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Thermal Management System in Battery of Electric Vehicle: A Review

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Abstract
The performance, safety, and lifetime of electric vehicles (EVs) are all affected by how well their battery systems deal with heat. This study reviews the current state of the art and future directions of thermal management systems for electric vehicle batteries. Some reliable sources were gathered to bolster the argument. An attempt has been made to explain why thermal management is so crucial for electric vehicle battery systems and how it affects the vehicle's overall efficiency. It investigates active cooling, passive cooling, hybrid cooling systems, and other methods used to control battery temperature. Focusing on preventing temperature fluctuations, excess heat production, and thermal runaway, this article emphasizes the significance of thermal management throughout the charging, discharging, and idling phases.

Keywords: Thermal, Management Battery, Optimum Temperature

1. Introduction

There is rising public concern about the global automobile industry's impact on the environment and energy regulations. Considering the dismal energy and environmental situation, there has been a welcome shift in strategy in the sphere of conventional transportation and energy, resulting in an increase in the production of vehicles that use renewable energy sources and have no harmful byproducts. Inefficient combustion engines (IC engines) are a major contributor to air pollution and climate change, both of which have serious consequences for human health and well-being [1]. The transportation sector now accounts for the largest share (49%) of global oil consumption. Energy saving measures in transportation will assist decrease excessive energy consumption without sacrificing utility or services, since the efficiency of oil use in automobiles is very low. Promoting clean or green energy cars is one of the most original ways to cut energy use. Among the many options being considered to lessen transportation's carbon footprint are hybrid electric cars (HEVs), plug-in hybrid electric vehicles (PHEVs), and pure electric vehicles (EVs). These cars are touted as providing long-term energy savings, access to zero-carbon emission solutions, and the highest potential for using new energy sources [2].

There has been a lot of talk about how electric cars (EVs) might lessen the negative impacts of burning fossil fuels and help the environment. The rising popularity of electric vehicles has prompted researchers to develop better batteries with improved energy density, performance, and safety. When it comes to the many moving parts that make up an electric vehicle's battery system, thermal management is one of the most important in terms of preserving battery performance, guaranteeing safety, and increasing the battery's useful lifetime. Keeping a battery system at the right temperature is crucial to its proper functioning. Battery deterioration, energy efficiency, and safety risks like thermal runaway may all be exacerbated by overheating during the charging and discharging processes. However, the battery's performance might be negatively impacted by very low temperatures, resulting in reduced power output. Therefore, efficient thermal management solutions are required to keep the battery within the acceptable temperature range.[3]

It delves into the difficulties of controlling the temperature of EV batteries, goes through the many methods now in use, and shines a light on the most recent developments in the sector. This study aims to stimulate additional research and development in the vital area of thermal management systems by reviewing the available literature on the topic. The importance of thermal management in EVs and its effect on vehicle performance is emphasized early in the study to provide a groundwork for the subsequent discussion. It highlights the need of keeping batteries at their optimum temperature for increasing energy efficiency, prolonging their lifespan, and ensuring proper charging and discharging. After that, the different methods and tactics used in thermal management systems for EV batteries are discussed in detail in the review. The efficacy of active cooling techniques, such as liquid cooling and refrigerant-based systems, in removing the heat produced by battery operation is investigated. Natural convection and radiation, which are used in passive cooling systems, are also considered. The large energy storage capacity and enhanced temperature control capabilities of phase change materials (PCMs) used in thermal management systems are being investigated.[2]

The difficulties of temperature control in EV batteries are also discussed in this overview to aid comprehension. Efficient thermal management should reduce energy losses without decreasing cooling efficiency, so this trade-off must be considered. Additional difficulties arise from batteries' complicated thermal behavior, such as thermal coupling effects and non-uniform temperature distribution. Modeling and simulation methods are often used to make the best use of thermal management measures. Mathematical models, CFD simulations, and thermal-electrochemical models are all discussed as potential tools for improving cooling system designs, forecasting battery temperature distributions, and understanding heat transfer processes. Researchers and engineers can analyze the efficacy of thermal management and explore design choices with the use of models and simulations before committing to a particular solution.

