Optimizing Safety in Lithium-Ion Battery Storage and Handling

C N Anil Kumar

ABSTRACT

The rising energy demands have prompted the development of various advanced technologies, with Lithium-ion technology emerging as a leading and efficient energy source. However, this technology poses significant hazards to human health and safety. Recently, incidents involving Lithium-ion batteries have surged due to multiple factors and failure modes, with thermal runaway being a major contributor to these accidents. To address these concerns, innovative technologies and strategies in fire safety and Lithium-ion battery safety are being implemented to mitigate the occurrence of thermal runaway and battery-related incidents.

KEY WORDS: Lithium-Ion, Thermal Runaway, Fire Safety, Electrical Safety

INTRODUCTION

Lithium-ion batteries are essential for modern energy storage, particularly in industrial applications and consumer electronics. These rechargeable batteries operate through the reversible reduction of lithium ions, comprising key components such as an anode, cathode, separator, electrolyte, and two current collectors. The anode and cathode store lithium ions, while the electrolyte allows positively charged lithium ions to move between them. During discharge, lithium ions flow from the anode to the cathode, creating an electron flow that powers devices like cell phones and computers. Conversely, during charging, lithium ions return from the cathode to the anode, with electrons moving in the opposite direction, providing a continuous electric current. Various materials optimize lithium-ion battery performance, including Lithium Nickel Manganese Cobalt Oxide (NMC), Lithium Nickel Cobalt Aluminum Oxide (NCA), Lithium Iron Phosphate (LFP), Lithium Cobalt Oxide (LCO), Lithium Nickel Manganese Oxide (LMO), and Lithium Titanium Oxide (LTO). This paper explores the safety aspects of lithium-ion batteries, emphasizing best practices and strategies to mitigate risks in industrial and energy storage applications [1].

DISCUSSION

Hazards & Risks

Lithium-ion batteries come with several safety risks that should be taken seriously. First, if not handled correctly, they can cause electrical shocks, which can be dangerous. Second, these batteries can catch fire if they are damaged, overcharged, or exposed to high heat. Third, if a battery fails, it can lead to thermal runaway, where it releases a lot of heat, flammable gases, or flames. Fourth, short circuits can create arc flashes, which can cause burns and fires. Additionally, when lithium-ion batteries fail, they can release harmful and flammable gases. Another issue is the formation of dendrites, which are tiny spiny structures that can grow on the battery's surface. If these touch the battery's cathode, they can cause a short circuit and potentially start a fire. Thermal runaway can happen due to overheating, overcharging, physical damage, extreme cold, malfunctions, or deep discharge. Short circuits can also occur from accidental contact or dendrites. Manufacturing defects and design flaws can add to these safety concerns. It's important to understand these risks and take steps to use lithium-ion batteries safely in different situations.

Case studies

In 2023, the USA reported 445 Li-Ion battery fires, resulting in 214 injuries and 38 deaths. From 2011 to 2023, there were 63 failure events related to utility and commercial Li-Ion battery energy storage, with South Korea reporting 31 and the USA 19 incidents. Some defects, like thermistor issues, box damage, epoxy level problems, and feeder damage during welding, do not pose risks during cycling or passive storage but can be hazardous near combustible materials. In 2021, a fire at an abandoned paper mill in Illinois ignited over 200,000 Li-Ion batteries stored for a solar project due to water leakage from the roof. By August 31, 2024, South Korea had recorded 72 battery fire incidents in 2023. Additionally, defects such as shorted or dented cells, rusted cells, and packaging with IR failure are also dangerous during cycling and passive storage.

Types of Application

Industries generally find variety of applications of Lithium-Ion batteries in its operations. Individual battery cells applications include portable hand tool batteries, AAA, AA, and 9V rechargeable batteries, AED batteries, and spare laptop batteries (either disposed of or stored). Battery packs applications consist of batteries for automated guided vehicles, powered industrial trucks, robotics, electric vehicles, machine UPS, bulk storage, and battery energy storage systems (BESS) in both open air and box configurations.

General Activities

General activities associated with lithium-ion batteries include the following.

Manufacturing

Production of battery cells, modules, and packs, involving processes like electrode fabrication, cell assembly, and quality testing.

Testing

Conducting performance, safety, and reliability tests to ensure batteries meet industry standards and specifications.

Charging and Discharging

Managing the charging cycles and discharging processes to maintain battery health and optimize performance.

Monitoring

Using battery management systems (BMS) to monitor voltage, temperature, and state of charge (SOC) to ensure safe operation.

Maintenance

Performing regular checks and maintenance to extend battery life and prevent issues like thermal runaway.

Recycling

Implementing processes for recycling used batteries to recover valuable materials and reduce environmental impact.

Research and Development

Innovating and improving battery technology, including enhancing energy density, lifespan, and safety features.

Installation

Setting up batteries in various applications, such as electric vehicles, renewable energy systems, and consumer electronics.

Disposal: Following regulations and guidelines for the safe disposal of end-of-life batteries to minimize environmental risks.

