Loss prevention standards

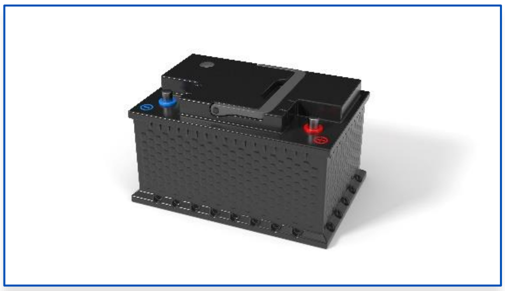
Engineering:

High Voltage Batteries

The use of battery technology presents a range of risks, and this document provides guidance on the use, storage and handling of high voltage batteries.

High Voltage Batteries

Introduction



This document focuses largely on lithium-ion type batteries with references to other types of batteries.

Batteries, specifically lithium-ion batteries can develop into significant and unstoppable thermal runway fires (an exothermic chemical reaction generating more heat than is being dissipated). The use and storage of these type of batteries is widespread and in applications large and small.

In all cases a fire risk assessment should determine the nature and extent of the fire challenges and the control measures that should be put in place.

The following information should be used to help evaluate current operational policies and procedures and to highlight any potential areas where improvements can be made.

Whist this document does briefly refer to Energy Storage Systems (ESS) and electric vehicle batteries, its primary focus is on the use, storage and handling of smaller systems in the commercial environment, such as: a motor trader servicing vehicles; small warehouse storage units, emergency lighting systems; and battery powered vehicles such as golf carts or forklift trucks.

Battery Types

Lead Acid

Lead acid batteries are commonly classified into three usages:

- Automotive: starter or starting, lighting, and ignition(SLI)
- Motive power: traction or deep cycle
- Stationary: uninterruptible power supplies (UPS)

They were the first rechargeable battery developed for commercial use. Despite its advanced age, the lead chemistry employed continues to be in wide use today and they are typically used in automobiles, golf carts, forklift trucks, marine equipment and UPS.

The most common sealed lead acid batteries are valve-regulated lead acid (VRLA) and absorbent glass mat (AGM). Packaged in a plastic container, these batteries are used for small UPS, emergency lighting and wheelchairs. Larger VRLA is used as power backup for cellular repeater towers, internet hubs, banks, hospitals, airports and more.

AGM works best as a mid-range battery with capacities of 30 to 100Ah and is less suited for large systems, such as UPS.

Typical uses are starter batteries for motorcycles, start-stop function for m-lithium-ion battery, a rechargeable battery that uses lithium ions as the primary component of its electrolyte.

Batteries do vary in size and configuration. Larger batteries may be found in ESS and vehicles, while smaller batteries are used in laptops and mobile phones. Batteries are arranged in series to increase their voltage. Types and their common uses are:

- Lithium manganese oxide batteries are notable for their high temperature stability and are also safer than other lithium-ion battery types. For this reason, they are often used in medical equipment, but they may also be used in power tools, electric bikes, etc.
- Lithium iron phosphate batteries (LFP), also known as li-phosphate batteries, benefit from low resistance properties, which enhance their safety and thermal stability. These batteries are often used in electric motorcycles as well as other applications that need a long lifecycle and significant safety
- Lithium nickel manganese cobalt oxide batteries (NMC) are made of several materials common in lithium-ion battery types. NMC batteries can have either a high specific energy density or a high specific power. They cannot, however, have both properties. This battery type is most common in power tools and in powertrains for vehicles
- Lithium nickel cobalt aluminium oxide batteries are also called NCA batteries and are becoming increasingly important in electric powertrains and in grid storage. NCA batteries are not common in the consumer industry but are being investigated for potential uses in the automotive industry. They provide a high-energy option with a good lifespan, but in comparison with other lithium-ion battery types there are more safety concerns and they have higher costs
- Lithium titanate, also known as li-titanate, is a class of battery that allows for ever-increasing applications. The main advantage of the li-titanate battery is its remarkably fast recharge time. Currently, manufacturers of electric vehicles and bikes use li-titanate batteries, and there is potential for this type of battery to be used in electric buses for public transportation

