issue for the lithium-ion batteries themselves, or leakage of the electrolytes from the batteries. In these scenarios, concentrations of agent are selected based on those combustibles, following the Class A, B or C protection given in EN 15004-1. Agent concentrations for several of the common electrolytes have been established for a number of the gaseous agents, but it is important to reiterate that protection is not based on a lithium metal fire. Fires involving lithium metal require different considerations to those applied for lithium-ion batteries.

In the scenario where the lithium-ion batteries have entered an advanced thermal propagation stage, extinguishing gases may not have the heat capacity to remove sufficient heat to allow the battery to cool fast enough and until the materials of combustion are consumed, the fire will continue. The fire is also not dependent on an oxygen supply.

So, protecting even with very high concentrations of any agent, including halocarbon agents that extinguish principally by heat absorption or with the Inert Gas systems designed to displace oxygen may not extinguish the fire.

After off-gases have been released, they could create a flammable atmosphere and should be ventilated. If this is not possible, gaseous agent may be deployed to develop an inerting concentration.

6.5.1.2 Condensed Aerosol Systems

Condensed aerosol systems use similar control and monitoring equipment to gaseous fire suppression systems. They also flood the room with a fire suppression agent. Unlike gaseous fire suppression systems, condensed aerosol systems consist of a solid block compound stored in a non-pressurised container (or generator).

Condensed aerosol generator sizes vary from very small (a few grams) to large (several kilograms). The operation is common to all. Each generator stores its respective volume of agent and has suitably sized discharge outlets. The condensed aerosol generators that store the fire suppression agent are mounted directly in the protected area.

The aerosol consists of micro or nano sized solid particles suspended in another substance such as gas without being dissolved into the gas.

Fire is extinguished by inhibiting the chemical reaction that is a fire (by removing the fourth side of the Fire Tetrahedron).

The number and position of condensed aerosol generators should be in accordance with the guidance given by the equipment manufacturer and with the recommendations of EN 15276: 2019.

EN 15276 states that condensed aerosols should only be used in unoccupied or normally unoccupied areas.

6.5.1.3 Watermist systems

Water mist systems uses small water droplets to provide flame cooling and steam smothering of fires. Their design basis is always determined by full scale fire testing. therefore, water mist should only be used for the protection of lithium-ion batteries where there is an established test protocol.

Note: *There are currently a number of research projects currently investigating the application of watermist on vehicle fires.*

6.5.1.4 Sprinklers systems

Automatic fire sprinkler systems consist of special nozzles, held closed by heat sensitive frangible elements, mounted in steel pipework, at ceiling/roof level, and connected to a dedicated water supply via control valves. The heat from a fire causes one or more sprinklers to open to discharge water onto the seat of the fire and adjacent combustibles. The amounts of water and the number of sprinklers expected to open will increase as the fire load density increases.

In heated buildings, they may be charged with water, but in areas subject to freezing, they will be primed with air until a sprinkler opens. In areas where water damage could be problematic, systems may be primed with air and water admitted when smoke is detected ahead of sprinkler operation.

Only sprinklers in the immediate vicinity of a fire open when subjected to the heat from a fire. Sprinklers provide direct wetting of combustibles and surroundings. Sprinkler protection of lithium-ion batteries is outside the scope of current standard sprinkler design standards e.g. EN, NFPA/FM, however, specialist standards are being developed for example NPFA 855, see next page:

Energy Storage Systems:

National Fire Protection Association (USA) Standard NFPA 855[2]) provides design criteria for Energy Storage Systems (ESS) based upon The NFPA Research Foundation Report 'Sprinkler Protection Guidance for Li-Ion Based Energy Storage Systems' published in June 2019.

Based upon the tests the recommended design basis is a follow:

- K80 sprinklers, at 3m x 3m spacing, with an application density of 12.2 litre/minute/m^2 and an assumed area of operation of 230m^2, with a water supply duration of 90 minutes.

The system is envisaged to 'control' the growth and spread of fire. It is not being claimed to be able to suppress or extinguish a fire in Energy Storage Systems.

WARNING: This is strictly on the basis that the hazard being protected is within the limits of the tests carried out under a 4.6m high ceiling. It is also on the basis that the other fire safety design features addressed in the report are also adopted.

Sprinklers rely on a build-up of heat at ceiling/roof level to activate the sprinkler heads. Their speed of response depends upon the size/ heat output of the fire and the height of the heads above the fire. Sprinklers should be considered as providing fire suppression rather than extinguishment.

6.5.1.5 Water Deluge systems

Deluge systems, unlike sprinklers, use open nozzles so that, when actuated, water discharges from all nozzles in the system. Deluge is used primarily as a means of cooling surfaces exposed to fire. When activated by fire detection systems, they can come into operation more rapidly and provide more comprehensive coverage than sprinklers.