CONTROL MEASURES

Based on the hazards and risks present in the usage and handling of Lithium-Ion batteries, many safety strategies have been deployed across industries. The solutions have been classified based on the category of the equipment being used.

Fire Safety Protection

Active Fire Suppression Systems

1. Use a mix of 50% ethylene glycol and 50% de-ionized water to cool batteries and reduce fire risk.
2. These systems are designed for battery storage and Battery Energy Storage Systems (BESS).
3. A battery fire caused by thermal runaway is difficult to control.
4. Suppression systems should cool the battery and manage thermal runaway.
5. Fire systems should operate for at least 30 minutes to cool batteries and prevent re-ignition.
6. Quick smoke detectors are recommended in charging and storage areas.
7. Water and water mist are preferred for cooling and safety in high-voltage systems.
8. Use powder agents like K2CO3 to stop flammable gas production.
9. For a 2,500 square foot room, use a sprinkler density of 12 mm/min (0.3 gpm per square foot).
10. Use dry aerosol systems in small areas with limited water use, like server rooms.

Passive Fire Protection Systems

1. Install fire-rated metal barriers between battery racks.
2. Use thermal barriers to prevent thermal runaway from spreading.
3. Foam and aerogel can be used in thermal barriers to protect sensitive parts.
4. Phase Change Material (PCM) should be used to manage heat during phase changes.
5. Allow for pressure release in battery areas to prevent explosions.
6. Keep hazardous gas levels below 25% of the Lower Explosive Limit (LEL).
7. Ensure battery packs are separated and that there is good airflow between them.
8. Store batteries in dedicated fire-rated rooms, away from flammable items.
9. Control battery room power from outside for safety.
10. Do not store combustible / flammable equipment in electrical rooms.

Other Fire Protection Measures

1. Test batteries according to UL or NFPA standards before use.
2. Have isolation mechanisms to disconnect battery units in case of fire.
3. Store batteries in well-ventilated spaces to help reduce temperature.
4. Create separate battery rooms with good ventilation and fire-rated structures.
5. No smoking is allowed in battery and electrical rooms to reduce fire risk.
6. Regularly check temperatures and address any changes over 3 degrees Celsius.
7. Test batteries for dendrite formation after several charge cycles.
8. Regularly maintain and test electrical systems and fire protection systems.
9. Limit hot work in battery rooms to avoid fire hazards.
10. Provide fire safety training for employees to ensure trained staff are available.

Emergency Response Requirements

Every site or region must create their own Emergency Response Procedure for Li-Ion battery fires based on their operations. However, the following cases must be considered:

1. If the Battery vents, avoid contact with internal battery materials. Evacuate the area and close doors if safe to slow the fire's spread. Ensure no one re-enters the building for any reason, as vented battery gases, vapor, and smoke are highly toxic and flammable.
2. If the battery gets too hot, place it on a non-flammable surface and evacuate at least 15 feet away. If available, cover the battery with a fire blanket. If a hissing sound or smoke starts, follow the procedure for thermal runaway.
3. If thermal runaway occurs, evacuate the building unless you are authorized for firefighting. If trained, you may attempt to extinguish a fire smaller than a 5-gallon waste can. Do not pour water directly on the burning battery; instead, if safe, dump half a gallon of sand over the fire quickly for better cooling. Use an appropriate fire extinguisher if available, and dispose of batteries safely once cooled.
4. For leakage from a Li-Ion battery, evacuate the area and remove any nearby combustible materials.
5. For first aid, provide measures for inhalation hazards and contact with skin or eyes.

Battery Management System

A Battery Management System (BMS) is an electronic system that manages a rechargeable battery (or battery pack). It ensures the safety, performance, and longevity of the battery by monitoring its state, controlling the charging, and discharging process, and balancing the individual cells within the battery pack. The BMS helps prevent overcharging, overheating, and deep discharging, which can damage the battery and reduce its lifespan.

1. Monitoring: The BMS keeps track of the battery pack's operating parameters and alerts users if any battery is nearing its limits.
2. Gas Detection: It uses aspiration-type lithium-ion off-gas detectors to find early signs of battery failure by checking for electrolyte vapours.
3. Temperature Monitoring: Thermal imaging infrared (IR) sensors scan battery surfaces for hot spots, helping to prevent fires or explosions.
4. Power Quality Monitoring: Power quality (PQ) sensors check the quality of electricity lines and alert users to issues like voltage drops, spikes, or interruptions.

Labelling Requirements

1. Batteries must be labelled according to international and local standards, such as the Bureau of Indian Standards (BIS) in India.
2. All batteries should have a crossed-out wheeled bin symbol to indicate proper disposal.
3. Batteries containing lead (Pb), mercury (Hg), or cadmium (Cd) must display the corresponding symbols.
4. Rechargeable batteries should be labelled with their capacity in milliampere-hours (mAh) or ampere-hours (Ah).
5. Automotive batteries should show their capacity in ampere-hours (Ah) and Cold Cranking Amperes (A).
6. The minimum label size varies depending on the type of battery, and all batteries must include a QR code for accessing information.
7. The labels should indicate the type of lithium-ion battery, its voltage rating, its ampere-hour rating, and sometimes its dimensions.