Battery Failures

Lithium Cells

There are several ways to exceed the thermal stability limits of a lithium cell and cause an energetic failure. Energetic lithium battery failures may be induced by the following:

- External forces, such as exposure to fire or mechanical damage
- Problems involving charge, discharge, and/or battery protection circuitry design and implementation
- Internal cell faults that result from rare or subtle manufacturing problems

Generally, the root causes of energetic cell and battery failures can be classified as:

- Thermal exposure, e.g. external heating
- Mechanical damage, e.g. denting, dropping, impact
- Electrical abuse, e.g. overcharging, external short circuit, over-discharge
- Poor cell electrochemical design, e.g. imbalance between positive and negative electrodes
- Internal cell faults associated with cell manufacturing defects, e.g. foreign metallic particles, poor electrode alignment

Lead Acid

A common cause of lead acid battery failure is acid stratification. The electrolyte on a stratified battery concentrates on the bottom, causing the upper half of the cell to be acid poor. When charging, the temperature inside a lead acid battery can rise to a critical level. Heat is unable to dissipate fast enough, the chemical reaction inside the battery accelerates and leads to an even higher charging current and heat generation.

Factors that Influence Failure

Total Energy Stored

The severity of a lithium cell failure will be strongly affected by the total energy stored in that cell; a combination of chemical energy and electrical energy. Thus, the severity of a potential thermal runaway event can be mitigated by reducing stored chemical energy (i.e. by reducing the volume of electrolyte within a cell), or if possible, by changing the cell electrolyte to a non-combustible material (i.e. the cell chemistry).

Electrolyte Type

The electrolyte is a substance that produces an electrically conducting solution. The most flammable component of a lithium cell is the hydrocarbon-based electrolyte. The hydrocarbon-based electrolyte in lithium cells means that under fire conditions, these cells will behave in a fundamentally different way than other batteries that contain water-based electrolytes. Fire impingement on lithium cells will cause release of flammable electrolyte, increasing the total heat release of a fire.

Although all charged cells contain stored electrical energy, even fully discharged lithium cells contain appreciable chemical energy that can be released through combustion of the electrolyte and case. Water-based battery chemistries, under some charging conditions, can produce hydrogen gas through electrolysis of the water. However, this hazard is seldom a concern during storage where no charging occurs.

Based on the nature of water-based electrolytes, if cells with such an electrolyte are punctured or damaged, leakage of the electrolyte can pose a corrosive hazard, but this normally does not pose a flammability hazard. In comparison, leakage or venting of lithium cells can release combustible or flammable liquid or vapour.

When a cell vents the released gases mix with the surrounding atmosphere. Depending upon several factors, including fuel concentration, oxygen concentration and temperature, the resulting mixture may or may not be flammable.

Design Life and Other Factors

Batteries at the end of their design life are more vulnerable to thermal runaway. Due to the heat generated within the battery, the battery can become pressurised and deform.

In addition to the above the following are other potential causes for battery fires or explosions:

- Overcharging
- Internal physical damage
- Internal short circuit
- Being used in a hot/high temperature environment

Cases

In many cases the design of batteries is such that the external shells are combustible, e.g. plastic. Therefore, any heat or fire event from the cell itself or exposing the cell can also involve the battery case causing the case to deform; loss of containment of the electrolyte; and the fire to be larger.

Maintenance

All batteries should be subject to periodic inspections and maintenance. Consideration should also be given to using a thermographic camera to look for hotspots:

- Check and report any signs of external damage to the battery or the charging network
    - If there are signs of damage then these items should be withdrawn immediately
- Ensure that battery chargers and procedures are correct for the battery type
- Ensure that fixed electrical wiring and portable appliance testing is completed as required
- Consider the installation of a 'thermal runaway monitor' on battery packages (UPS)

In the event of a failure, isolate the battery or string of batteries, or shut down the charger. Cool the battery and ventilate the room.

