**International Journal of Research Publication and Reviews**

Journal homepage: www.ijrpr.com ISSN 2582-7421

# A Study On Thermal Challenges In Lithium-Ion Batteries: Managing The Heat

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ABSTRACT :

The paper comprises the study on thermal challenges in the Lithium-ion batteries. Lithium-ion batteries are first invented by the British scientist named Mr. Stanely Whittingham in the year of 1970. The battery provides best performance and having more capacity. These batteries are having two electrodes named anode and cathode and a separator between them. But these batteries having an issue with the thermal runaways. This thermal runaways causes the batteries burn or blast. Now-a-days Many thermal issues Takes place in the batteries. Most of the issues occurring in the electric vehicles because of using the batteries in these vehicles widely due to high energy density, more capacity, best performance, long life span. When the battery is over heated thermal runaway takes place and increase the temperature of the battery to critical state and causes the burning. These thermal issues are can be controlled by providing the cooling vents in the machines, using quality materials in electrodes, preventing the short circuits. By controlling these thermal issues lithium-ion battery can be used in most of the applications and these batteries are unstoppable. The main aim of the topic to find the best ways to prevent the thermal issues from the batteries.

**Keywords**: Lithium-ion batteries, Thermal Runways, Safety, Rechargeable, Reusable.

## 1.INTRODUCTION :

### *1.1. Introduction to Thermal issues in Lithium-Ion Batteries.*

Battery: A Battery is a Electrochemical device which can be charged with Electric current and discharged whenever required.
Thermal Runaway: It is a chain reaction in battery cell which is very difficult to stop once it was started.
The Lithium-Ion Batteries first invented by the British scientist named Dr. Stanley Whittingham in the year 1970. He is also awarded with the Noble Prize. These batteries are also great at holding their charge. These batteries are dangerous if the properly not manufactured, because of cells have flammable electrolytes. These lithium-ion batteries are having the basic components.

- Anode: The electrode in a electrical device through which current flows in from an outside circuit.
- Cathode: The electrode where electricity flows out of the circuit.
- Electrolyte: It is a substance that dissociates in water into charged particles called ions.
- Separator: It is a polymeric membrane positioned between the anode and cathode.

When the battery is heated then the thermal runaway Increase the temperature of the battery to a critical condition. These batteries are power the devices, electrical vehicles and also stores the renewable energy. Its rechargeability and high energy density made them popular for the modern technology. These batteries are sensitive to temperature variations and life span, performance of the battery is also decrease if it Exceed its temperature range. Thermal abuse, mechanical abuse and electrical abuse are also the part of thermal runaways. Now-a days the accidents to the electric vehicles due to thermal runaways in lithium batteries are occurred. Many scholars are studying thermal runaway of lithium-ion batteries and trying to find some better ways to control the thermal issues. The safety of the battery is Depends upon its operating environment. The battery should not be overheated. The batteries are having some harsh working conditions like vibration, over charge, over heat, short circuit and some abuse conditions.

## 2. LITHIUM-ION BATTERY :

### *2.1. Working principle of Lithium-ion battery.*

Lithium-Ion Batteries are consisting of four components named cathode, anode, separator, and Electrolyte. The anode and cathode carriers the charge carries to the lithium-ion battery. The separator divides the electrodes to prevent the short circuits. The function of the parts affects the lithium-ion battery negatively. The electrodes emit uncontrollably high heat when operation begins. Damage to a separator causes LIB processes to shift from regulated to unregulated electrochemical reactions, producing heat in the process. In such instances, the electrolyte works as a fuel supply for further heat creation.

So the necessary safety measures ought to be implemented. Improving LIB safety performance requires regulating the battery. The four cell types that are most frequently utilized in LIBs are coin, pouch, prismatic, and cylindrical cells. Both high- and low-capacity cells are classified as cylindrical cells. Low-capacity cells are utilized in the majority of applications because high-capacity cylindrical cells have a high impedance. Due to the huge capacities of prismatic cells, fewer cells must be connected to create a battery pack with the necessary capacity, which improves system stability overall. Coin cells are tiny devices that are commonly used to test materials in laboratories. Prismatic cells have the highest safety risk, followed by pouch cells and cylindrical cells. Prismatic cells have poor heat dissipation, which complicates the cooling procedure and cell construction. Better heat dissipation is made possible by cylindrical-based battery packs because of their small size, lower energy storage capacity, and space between individual cells. Prism and cylindrical cells have a metallic shell that can sustain high pressure. A pouch cell battery may enlarge and develop a weak spot on its surface, which could result in a fire.