2. Issues Related to Battery Thermal Management

Due to the difficulties inherent in maintaining a constant battery temperature, thermal management is an essential part of the battery systems in EVs. Battery performance, safety, and longevity are all discussed here in relation to the difficulties in heat management. Here are several ways that the problems may be broken down:[4]

i. Heat Generation and Dissipation: When being charged or discharged, the batteries in electric vehicles give out heat owing to resistive losses and electrochemical reactions. Battery deterioration and energy efficiency losses may be hastened by an increase in temperature, thus it's crucial that this heat be dissipated effectively. The difficulty is in developing efficient cooling systems that control heat dissipation with low power consumption.

ii. Temperature Variation and Uniformity: Maintaining battery performance and life span requires ensuring that temperatures remain consistent throughout the battery pack. However, temperature gradients may be caused by many variables, including the fact that current is not always distributed uniformly, internal resistances might vary, and cells can have different characteristics. This problem necessitates the creation of thermal management systems that may reduce temperature swings and encourage consistent cooling throughout the battery pack.[5]

iii. Thermal Runaway: Extreme heat production may cause thermal runaway, a potentially catastrophic situation in electric vehicle batteries. This may result in the release of gases, the disintegration of electrolytes, and possibly a fire or explosion due to the buildup of heat. It is crucial to preserve the EV's battery pack and other components from damage by avoiding and controlling thermal runaway. Thermal runaway internal short circuit is shown in the figure 1.1 [21]

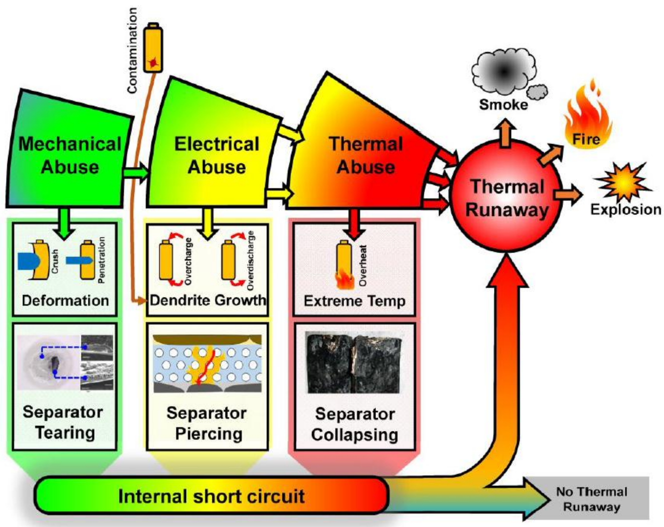

Figure 1.1: Thermal Runway Internal Short Circuit [21]

iv. Transient Thermal Behavior: When operating under variable circumstances, such as quick charging, high discharge rates, or regenerative braking, battery systems exhibit transient thermal behavior. The rapidity of these occurrences makes it difficult to implement thermal management solutions in advance; instead, they must be implemented in real time. When transitory thermal behavior is ignored, performance drops, battery life is shortened, and safety is compromised.[6]

3. Impact of Temperature on Battery Performance, Safety, and Lifespan

Batteries used in EVs are sensitive to temperature, which has a major impact on their performance, safety, and longevity. If you want your electric vehicle's battery to perform at its best and last as long as possible, temperature management and control are essential. Here, we'll discuss how temperature affects battery performance, safety, and longevity to stress the need of thermal management in EV applications.[7]

Temperature has a significant effect on battery performance, modifying important metrics including capacity, power output, and efficiency. A battery's capacity drops at cold temperatures, reducing the quantity of energy that can be stored and later discharged. Higher capacity is possible at higher temperatures, but this is usually accompanied by faster deterioration and a shorter battery life. Higher temperatures are associated with better power delivery, whereas lower temperatures restrict power output possibilities. Furthermore, a battery system's efficiency is affected by temperature because, at higher temperatures, internal resistance increases, which results in greater energy losses during the charging and discharging operations.[8]