Note: Location of batteries and charging points and their emergency isolation should be carefully considered. There have been instances of items on charge starting to smoke or igniting, with the isolation switches being located directly adjacent to or above the item on charge that is now on fire. This makes it difficult to safely isolate and remove the battery on charge.

Disposal

If a battery is to be disposed of an assessment should be carried out to determine the level of damage, if any, to the battery. Where such damage is detected, a risk assessment should be carried out to determine whether the battery should be removed to a safe storage zone, preferably outside in the open, due to the increased risk of fire.

Consideration should be given to how the batteries are safely disposed of and how/where they are kept, such as:

- In dedicated, normally closed and sealed lidded non-combustible containers
- Not mixed with any other waste materials or any combustible items
- Away from heat/ignition sources including direct sunlight

Small non-combustible receptacles should be used to collect waste batteries with the contents being periodically transferred to a larger container outside the premises as described above.

Containers for the bulk storage of waste batteries outside the premises should be:

- Constructed from non-combustible material and be sited away from the buildings (ideally at least 10m)
- Protected from the effects of the weather while awaiting disposal by a specialist contractor
- Removed regularly from the premises to avoid substantial accumulation

There should be a specific risk assessment and disposal plan relating to the removal of faulty or damaged batteries, with specific care being taken to identify the correct Personal Protective Equipment (PPE) to be worn, and any transportation procedures necessary.

Other Safety Considerations

Lithium batteries should be stored, charged, used and disposed of in accordance with the manufacturer's instructions. Considerations should include:

- Good housekeeping throughout their life cycle including whilst in storage
- High voltage batteries should be:
  - Kept dry
  - Kept in good condition; any damaged batteries should be removed and isolated as described above
  - Not exposed to water or any other liquid – including escape/release from above the batteries
  - Not exposed to high temperatures
  - Segregated from all other combustible items
- Employees should receive appropriate training for the safe handling, storage and transportation of batteries
  - Training should include the implementation of emergency arrangements for dealing with battery failures and emergency situations
- Charging procedures should be fully documented and tested

Fire Protection

As they can present distinct fire protection challenges, batteries should be stored in a location designed with this purpose in mind. If automatic sprinkler protection is not to be provided within the building, then greater consideration should be given to the location of the batteries in relation to:

- How a public fire-fighting authority will be able to access an intense smoky fire?
- What fire-fighting water is available and from where?
- What the battery arrangement would expose if on fire?
- How the fire compartmentation is arranged?
- How any ventilation systems communicate through the building in relation to this area?

The area should be subject to a fire risk assessment in compliance with the Regulatory Reform (Fire Safety) Order 2005 (or equivalent legislation in Scotland and Northern Ireland) (refs 4-8) and in compliance with the Dangerous Substances and Explosive Atmospheres Regulations 2002(DSEAR) (ref 10) to ensure that it is remote from identified hazard zones. It should also consider the property damage and business interruption implications of a fire in the battery storage area(s).

Storage areas should provide at least 60-minutes of fire resistance (insulation and integrity) between the stored batteries and any other part of the premises.

Charging areas should also be segregated, in its own fire compartment (at least 60-minutes) and should not be permitted within an area intended for the bulk storage of batteries.

Fire and Gas Detection

As a minimum, automatic fire detection should be provided in all compartments. The automatic fire detection and associated alarm system should be monitored either on-site at a constantly attended location or by an approved off-site Alarm Receiving Centre with accreditation by an independent UKAS accredited third party certification body.

Off-gassing is often the first indication of a battery failure. Where battery enclosures exist, gas detectors sensitive to the hydrogen, carbon monoxide and carbon dioxide emitted may provide warning and could be linked to a battery management protection system.

