

Challenges in Battery Thermal Management for Electric Vehicles: A Bibliometric Analysis

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Abstract: " In the dynamic field of electric mobility, battery thermal management plays a critical role in ensuring the seamless operation of electric vehicles (EVs). This review delves into the significance of battery thermal management, addressing the intricacies of managing temperature within EV batteries. It explores the relationship between heat generation, dissipation, and control, underscoring the importance of efficient energy management and heat prevention. The need for adaptable thermal management systems tailored to diverse driving conditions is emphasized, along with strategies for averting thermal runaway incidents. The review also assesses current methods and technologies, including passive and active thermal management, phase change materials, liquid and air-cooling systems, and thermal interface materials. It considers factors like integration with vehicle systems, environmental and economic considerations, safety, regulatory insights, and presents case studies. The review closes by outlining forthcoming trends in EV battery thermal management."

Keywords: *Electric vehicles, battery thermal management, heat generation, temperature regulation, thermal runaway, strategies, innovations, integration, safety, sustainability.*

1. Introduction

Electric vehicles (EVs) are increasingly becoming a significant part of the automotive industry. They offer a promising solution to several pressing environmental issues, such as reducing greenhouse gas emissions, decreasing dependence on finite fossil fuels, and mitigating the impact of air pollution. The success and viability of EVs are closely tied to the continuous advancements in battery technology. These advancements influence a wide range of factors, including the performance and range of EVs, as well as their overall sustainability as a contemporary mode of transportation [1].

The battery serves as the heart of an electric vehicle. It is responsible for providing the necessary energy to power the electric motor and other auxiliary systems within the vehicle. Maintaining optimal thermal conditions within these batteries is of paramount importance. Excessive heat generation during various operations such as charging, discharging, and high-power operations can lead to accelerated degradation of the battery. This not only affects the performance but also raises potential safety risks, including thermal runaway events [2].

The management of battery temperature is a complex task that extends beyond mere thermodynamics. It involves managing the heat released during operations and ensuring a uniform temperature distribution across the battery cells,

modules, and packs. This task becomes even more challenging considering the varying driving conditions, fluctuations in external temperatures, and the evolving states of the battery [3, 4].

This review paper provides an in-depth survey of the challenges associated with battery thermal management in electric vehicles. It begins by discussing the fundamental principles underlying battery thermal behavior. It then explores existing strategies and technologies used for thermal management. These include both passive and active approaches, phase change materials, liquid and air cooling systems, and thermal interface materials.

The review also delves into recent research breakthroughs in this field. These breakthroughs offer innovative solutions to some of the longstanding challenges in battery thermal management and open up new avenues for further research and development.

In addition to these technical aspects, the review also considers how battery thermal management integrates with other vehicle systems. This includes discussions on vehicle thermal management, power electronics and drivetrain integration, and interactions with climate control systems.

Environmental and economic considerations are also taken into account in this review. It assesses factors such as energy efficiency, life cycle assessments, and cost-effectiveness of different thermal management strategies.

Safety and reliability aspects are also discussed,

particularly in relation to thermal runaway mitigation and its impact on battery degradation. The review also provides regulatory insights by touching upon government regulations and industry standards that influence battery thermal management practices.

The review concludes by outlining future trends in battery thermal management for EVs. It highlights emerging trends that promise to enhance efficiency, safety, and sustainability in EVs [5, 6].

This study also includes ground-breaking research, innovative engineering, and a commitment to advancing electric mobility [7]. This review paper serves as a guide for researchers, engineers, and stakeholders in the electric vehicle ecosystem, highlighting the crucial role of effective battery thermal management in the success of electric mobility [8].

As the automotive industry stands at the threshold of overcoming technical barriers and moving towards cleaner transportation options, understanding and addressing the challenges of battery thermal management is crucial [9]. This paper serves as a comprehensive guide for researchers and engineers working in this field, providing valuable insights into the fundamental principles of battery thermal behaviour and highlighting recent advancements and innovative approaches.

The aim of this review paper is to explore the challenges in battery thermal management for next-generation electric vehicles through a literature review process. The primary goal is to provide a deep understanding of the fundamental principles of battery thermal behaviour. The review emphasizes recent advancements and innovative approaches in battery thermal management. The ultimate goal is to guide future research and innovation in this field. By consolidating knowledge, identifying gaps, and outlining potential research directions, the paper aims to inspire continued progress in electric vehicle technology.