6.5.1.6 Foam systems

Foam systems use foam additives proportioned into a water stream. Foams are generally formulated for use for blanketing and smothering flammable liquid fires. Testing on battery fires has not been published to date.

6.5.1.7 Wetting Agents

Wetting Agents (WA), are defined as;

"liquid concentrates which, when added to plain water in proper quantities, materially reduce the surface tension of plain water and increases its penetration and spreading ability."

There is a range of wetting agents available, but there are key differences between these due to their manufacture or their end use, unlike foams which have a common derivation. However, WA are different.

Some WA are used on ships and are heavily reliant on salt to perform fire suppression, and benefit from saltwater as their mixing agent; some are found in powdered form and require mixing at the pump via a dip tube, some Class A wetting agents, generally used in CAFS, are derivatives of Class B foams and still contain PFAS chemicals and can have significant usage issues, another uses a modified co-polymer, and yet another is based upon tree extracts (saps). Accordingly, they have a wide range of abilities and benefits. Not all WAs are equal, being a WA does not mean that all achieve suppression by reducing the material temperature alone.

As a result, judgements on the efficacy of WAs in this area are more complex, in that the primary WA ability to suppress a high temperature threat, through its penetration and spreading benefits, has to be allied to other benefits to suppress fire incidents and thereby meet the operational need.

Examples of these benefits could include:

- The speed to reduce the battery and/or collateral material temperature below the flash point, and that this is maintained for an extended period, i.e., there is no re-ignition,
- the range of materials which can be extinguished, i.e., not just Class A,
- economic quantities of suppressant needed,
- impact on, and flexibility of delivery methods,
- 'green' qualities of the suppressant,
- scale and complexity of post-event clean-up.

Wetting agents have been used, on fires started by batteries going into thermal runaway, in fire suppression system at industrial sites by exhibiting the benefits outlined above, examples are given below.

WA Applications in the industrial and domestic waste industry.

A) Large scale 'raw' waste re-cycling centres.

These are generally modern constructions, with operating areas both external and enclosed. The primary elements of the approach are:

- A sophisticated software controlled, automated, scanning camera seeking temperature changes in piles of waste, often of several thousand tonnes.
- A high-powered pumping system.
- One or a number of water cannons, able to be directed to the point of temperature increase, with an 80-metre operating range.
- A water-based fire suppressant solution, either pre-mixed or inducted, including Cold Fire at a percentage of 1-3% depending upon the waste mix.
- The system operates 24/7, and can be set to operate totally automatically or manually to meet site needs.
- The control over volume and duration, (e.g., three-minute delivery runs, followed by status checks), is to minimise suppressant usage and therefore run-off volumes (if any), to ensure a speedy clean-up and return to normal operation, within say one hour.

- A number of systems are installed, with a considerable pipeline of orders due in the coming year. A high percentage of incidents are caused by 'crushed' batteries from the waste handling process. For example, one large scale site has had nineteen fires in the past twelve months, the great majority from batteries, all successfully dealt with the minimum of downtime.

B) Sorted waste bunkers

These maybe standalone sited pre-delivery storage units or the final stage in the process described in A.

- These are groupings of relatively small storage units with capacities of a few hundred tons of re-saleable waste awaiting onward shipment.
- These bunkers are monitored by fixed smoke detection cameras, allied to high resolution software analysis tools.
- Suppressant, including for example "Cold Fire", either pre-mixed or inducted is supplied to each bunker through fixed sprinkler pipework.
- Run times will be adjusted to reflect the nature of the waste.

NB. These approaches have not yet been tested where batteries alone are the product being protected. However, one could see that either of the above could have applications if an off-gassing warning system was available to warn at the earliest stage.

6.5.1.8 Aqueous Vermiculite Dispersion

Aqueous dispersions include an aqueous dispersion of chemically exfoliated Vermiculite which is applied in the form of a mist. Vermiculite is the name given to a group of hydrated laminar aluminium-iron-magnesium silicates. Raw vermiculite consists of thin, flat flakes containing microscopic layers of water.

The chemical exfoliation of vermiculite produces microscopic, individual platelets that are freely suspended in water, which yields a stable aqueous dispersion of vermiculite. Vermiculite particles are deposited on the surface of the burning cell, creating a film over the surface. The film dries instantly and the vermiculite platelets overlap each other and bind together. This forms a non-flammable physical oxygen barrier between the fire source and the atmosphere. This process has a cooling effect on the fire. As vermiculite platelets begin to build up the fire is brought under control.

The dispersion simultaneously cools the fuel source as well as encapsulating it and insulating the cells preventing further thermal runaway; this prevents the propagation of the fire.

It is used in the following systems:

- Fixed Installations.
- Portable Extinguishers.
- Mobile Fire Extinguishers.
- Backpack Extinguishers.