Since significant smoke is generated once battery failure starts, detectors should be sensitive to the smoke produced. These detectors should be interlocked to any battery management protection system. If possible, an aspirating high-sensitivity smoke detection system could be employed, as this will afford a fire alarm much earlier in the fire propagation.

In addition, heat is given-off when battery failure occurs. Where battery enclosures exist, detectors sensitive to the heat emitted may provide an early warning, and these may take the form of linear heat sensing cables or infra-red fire detectors.

Fire Extinguishing Systems

Ideally automatic fixed suppression/extinguishing systems should be provided whenever there is a combustible occupancy. While this may not be possible, they should be considered where the property and/or business exposures are considered too great, or where the battery systems are large, or where there the storage warrants it. These systems should be automatically activated and where not automatic sprinklers, should also be able to be activated manually. Automatic activation should be via automatic fire detection and through any battery management system.

Systems should consider the most likely hazards in the battery enclosure storage area and the existing infrastructure. The most effective extinguishing agent for the application should be selected following a risk assessment and taking into consideration the effectiveness of the agent as well as toxicity, asphyxiation potential, environmental and contamination issues in the context of the application of the system.

Aside from sprinkler protection the principal alternatives are:

- Dry powder - which is corrosive, can cause contamination problems of electrical and control systems and can be difficult to clean-up afterwards
- Carbon dioxide – which can present life safety exposures
- Other clean agent gaseous extinguishing systems
- Water mist

Any fire detection and/or fire extinguishing systems should be interlocked to:

- Electrically isolate the charging batteries from the charger
- Electrically disconnect the batteries from their downstream services, where possible
- Shut down any ventilation systems
    - There have been fires where a small number of batteries ignite and the significant amount of smoke generated contaminated an entire building via an 'operating' ventilation system or penetration in a wall

A suitable number of fire extinguishers should be available and immediately accessible in the case of a fire. They should be carbon dioxide and clean agent, and as the last resort a dry powder extinguisher. Such portable extinguishers should be approved and certified by an independent, third party certification body and be installed, inspected and maintained. Individuals expected to use these devices in the event of a fire should be suitably trained to use them.

Emergency Response

As indicated above, if site personnel are expected to use manual fire extinguishers, appropriate training and refresher training should be provided.

Aside from 'normal' emergency response and evacuation plans, fires involving batteries require special attention. When a battery fire is finally extinguished a significant fire hazard may still remain in those adjacent batteries exposed to and affected by the fire but not directly involved. They may have been exposed to elevated temperatures, acid gases and smoke. They could still be hot and potentially vent combustible or toxic gases. They also have the potential to ignite and restart the fire. They could also have been exposed to dry powder or water extinguishing media which could have an impact on their behaviour.

As a result, post-fire management operations should commence as soon as practicable by suitably equipped and trained personnel to make the batteries safe, remove and isolate those exposed and fully risk assess the arrangements remaining.

Checklist

A generic High Voltage Batteries Checklist is presented in Appendix 1 which can be tailored to your own organisation.

Specialist Partner Solutions

Aviva Risk Management Solutions can offer access to a wide range of risk management products and services via our network of Specialist Partners who are reputable companies offering agreed discounted rates for Aviva customers.

For more information please visit:

Aviva Risk Management Solutions – Specialist Partners

Sources and Useful Links

- The Dangerous Substances and Explosive Atmospheres Regulations 2002 – Health and Safety Executive
- RC61- Recommendations for the storage, handling and use of batteries - RISCAuthority

Additional Information

Relevant Loss Prevention Standards include:

- Lithium Battery Storage and Recycling
- Contamination Following a Fire
- Smoke Contamination
- Electric and Hybrid Vehicle Awareness
- Emergency Response Teams
- Fire Compartmentation
- Gaseous Fire Extinguishing Systems
- Thermographic Surveys
- Water Mist Fire Protection Systems

To find out more, please visit [Aviva Risk Management Solutions] or speak to one of our advisors.

Email us at riskadvice@aviva.com or call 0345 366 6666.*

*Calls may be recorded and/or monitored for our joint protection.