Battery safety is also related to temperature. Thermal runaway, defined by uncontrolled temperature growth inside the battery, is a dangerous situation that may be avoided with proper temperature regulation. The results of thermal runaway may be catastrophic, including the release of gases, the buildup of pressure, and the possibility of an explosion. Additionally, battery electrolyte breakdown due to high temperatures might compromise battery system stability and safety.[9]

4. Techniques and Strategies for Thermal Management

Battery performance in electric vehicles (EVs) is greatly aided by careful thermal control. The performance, lifetime, and safety of a system's batteries all depend on how well the system deals with heat. Here, we'll go through the different methods and approaches used for EV battery heat control.[10]

i. Active Cooling Methods:

- **Liquid Cooling Systems:** In liquid cooling, a liquid coolant is circulated near to the battery cells through channels or heat exchangers. This coolant is commonly water or a glycol-based solution. This method efficiently distributes heat produced by battery activity, keeping temperatures steady.
- **Refrigerant-Based Systems:** In place of water, refrigerants like R134a and R1234yf are used in refrigerant-based cooling systems. Thermal management is improved because to the systems' efficient heat transmission and their ability to provide accurate temperature control.

ii. Passive Cooling Methods:

- **Natural Convection:** Passive cooling strategies use the battery pack's inherent ventilation and convection currents to remove excess heat. This method minimizes the need for active cooling components by making use of the battery pack's layout to improve ventilation and heat transmission.
- **Radiation:** Emitting and absorbing radiation of a certain wavelength allows for the dissipation of heat, making thermal radiation another passive cooling technique. Radiative cooling surfaces are commonly coated or made from certain materials to maximize the efficiency of radiation heat transfer.[11]

iii. Hybrid Cooling Systems:

Hybrid cooling systems use both active and passive strategies to regulate temperature more effectively. These systems combine passive cooling methods like natural convection or radiation with active cooling components like liquid or refrigerant-based cooling. Hybrid cooling systems can improve heat dissipation and temperature management since they combine the best features of both technologies.[12]

iv. Phase Change Materials (PCMs)

By tapping into the latent heat associated with phase changes, phase change materials provide useful tools for thermal control. The phase transitions of PCMs allow for efficient thermal management due to their ability to absorb and release heat. They are built into the battery system and function to release stored heat as temperatures drop, keeping the battery at an optimal temperature.[13]

5. Design parameters for BTMS

i. Design configuration of battery manufacturing

An electric vehicle typically consists of a motor driven by electricity, a power electronics controller, a battery pack providing the vehicle's energy, and a mechanical transmission that transfers that energy to the wheels. Since the lithium-ion batteries themselves are the subject of this article, we will look at the battery pack as a whole. Cathode, anode, and electrolyte (lithium salt in a non-aqueous organic solvent) are the three main parts of a lithium-ion battery. Using a combination of solvents allows the electrolyte to meet the requirements of strong ionic conductivity, low viscosity, and small volume. Li-ions may freely flow between the anode and cathode thanks to a separator with a permeable membrane that prevents short circuits. The charging process, also known as intercalation, operates in the opposite way. Figure 1.2 depicts the flow of Li-ions and the general functioning of the cell.[14]

Prismatic pouches have been proposed as a viable alternative to cylindrical batteries because of their superior thermal management and lower production costs. Nonetheless, some people still favor cylindrical batteries due to their convenience in mass production. BTMS and other control devices are packed into modules made up of many of these cells that have been linked together with voltage regulators, safety control devices, and thermocouples. Fig. 1.3 depicts the seven stages that make up the value chain for batteries used in electric vehicles.[15]