Fixed installations are designed to suit the specific requirements of the location and application. These are often specified as a mixed strategy, combined with the dispersion in portable and mobile fire extinguishers to enable an agile response in a fire situation. Current projects using the product in fixed installations include electric vehicle manufacturing production lines, battery processing and storage facilities as well as onboard systems in public service and industrial electric vehicles.

Vermiculite dispersions have been successfully tested using established test protocol, by lithium battery specialists, ZSW.

Vermiculite is a naturally occurring mineral that is exempt from REACH regulations. It is chemically and physically inert, releasing only steam when exposed to raised temperatures rendering it sterile. It is non-toxic to humans, flora and fauna.

Some benefits of using vermiculite dispersions when considering a lithium-ion battery-based risk are:

- The water content cools the fire source immediately.
- Vermiculite platelets encapsulate the fuel source creating a physical oxygen barrier which withstands further exposure to heat.
- The vermiculite film is not electrically conductive.
- It can be applied as a fire break to prevent the propagation of fire.
- It can be easily deployed using standard firefighting equipment.

It is environmentally friendly.

6.5.1.9 Powder systems

Powder comprises very fine particulates of metal salts which inhibit the combustion process, similar to aerosols (see above). Powder does not have any cooling properties.

As these are not metal fires, class D powders such as L2 (for lithium metal fires), are not suitable for lithium-ion battery fires.

6.5.1.10 Oxygen Reduction Systems

Oxygen reduced air is used as a fire prevention method, creating a closely controlled environment with continuously lowered oxygen concentrations within an enclosure.

Oxygen reduced air (often through the addition of Nitrogen) is introduced into the enclosure to produce an oxygen concentration below that necessary for combustion.

Reduced oxygen concentrations can be used to prevent or suppress flaming combustion, thus creating conditions in which fires cannot freely develop.

The level of oxygen reduction must be defined by the ignition threshold of risks within the enclosure.

The design basis should be determined through fire testing (see EN 16750:2017) but, to date specific test data has not been published in relation to lithium-ion batteries.

Oxygen Reduction Systems can prevent Flame Stacks but this can lead to excess toxic & flammable fumes leaving the enclosure which then need to be dealt with.

Therefore, oxygen reduction systems should only be used for the protection of Li-Ion batteries where specific testing has first taken place.

6.5.2 Portable fire Extinguishers

Portable fire extinguishers should only be used on individual small rechargeable devices (such as laptops, mobile phones, e-cigarettes, power tools etc.) containing lithium-ion batteries which have been disconnected from mains power. Complete extinguishment may not be possible but use of a nearby water or water-based extinguisher should prevent the fire from spreading to other nearby materials, whilst the alarm is raised.

7. POST FIRE MANAGEMENT

7.1 Batteries

When a battery fire is extinguished a significant fire hazard may still remain; those batteries involved in and affected by the fire are likely to be hot and still pose the potential to vent combustible and toxic gases and also have the potential to reignite.

It is therefore necessary that post fire management operations commence as soon as practicable by suitably equipped and trained personnel. This may include:

- Ventilation
- Extraction
- Isolation
- Fire watch (using thermal imaging cameras to monitor the temperature)
- Recovery

The level of post fire management of the battery will be dependent on battery size for single cell/pouch devices once the fire is extinguished the risk of further fires is minimized.

7.2 Media

Media should be disposed of via an environmentally suitable method.

The design and installation standard for the various fire fighting systems include information on the post discharge provisions.

Toxic gases dampened down by water-based systems can lead to contaminated run-off which will need to be contained.

8. CONCLUSIONS

Lithium-ion batteries can develop into significant and unstoppable thermal runaway fires so carefully considered measures are required to address the hazards that these pose and the options available to manage such risks.

Incipient and pre-fire conditions in lithium-ion batteries can be detected by monitoring several phenomena such as gas & vapour emissions and abnormal temperatures.

Evidence has shown that the key to successful extinguishing of a lithium-ion battery fire is suppressing/extinguishing the fire and then cooling the adjacent cells that make up the battery pack/module.

The fire hazard may remain after the operation of the fire protection system due to the likely damage to adjacent cells caused by the original failure; therefore, remedial actions may be required to prevent a re-escalation.

The use of lithium-ion batteries is widespread and in applications using cell quantities large and small. For this reason, consideration of any fire protection measures must take into account the particular circumstances and hazard configuration and whether any fire protection measures have been validated for the particular application.

In all cases, a risk assessment is required to determine the nature and extent of the fire challenges and the safety measures that should be put in place.

9. REFERENCES

1) FAA Office of Security and Hazardous Materials Safety

2) NFPA 855, NFPA 1 Batterymarch Park, Quincy, Massachusetts, USA 02169-7471

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