### *2.2. Challenges in Lithium-Ion Batteries.*

Li-ion batteries are beginning to be utilized more frequently in electric vehicles after initially being mostly found in portable electronics like laptops and cell phones. In order to store sustainable energy produced from renewable sources, Li-ion batteries will also be taken into consideration for use in sustainable energy systems. The creation of next generation Li-ion batteries and upgrades to current Li-ion batteries due to thermal concerns are necessary given the rising need for energy storage. in an effort to lower Li-ion battery costs. Creating new battery chemistry to take the place of the current Li-ion battery technology is still difficult. It is preferable to identify electrode pairs with both high specific capacities and high operating cell voltages in order to maximize the energy density of Li-ion batteries. Numerous anode candidates have the potential to raise the specific capacities. One further issue that must be appropriately addressed is the safety risk. The significance of battery safety has been brought home by recent reports of Li-ion battery fires involving Tesla Model S cars and German 787 passenger planes. In order to guarantee the widespread adoption of electric vehicles and broaden the market for vehicles powered by Li-ion batteries, attention must be paid to battery management systems that improve the safety of the massive battery packs found in automobiles. All solid-state batteries and Li-ion batteries based on aqueous electrolyte should be developed to be non-flammable. High voltage (5 V) cathodes and high capacity anodes will be used in next-generation lithium-ion batteries. The development of electrode materials with a reduced carbon footprint is still difficult.

### *2.3. Components in the lithium -ion battery.*

**2.3.1. Anode:** Anode materials are more well studied and come from a larger variety of sources. Anode materials have an impact on Li-ion battery electrochemical properties, such as cyclability, charging rate, and energy density. In commercial Li-ion batteries, carbon still holds a dominant role. An excellent cyclability is achieved by the minimal irreversible migration of lithium ions in and out of graphitic carbon thanks to its layered structure. Over the course of the last 20 years of development, carbon anodes have come closer to reaching the 372 mAh/g theoretical maximum capacity. For lithium storage, silicon and a host of other materials that are known to alloy with lithium are excellent substitutes for carbon. These substances could electrochemically alloy and de-alloy with lithium at room temperature. When a substance is charged or discharged, significant changes in its specific volume cause the alloying process to occur. Within a few cycles, the extreme mechanical stress may cause the crystal structures to collapse and the active materials and current collectors to fragment into tiny fragments. Their weak cyclability as a result has severely restricted their applicability in real-world scenarios.

**2.3.2. Cathode:** The ingredients like electrodes, electrolyte, and separator are what give lithium-ion batteries their safety. The intricate internal workings of Lithium-ion batteries can occasionally result in thermal runaway due to their complicated engineering design. To enhance the cathode materials' thermal performance, a great deal of effort has been done. There are two main methods used: protective coating and element substitution. The cathode materials outside surface can be coated with a protective substance to enhance its thermal performance. This protective coat is a thin layer of a lithium ion conducting substance that, by averting side reactions, mostly shields the cathode's surface from direct contact with an electrolyte. The addition of a protective covering results in less heat being produced. Chemical or thermal materials can be used to cover the cathode. The cathode materials are distinct in that the micro particles have a concentration gradient, with a decreasing concentration of Nickle and an increasing concentration of Manganese at the surface. The core of the micro particles is rich in Nickel, while the outer layer is rich in Manganese. The high capacity is provided by the nickel rich cathode's core. The surface and outer layer with the concentration gradient Increase the thermal stability. The cathode materials showed excellent safety qualities and an amazing high reversible capacity.