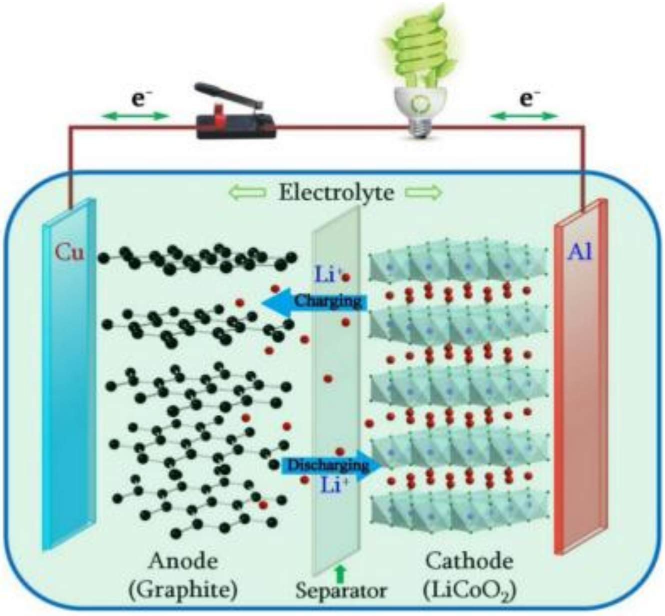

Figure 1.2: Intercalation and de-intercalation in a lithium-ion battery [14]

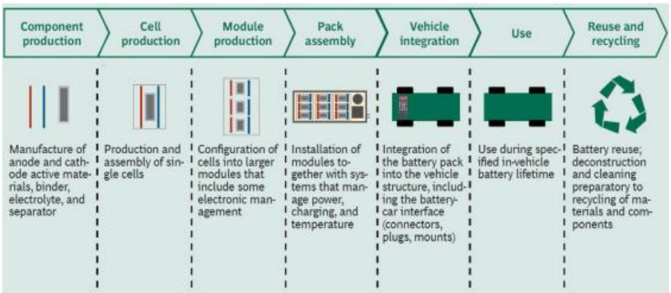

Figure 1.3: The seven steps of value chain of a Lithium-ion battery [15]

ii. Market assessment for design configuration

Since this technology is quickly displacing more conventional forms of power storage, an examination of the global lithium-ion battery sector is essential. Multiple metal-based battery options are now on the market. Lead acid and nickel-metal hydride (NiMH) batteries, which have been on the market for a while and are used either as the primary or secondary power source in many vehicles, are still widely used. As a potential energy source for future EVs, the lithium-ion battery has been widely seen as a viable choice due to its much lower weight compared to other electrochemical based batteries. Lithium-ion batteries need to prove their worth by revealing their limitations, which prevent them from being mass-customized. With its great energy density, low cost, and lack of significant concerns apart from its safety and performance at raised temperatures, the lithium-ion battery emerges as the clear winner when comparing the various lithium-based electrochemical batteries. Lithium-ion batteries have been the subject of much study, and the need for temperature control has been shown via both theory and experiment.[19]

It is common practice to make comparisons between the power output and energy density of these different electrochemical power sources. This methodology is helpful for determining the price-to-earnings ratio and adds to the growing body of data demonstrating Lithium-ion batteries' advantages. P/E sweet spots for BEVs, PHEVs, and EVs. It's important to remember that HEV batteries, although recharged more often while driving, store less energy and are hence smaller. Since it requires more power than energy, its P/E ratio is high. However, a PHEV's performance calls for a battery to provide as much energy and power, making it a vehicle in the middle of the P/E spectrum. Due to its high energy usage, an electric automobile has a lower P/E ratio than hybrids.[16]

6. Different Approaches for Effective BTMS

It is possible to model the thermal behavior of a Lithium-ion battery using mathematical expressions and descriptions based on specific thermal conditions. A Computational Fluid Dynamics analysis of Lithium-ion battery is essential to determine its thermal characteristics. Researchers have used a variety of approaches, such as battery temperature distribution models, thermal runaway models, and numerical simulations of BTMS. A transient thermoelectric model was used to project the temperature dispersal within the 18,650 cylindrical battery cells. There was a greater rise in temperature during discharge than during charging of the battery, the difference decreasing with an increase in C-rate. A relationship was found between thermal behavior and entropy change [22]

Thermal swelling and electrochemical swelling were examined by Oh and Epureanu. A coupled 3-D thermal-structural model was used to study the influence of thermal conduction and thermal expansion coefficient on temperature fluctuations of battery cells and packs. As shown in Figure 1.4 thermal augmentation is simulated and results from various pulse excitations are provided [23]