Handling and Storage Requirements

1. Store lithium-ion batteries in a cool, dry, and well-ventilated place at room temperature, away from heat sources.
2. Keep batteries at least 3 meters away from explosives, combustibles, and other flammable materials.
3. Regularly check the battery's health; if you see any damage or swelling, stop using it immediately.

4. Monitor the battery temperature to prevent overheating.
5. Handle batteries gently, avoiding drops, punctures, or crushing, and keep the area clean to prevent damage.
6. Do not expose batteries to high temperatures or humidity; the ideal temperature range is 4 to 27 degrees Celsius.
7. Avoid storing batteries in direct sunlight or areas prone to water spills.
8. Never short-circuit the battery and avoid using metal accessories that could cause accidental short circuits.
9. Do not open, modify, or burn lithium-ion batteries, and do not stack heavy materials on top of them.
10. When storing batteries for a long time, keep them charged at no more than 50% capacity and remove them from equipment if not in use for an extended period.

Charging Requirements

1. Always use a charger designed specifically for your device or battery.
2. Only use chargers provided by the manufacturer.
3. Choose chargers that have battery monitoring and auto cut-off features to prevent overcharging.
4. Ensure batteries are charged and discharged within the manufacturer's recommended temperature range.
5. Purpose-built battery charging cabinets are available that include fire monitoring and suppression systems.
6. Never charge damaged or non-rechargeable batteries, as they can explode or catch fire.
7. Always handle and store damaged batteries with care.
8. Never charge lithium-ion batteries unattended or overnight, and don't leave them plugged in when not charging.
9. Provide adequate ventilation in charging areas.
10. Avoid charging batteries in parallel and maintain a safe distance from combustibles when charging.

Dismantling Requirements

1. Obtain authorization before initiating the dismantling process.
2. Use a fume hood along with PPE, including a respirator, nitrile gloves, and safety glasses.
3. Keep a sand/fire extinguisher nearby for safety.
4. Use non-conductive tools to open the battery and avoid prying it open with sharp tools.
5. Tape the leads for insulation and place them in a clear disposal bag after dismantling.

Discharging Requirements

1. Discharge batteries in a well-ventilated area away from flammable materials.
2. Wear mandatory PPE: anti-corrosive gloves, respirators, aprons, and safety goggles.
3. Pour enough salt water to fully submerge the battery.
4. Use a nylon rope to immerse the battery in the saltwater; this may produce smoke.
5. If abnormal smoke appears, add more salt water until the smoke stops.
6. After discharging, remove the battery, dry it, and store it separately for recycling.
7. Store damaged or discharged batteries at least 15 meters away from the main building in closed metal bins.
8. If stored in a separate building, ensure it is at least 6 meters away.
9. Never leave discarded batteries unsupervised while on operational premises.
10. Ensure the work area is free of combustibles, inspect the batteries beforehand, and keep sand or vermiculite nearby, with steel bins filled with water at least 3 meters away from the building.

Packaging Requirements

1. Insulate both battery terminals with caps or heat shrink to prevent short circuits, as used batteries can still have some charge.
2. Pack batteries in EPE foam padding that is at least one inch thick on all sides for protection against impacts.
3. Secure the batteries upright and add padding to stop them from moving inside the packaging to avoid short circuits.
4. Display caution stickers or labels for lithium-ion batteries, including emergency contact information.
5. Do not dispose of batteries with sharp objects or liquids.

Transportation Requirements

1. Always check that the battery terminal voltage is 0V before transporting.
2. Do not stack bins; ensure that bins or trolleys carrying scrap batteries are secured inside the vehicle.
3. Secure or remove any loose items to prevent accidental damage to the battery during transport.
4. Replace worn-out impact absorption padding with new padding as needed.
5. Take precautions to prevent accidental dripping or leakage of water into the battery packs while in transit (e.g., during rain).
6. Follow regulations like UN3480, UN DOT 38.3, and IEC 62281, or any country-specific rules for transporting lithium-ion batteries.
7. Whenever possible, transport batteries in their original containers; if not, use non-conductive containers with compartments.

CONCLUSION

In conclusion, effective fire protection and emergency response procedures for Li-Ion batteries are essential for ensuring safety in environments where these batteries are used. Active and passive fire suppression systems play a critical role in managing fire risks, with specific measures tailored to mitigate thermal runaway and handle battery venting. Comprehensive emergency response protocols must be established at each site, addressing various scenarios such as battery overheating, thermal runaway, and leakage. Additionally, regular maintenance, safety training, and effective first aid measures are vital for minimizing hazards associated with battery use. By implementing these strategies, organizations can better protect personnel, property, and the environment from the risks posed by Li-Ion batteries.