**2.3.3. Separator:** Li-ion battery separators are crucial parts of the battery. Most electrochemical devices that use a liquid electrolyte, such as fuel cells, capacitors, and different types of batteries, frequently use separators. In a Li-ion battery, the separator is essential for preventing short circuits by preventing direct physical contact between the cathode and anode. The separator permits lithium ions in the electrolyte to flow through it concurrently. When in contact with the electrolyte and electrodes, the separators must be inert and chemically stable. It must also be mechanically durable to endure the stress and puncture caused by electrode materials. Many separators have been investigated, such as nonwoven fabric mats, inorganic membranes, and microporous polymer membranes. Microporous polymer membranes based on polyolefin materials are primarily utilized in commercial Li-ion batteries with liquid electrolyte. To improve ionic conductivity and lower resistance, the microporous polymer membranes could be made extremely thin and porous. Utilizing microporous polymer membrane as a separator has an additional intriguing benefit when used with multilayer composites that are appropriately developed. If there is a short circuit or thermal runaway, the separator has the ability to cut off the battery.

**2.3.4. Electrolyte:** Anode and cathode redox environments, as well as the voltage range involved, require careful selection of the electrolyte to prevent breakdown or degradation. The electrolyte should have a stable and inert state within a reasonable temperature range. A solution of lithium salts in organic solvents is commonly used as a liquid electrolyte in Li-ion batteries. Due to the flammable nature of the solvents, which are extremely hazardous, the current organic liquid electrolyte may catch fire in cases of thermal runaway or short circuit. In the future, the electrolyte should also be less expensive to create and have a better environmental impact. Lithium salts at high concentrations are solvated using carbonate solvents that have a high dialectic constant. In order to achieve high ionic mobility within the operational temperature range, solvents having a low melting point are necessary.

***2.4. Thermal Effects in Lithium-Ion Batteries.***

The operating and storage temperatures of lithium-ion batteries have an impact on their safety, longevity, and performance. These consist of low temperature performance, capacity, thermal runaway, and electrical imbalance between several cells in a battery pack. The influence of temperature on each of these events is emphasized. coupling between transport processes and electrochemical reactions, which influences temperature. Even when batteries are not cycled and are kept in storage, capacity and power decline may still occur. When the battery is submerged at a greater temperature and state of charge, the power fade increases significantly. the quantity of energy that can be recovered from lithium-ion batteries after they have been cycled or stored at different temperatures. Reversible self-discharge of lithium-ion batteries lowers their capacity retention. While self-discharge is not anticipated to be a major issue for lithium-ion batteries used in electric cars, it can be in other applications when the cell is left in a hot environment for extended periods of time without being utilized. Thermal runaway occurs in batteries when elevated temperatures trigger heat generating exothermic reactions, raising the temperature further and potentially triggering more deleterious reactions.

***2.5. Heat generation and gas venting behaviour of lithium-ion batteries.***

Because of the migration of lithium ions and the electrochemical reaction, lithium-ion batteries can get hotter. Under normal circumstances, however, this temperature rise should not have a negative impact on the safety or performance of lithium-ion batteries. On the other hand, if there is misuse that raises the battery's temperature further, the internal electrochemical side reaction may become more intense, producing a lot of heat along with flammable gasses and ultimately resulting in a thermal runaway catastrophe. The mechanism of heat generation and the behaviour of lithium-ion batteries' gas venting during the thermal runaway process will be outlined in this section.

**2.5.1. Heat generation mechanism:** The electrochemical reaction heat produced by interface charge transfer, known as activation polarization loss, concentration polarization loss, and ohmic polarization loss, are the primary sources of heat in lithium-ion batteries. A lithium-ion battery's heat generation rate is defined as the amount of heat produced per unit volume per unit of time. The Bernardi equation, which is based on the law of conservation of energy, is frequently employed in the research of heat generating characteristics of lithium-ion batteries under typical charging and discharging conditions.

**2.5.2. Gas venting behaviour:** The solid-electrolyte interphase breaks down, the anode collapses, the intercalated lithium reacts with the electrolyte, the separator melts, the active ingredients in the cathode and the electrolyte lithium salt break down, the electrolyte solvent oxidizes, the intercalated lithium reacts with the binder, the ceramic coating of the separator collapses, and an internal short circuit happens when lithium-ion batteries are abused from various sources. A lithium-ion battery experiences sudden temperature changes during these times, along with a noticeable gas leak.