2. Battery Thermal Management: Fundamentals and Importance

One of the most important aspects of electric vehicle (EV) design and operation is thermal management. It has a significant impact on the performance, efficiency, safety, and viability of EVs in various ways. This section explains how thermal management affects different components and systems of EVs and why it is essential for their optimal functioning. The battery is the main source of energy for EVs. It provides the power to drive the vehicle forward. However, the battery's operation depends on its temperature, which needs to be kept within an optimal range. If the battery becomes too hot or too cold, it can affect its capacity, power output, and

lifespan negatively. Thermal management helps to prevent the battery from overheating or undercooling, which can reduce its ability to store and deliver energy over time. Thermal management also helps to avoid battery degradation, which is a gradual loss of performance and durability due to chemical and physical changes in the battery [10].

Another benefit of thermal management is that it improves the energy efficiency of EVs. By controlling the temperatures of the battery, power electronics, and other components, thermal management reduces energy losses due to heat dissipation. This means that more energy is available for driving the vehicle and less energy is wasted as heat. This results in a longer driving range and better energy utilization for EVs. EVs can travel farther on a single charge and need less frequent recharging cycles [10].

Thermal management also enhances the safety and reliability of EVs. High temperatures in the battery can cause thermal runaway—a dangerous phenomenon that can lead to fires or explosions. Thermal runaway occurs when a positive feedback loop of heat generation and temperature rise triggers a chain reaction of exothermic reactions in the battery. Thermal management systems monitor and regulate the temperature dynamics in the battery, preventing such events from happening [11].

Thermal management is not only important for the battery, but also for the whole vehicle architecture. Power electronics, such as inverters and motor controllers, generate heat during operation, which needs to be cooled down to protect their efficiency and durability. Power electronics convert and control the electric power flow between the battery and the motor. If they overheat, they can malfunction or fail, affecting the performance and safety of the vehicle. Moreover, thermal management is related to cabin comfort, as the temperature regulation in the passenger compartment depends on sophisticated climate control systems [12]. These systems provide heating or cooling to maintain a comfortable environment for the passengers and drivers. They also use energy from the battery, which affects the driving range and efficiency of EVs. Electric vehicle (EV) operation is affected by external environmental factors. Ambient temperature, humidity, and driving conditions influence the heat generation and dissipation in the vehicle. Thermal management systems adjust to these factors in real-time, optimizing performance while ensuring the safety and comfort of occupants. Thus, they improve the experience of using EVs. As electric vehicle technology progresses, thermal management offers opportunities for innovation. Advanced materials, novel cooling methods, and smart control algorithms are some of the potential developments that can enhance thermal management systems. These innovations aim to increase the efficiency and lifespan

of key electric vehicle components [13]. In summary, the role of thermal management in electric vehicles is important and integral. It controls the temperature dynamics within batteries, power electronics, and the vehicle’s design. Thermal management enables electric vehicles to cope with the changing challenges of different environments. In doing so, it supports the goals of improved performance, extended longevity, and a cleaner and more sustainable transportation future.

3. Bibliometric Analysis

This review uses bibliometric analysis as a quantitative method to evaluate the current state of research in a specific academic area. This technique examines how articles are related through citations and co-citations, resulting in a review that is replicable, systematic, and transparent. The passage explains the use of bibliometric analysis, including bibliometric review and network analysis, as a suitable approach for showing the research trends of a specific field over time [14].

The benefits of bibliometric analysis over traditional methods are discussed, including its objectivity and ability to generate high-quality insights about research development, emerging areas, and key issues affecting a particular research domain. It is compared with traditional methods that depend on subjective literature selection and fixed parameters, which do not effectively capture the evolutionary aspects of research [15]. The data was collected from the scopus platform. The two main keywords “Battery Thermal Management” AND “Electric Vehicles” were used to search the relevant papers.

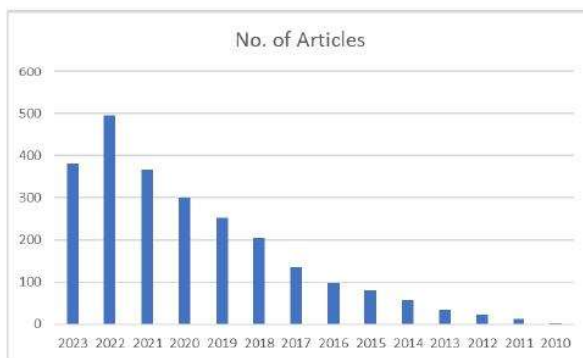


Fig 10: No. of articles published in the field of battery thermal management and electric vehicles

Figure 1 shows the increasing interest in the field of battery thermal management system and electric vehicles. It also shows that the growth is significant in this field in recent years. The distribution of articles in different journals related to this field is shown in figure 2. Journal of energy storage, Applied thermal

engineering and Energies are the most popular and preferred journals among authors. Figure 3 shows the country-wise contribution in this field and it shows that China is leading the world in the field of electric vehicles and battery thermal management system. After China, the major contributors in this field are United States, India and United Kingdom.