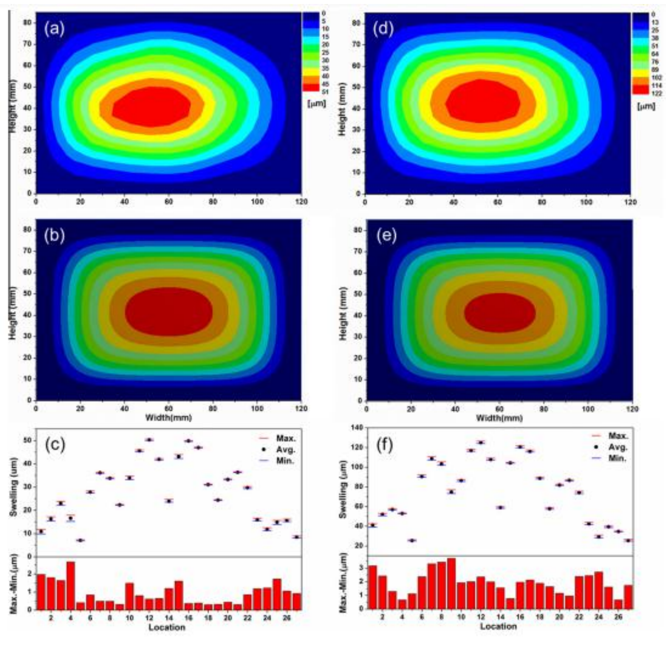

Figure 1.4: Thermal Swelling at Various battery Locations [23]

Various cooling and atmospheric conditions were investigated by ping et al. (2017) to gain an understanding of the various process parameters necessary for the development of BTMS. At low temperatures, the airflow velocity provided effective protection against overheating, but at higher temperatures, it was less effective. Lithium battery tolerance at high temperatures was also influenced by the thickness of the airflow stream. The temperature variations of the battery's primary surface were examined using a neural network technique by Panchal et al. Increased discharge rates increase battery surface temperature distributions, according to this study [25].

7. Challenges Observed

Dissipating the heat produced by running a battery effectively is a major hurdle for thermal management. When electric vehicle batteries are cycled at high rates of charge and discharge, they create a lot of heat, which may cause them to overheat and degrade more quickly. It is difficult to design cooling devices that are both effective at removing heat and efficient at using energy.

Another major obstacle is stabilizing the battery pack's internal temperature. Temperature differences throughout a battery pack may be caused by a number of factors, including inequalities in current flow, internal resistance, and cell-to-cell variance. Maintaining an equal temperature distribution throughout the pack is crucial for avoiding hot patches and fostering consistent cell performance.

The risk of thermal runaway is a major one for EV batteries. Unpredictable temperature rises caused by excessive heat production may set off a chain reaction of disastrous thermal occurrences. Gas release, electrolyte disintegration, and even fire and explosion are all possible outcomes of these processes. Protecting the EV's battery pack and other components from damage requires diligent attention to the prevention and management of thermal runaway.

Another difficulty encountered by thermal management systems is transient thermal behavior. Rapid charging, high discharge rates, and regenerative braking all contribute to extreme temperature swings in battery systems. The thermal management system has difficulties in keeping the battery within a safe and appropriate temperature range due to the constant fluctuations in ambient temperature.

8. Conclusions

Battery systems in electric vehicles (EVs) rely heavily on thermal management systems to function safely, efficiently, and for as long as possible. In-depth analysis of heat management methods and strategies for EV battery systems has been offered in this review study.

1. This analysis emphasized the relevance of heat management in EVs and its effect on total vehicle performance. It highlighted the necessity for appropriate thermal management systems by discussing the difficulties of temperature control, heat production, and thermal runaway.
2. Additionally, BTMS were analyzed for temperature uniformity, charging/discharging rates and flow rates.

3. Finally, this study focused on the real-time BTMS developed by different EVs battery manufacturers. Accordingly, air-cooled systems dominate hybrids, while liquid-cooled systems dominate electric vehicles.

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