## 3. SAFETY METHODS OF LITHIUM-ION BATTERIES :

***3.1. Safety methods for thermal issues.***

Now-a-days these thermal issues are the major problem in lithium-ion batteries. Lithium-ion battery safety is crucial because these batteries are widely used in various devices. Proper handling and maintenance can prevent accidents and ensure the safe use of lithium-ion batteries. There are some methods to control the thermal issues.

They are:

- Proper Charging
- Battery Management System (BMS)
- Ventilation
- Physical Protection
- Temperature Control
- Emergency Response

**3.1.1. Proper Charging:**

- Charging the lithium-ion batteries when the battery is going to discharge fully and avoiding the over-charging of the batteries. using the chargers designed for the battery type, voltage, and capacity of the lithium-ion battery.
- Avoid using of the substandard batteries it helps the lithium-ion batteries from physical damage due to incorrect connectors, overheat due to poorly connected chargers, short circuit due to low quality charger may not have necessary safety features.
- Slow charging is better for the lithium-ion batteries because it produce less heat while charging.

**3.1.2. Battery Management System (BMS):**

- By implementing the robust battery management system it can control the various aspects of the battery. It can control the temperature by placing the temperature sensors in the battery pack monitor the temperature of the cells. BMS measures the thermal management and control the discharging or reducing charging in high temperature conditions.
- It measures the current flowing in and out of the battery and this information is used to control charging and discharging rates this helps to

prevent the overcurrent passing and damaging the cells. It monitors the voltage of cells to ensure that no cell is overcharged or discharged which may causes the thermal issues.

- The BMS uses voltage, current, and temperature data to estimate the battery's SOC (how charged it is) and SOH (its overall health and remaining capacity). In extreme cases, when the BMS detects critical faults, it can initiate a safety shutdown of the battery to prevent dangerous situations like thermal runaway.

**3.1.3. Ventilation:**

- This ventilation helps in consistent air flow around the battery to carry away the heat because batteries generate heat during charging and discharging cycles. By the ventilation the battery can maintain a stable operating temperature it helps in increasing the life span of the battery.
- Ensuring the ventilation is free from dust otherwise the dust particles accumulate on the surface of the battery and impede the heat dissipation and causes overheating. Filters may be need for ventilation in the dusty environment.
- These ventilations helps the lithium ion batteries from overheating and causing thermal runaway to the lithium ion batteries. Ensure that airflow is directed to and from the battery packs to effectively remove heat. Fans or natural convection can be used to control airflow.
- Calculate and maintain an appropriate air exchange rate to ensure a sufficient supply of fresh air while removing any heated or potentially gaseous air from the battery installation area.

**3.1.4. Physical Protection:**

- Avoid physical damage to the battery, as it can lead to short circuits and thermal problems. Handle batteries with care, and avoid dropping or puncturing them. Protect batteries from physical impacts, punctures, and crushing. Damage to the battery's outer casing can lead to internal short-circuits and safety risks.
- Ensure that lithium-ion batteries are enclosed in devices or cases that are designed to securely hold and protect the battery. Avoid exposing lithium-ion batteries to extreme heat or cold. High temperatures can lead to thermal runaway, while low temperatures can reduce battery performance.
- Keep batteries away from water and moisture, as moisture can damage the battery's internal components and lead to malfunctions or short circuits. When disposing of old or damaged lithium-ion batteries, follow proper recycling and disposal procedures to minimize environmental and safety hazards.

**3.1.5. Temperature Control:**

- Operate and store lithium-ion batteries within their recommended temperature range (typically 0°C to 45°C or 32°F to 113°F). Extreme temperatures can lead to thermal issues. Similar to charging, discharging should also occur within the recommended temperature range. Operating a battery below the lower limit can result in reduced capacity and power output.
- In cold environments, insulating the battery or device can help retain heat. This can be important for applications in extreme cold conditions. In some cases, battery warmers are used to preheat batteries in extremely cold conditions to maintain their performance.
- Regularly check the temperature of lithium-ion batteries, especially during charging and discharging. Many devices have temperature sensors to provide feedback on the battery's condition.