Appendix 1 – High Voltage Batteries Checklist

Location	
Date	
Completed by (name and signature)	

	High Voltage Batteries	Y/N	Comments
1.	Is there a person responsible for the management of battery safety?		
2.	Have specific risk assessments been carried out with regards to battery work activities such as isolation, repair and maintenance? Are these risk assessments regularly reviewed and updated?		
3.	Have safe systems of work been devised for all relevant tasks in relation to high voltage batteries? Does this include what actions to take in an emergency?		
4.	Have all staff received training relevant to their roles and responsibilities in relation to high voltage batteries?		
5.	Do risk assessments include the risk of fire from the batteries? Does this include: • What the batteries expose? • Property damage and business impact?		
6.	Has the use and storage of batteries been included in the regulatory required fire risk assessment for the site?		
7.	Has the use and storage of batteries been included in a DSEAR risk assessment?		

	High Voltage Batteries Contd.	Y/N	Comments
8.	Are facilities suitable for the safe and correct storage of high voltage batteries? Are batteries segregated from all other combustible materials? Are the batteries stored in their own fire compartment?		
9.	Have precautions been identified and corrective actions taken to ensure batteries do not overheat?		
10.	Are batteries and charging areas subject to periodic and regular visual inspection? Is this recorded?		
11.	Are batteries and charging areas subject to maintenance in line with the original equipment manufacturer (OEM) guidelines? Is a thermographic camera used to periodically check the batteries and the charging system?		
12.	Are the batteries and any charging stations located in areas not exposed to water or any other liquid contamination?		
13.	Is there a formal procedure in place on how batteries are to be disposed of?		
14.	Are there safe battery disposal storage areas? Are they stored in non-combustible sealed containers? Are there suitable storage arrangements for damaged batteries?		
15.	Are the batteries connected to a battery management/control system?		
16.	Is automatic sprinkler protection provided within this building? Does it cover the battery areas?		
17.	Is automatic fire detection provided in all areas?		
18.	Is a local automatically actuated fire extinguishing system in place for the battery units?		

	High Voltage Batteries Contd.	Y/N	Comments
19.	Are fire alarms connected to a constantly attended location or an approved Alarm Receiving Centre?		
20.	In the areas of the batteries are the following interlocked to shut down the ventilation system(s): • Automatic and manually actuated fire alarms? • Any fire protection systems?		
21.	Are the batteries and charging systems interlocked to shut down upon: • Fire alarm? • Fire extinguishing system activation? • Battery management/control system?		
22.	In a fire situation are the electrical isolation points for batteries/chargers readily and safely accessible?		
23.	Are a suitable number of carbon dioxide or clean agent fire extinguishers available and immediately accessible in the case of a fire? If the above are not available are dry powder fire extinguishers available? Are appropriate personnel trained to use these devices in an emergency?		
24.	Is there a formal Emergency Response Plan for a fire involving the batteries? Does this include: • What steps to take in an emergency? • Manually isolating the battery charging and discharging circuits?		
25.	Is there a formal Emergency Plan in place to manage the exposure from the batteries immediately after a fire incident? Does this include what steps to take to make sure all the batteries are safe and thermally stable?		
26.	Is the Fire Evacuation Plan up to date to accommodate the presence of batteries?		

	High Voltage Batteries Contd.	Y/N	Comments
27.	Additional comments:		

Please Note

This document contains general information and guidance only and may be superseded and/or subject to amendment without further notice. Aviva has no liability to any third parties arising out of ARMS' communications whatsoever (including Loss Prevention Standards), and nor shall any third party rely on them. Other than liability which cannot be excluded by law, Aviva shall not be liable to any person for any indirect, special, consequential or other losses or damages of whatsoever kind arising out of access to, or use of, or reliance on anything contained in ARMS' communications. The document may not cover every risk, exposure or hazard that may arise and Aviva recommend that you obtain specific advice relevant to the circumstances.

27/10/20 V1.0