**3.1.6. Emergency Response:**

- Always prioritize safety. Ensure that all individuals are safely evacuated from the area if there is a risk of fire, explosion, or hazardous fumes. Contact emergency services immediately, including the fire department, if there is a fire or the potential for one. They are equipped to handle battery fires and chemical related emergencies.
- Ensure proper ventilation to disperse any potentially harmful fumes or gases that might be released during an incident. Fire fighters should use Class D fire extinguishers, dry sand, or other suitable extinguishing agents to combat lithium-ion battery fires. Avoid using water, which can exacerbate the fire.
- If there are signs of leakage or damage to the battery casing, it is important to contain the area to prevent contamination and exposure to harmful chemicals.

### *3.2. Thermal behaviour of lithium-ion batteries.*

It is equally crucial to make sure the battery operates within a safe temperature range as it is to enhance the electrochemical performance. Heat buildup and accumulation in large battery packs will unavoidably raise the battery's total temperature and quicken the electrochemical reaction inside. If the heat cannot be released adequately, it will cause smoking, an explosion, and a further dramatic rise in interior temperature. Even if there is no thermal runaway, operating in high-temperature conditions will negatively impact the battery's charging and discharging properties and reduce its lifespan. Temperature generally has an impact on a number of battery characteristics, including as how well the electrochemical system functions, how well a battery rounds trips, how well a battery accepts charges, how much power and energy it can hold, how reliable it is, and how much it costs over its lifetime. The mechanisms of lithium-ion battery aging, such as power loss and capacity degradation. Utilizing electrochemical techniques and post-mortem research, the scientists examined the impact of temperatures between 20°C and 70°C on the ageing behaviour of cycled lithium-ion batteries quantitatively. The rate of aging increases as the temperature drops below 25°C. The aging process accelerates as the temperature rises above 25°C. This discrepancy is merely due to various aging mechanisms. The increased rate of lithium loss and the significant rise in negative electrode resistance with cycling caused by the repeated film development over the anode surface are the causes of the larger capacity fading for the cells cycled at the higher temperature.

### *3.3. Battery Cooling system.*

The sensitivity of lithium-ion batteries to temperature is high. For battery operation, the temperature range is 15◦C to 35◦C.When quick charging or other high current loading situations are present, the transient battery may undergo an unacceptably high temperature rise. In a battery pack, lithium-ion batteries are typically placed in a series-parallel configuration. Increased resistance resulting from cell interconnections manifests as an unequal dynamic load. Because of the way the cells are arranged within the battery pack, batteries not only have uneven heat generation rates, but they also have uneven temperatures during the charging and discharging phases. Therefore, it is important to regulate the temperature in order to keep it within a reasonable range. There are now numerous established battery thermal management solutions available that aim to maintain temperature uniformity within a certain range. They investigate different cooling techniques. These consist of mixed cooling as well as liquid, vapour compression, and air cooling. The Battery Thermal Management system maintains the battery temperature within a reasonable range by using the proper cooling techniques. Therefore, the battery's internal temperature can be kept within a safe thermal limit even at a higher draining rate. When it comes to removing heat, the liquid cooling system appears more promising than the air cooling system. Temperature has a significant impact on all metrics: lifetime, mileage, and economy. The lifespan, efficiency, and mileage of the battery will all be increased if those BTM systems can maintain the temperature within an ideal range. More luxury cars will be available in the future.

### *3.4. Battery thermal management system.*

Incorrect temperature might result in unanticipated performance reduction and could even cause Li-ion batteries to thermally runaway. Consequently, when assembling the battery pack, a BTMS is needed. Maintaining a uniform temperature distribution across the cell and pack while keeping the batteries within the ideal operating temperature range is the fundamental goal of a battery tracking system (BTMS). Aside from that, some aspects including system dependability, weight, cost, complexity, and compactness must be taken into account for real-world vehicle applications.

#### 3.4.1. Battery Cooling:

There are two types of BTMSs for cooling: passive and active. BTMSs are classified as either internal or external systems based on the position of the heat removal mechanism. The majority of thermal management techniques remove heat at the battery's surface since they are external. Because of the thermal resistance between the cooling media and the battery core, the maximum temperature is found inside the cell. Increasing the convection velocity has the potential to significantly widen the cell's temperature differential. A viable way to increase temperature uniformity is internal cooling, which extracts heat directly from the inside. In order to dissipate the heat produced inside the battery, the liquid electrolyte that circulates through the channels is used. Compared to external cooling, the suggested internal cooling method observably enhances temperature homogeneity, as seen by the higher heat generation rate near the electrodes than in other places. When it comes to cooling media, thermal management techniques are divided into four categories: liquid cooling, air cooling, phase change cooling, and combinations of these.

#### 3.4.2. Air Cooling:

Compared to forced air cooling, natural air cooling has a substantially lower convective heat transfer coefficient. Thus, low energy density batteries are the only ones for which natural convection cooling works. Despite its clear benefits of simplicity, light weight, and affordability, it is little investigated at the moment. The forced air flow's heat transfer coefficient is significantly increased by the installation of fans or blowers, which is crucial for meeting heat dissipation requirements. Three areas have received the most attention in recent years when it comes to improving active air cooling: thermal model development, parametric optimization, and geometric construction. Through the use of thermal resistance model simulations, the impacts of various geometric layouts with various kinds of forced air flow intake and exit ducts are compared. The maximum temperature can be lowered even more and temperature uniformity can be increased by adding a pressure relief ventilation to the outlet air duct. It may also be helpful if the battery releases harmful fumes.

#### 3.4.3. Liquid Cooling:

Fluid chilling Because liquid coolant has a higher thermal conductivity than forced air cooling or natural cooling, it is a more desirable choice for the cooling medium. There are two types of liquid BTMSs: direct cooling and indirect cooling. The battery module is cooled directly by submerging it in the circulated dielectric coolant; indirect cooling is achieved by having the fluid circulate via separate tubing or a jacket surrounding the module or cold plate that the modules are put on. Indirect cooling always has more thermal resistance since heat must go through the tubes' or plates' surface before the coolant can remove it. Direct liquid cooling, on the other hand, uses a more efficient heat transfer method since fluid and batteries come into direct touch. But, when a high forced flow rate is required, the high viscosity of dielectric fluids, such mineral oil, results in significant power consumption. Using low-viscosity liquids, such as water, for indirect cooling, however, makes things different. forced air cooling, fin cooling, indirect liquid cooling, and direct liquid cooling—four different cooling techniques—by contrasting their thermal performances. More precisely, two to three times higher than the other methods, the air cooling method was shown to require the highest parasitic power cost. Further research revealed that, for automotive applications, indirect liquid cooling was preferable than direct cooling.

## 4. COMPARISION OF BATTERY MANAGEMENT SYSTEM, PROPER CHARGING, VENTILATION :

| S. No | Battery Management System (BMS) | Ventilation | Proper Charging |
|---|---|---|---|
| 1 | It is a crucial component in lithium-ion batteries that manages and protects the battery pack. It ensures safe and efficient operation. | These systems are used to control and manage the temperature within an environment where lithium-ion batteries are stored or used. | It involves following guidelines and recommendations to charge lithium-ion batteries safely and efficiently. |

| | | | |
|---|---|---|---|
| 2 | It monitors the state of charge, state of health, and temperature of individual cells within the battery pack. | Ventilation helps dissipate heat generated during battery operation. | This includes using the right charger, avoiding extreme temperatures during charging, and not overcharging or deep discharging the battery. |
| 3 | It balances the cells to prevent overcharging or over-discharging and can disconnect the battery in case of critical issues. | It prevents the temperature from exceeding safe limits. | It also involves avoiding rapid charging in extreme conditions. |
| 4 | BMS plays a significant role in preventing thermal runaway and overvoltage, which can lead to battery fires. | It is crucial to avoid overheating, which can lead to thermal runaway, reduced battery life or battery failures. | Following proper charging practices reduces the risk of overcharging, overheating, and other issues that can lead to damage to the battery. |
| 5 | It can optimize the battery's performance, extend its lifespan, and improve its overall efficiency. | Maintaining an appropriate temperature through ventilation can help ensure that the battery operates optimally and has a longer lifespan. | Charging the battery correctly can help maintain its capacity and extend its lifespan. |

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