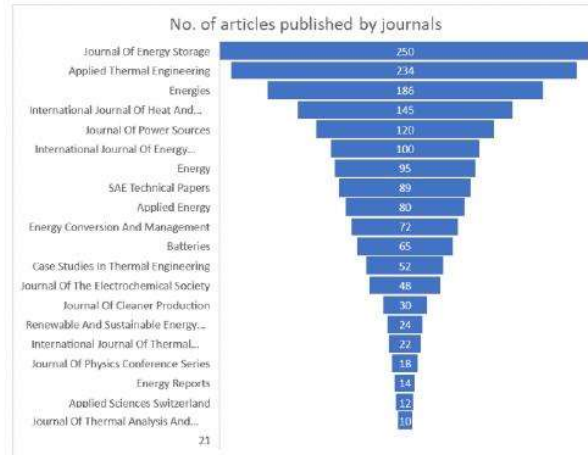


Fig 11: No. of articles published by journals in the field of electric vehicles and battery thermal management systems

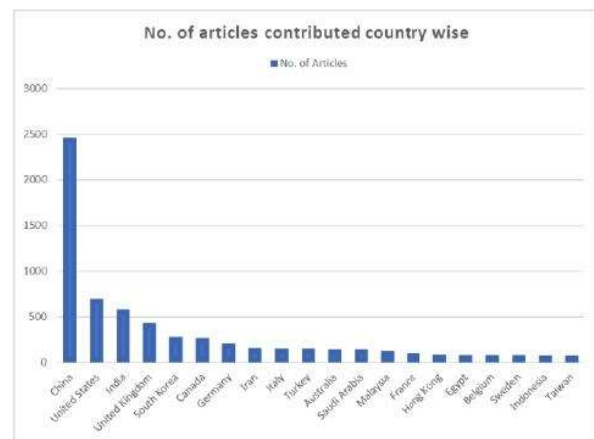


Fig 3: Country wise contribution in the field of electric vehicles and battery thermal management systems

4. Innovative Approaches and Research Directions

In the relentless pursuit of enhanced efficiency and sustainability within the electric vehicle (EV) realm, innovation takes center stage in the field of battery thermal management. Table 2 unveils a spectrum of

pioneering approaches and research directions that are reshaping the landscape of EV thermal management. From advanced cooling techniques that harness the power of phase transitions to sophisticated thermal modeling and simulation tools, and materials innovations with nanomaterials and thermally conductive polymers, these strategies are poised to revolutionize the way we manage heat in EV battery systems. Additionally, battery pack design optimization emerges as a critical facet, seamlessly integrating cooling solutions into the very framework of battery packs for enhanced thermal performance. Table 1 shows Innovative approaches and research directions in the field of battery thermal management systems.

Table 1. Innovative approaches and research directions in the field of battery thermal management systems

Innovative Approaches	Description
Advanced Cooling Techniques	Two-phase cooling, utilizing phase transition for enhanced heat transfer efficiency. Evaporative cooling uses latent heat of vaporization to dissipate heat effectively.
Thermal Modeling and Simulation	Computational Fluid Dynamics (CFD) simulations offer insights into temperature distribution, fluid dynamics, and cooling mechanisms, accelerating thermal management development.
Materials Innovations for Enhanced Heat Transfer	Nanomaterials, nanofluids, thermally conductive polymers, and composites enhance heat dissipation and redefine thermal management.
Battery Pack Design Optimization	Innovative pack designs incorporate cooling channels into structural frameworks, ensuring temperature harmony and holistic design optimization.

In the field of innovation, various approaches are being developed for battery thermal management. The exploration of advanced cooling techniques, thermal modeling, materials innovations, and optimization of battery pack design are all contributing to the future of thermal equilibrium in electric vehicles. This area of innovation, where science and creativity meet, is attracting researchers and engineers to explore new possibilities and push the boundaries of what can be achieved. As electric mobility continues to advance, these innovative approaches are crucial in driving it towards improved performance, sustainability, and safety.

4. Conclusion and Future Directions

The review of battery thermal management undertaken in this paper underscores its critical role in

the broader context of electric vehicles. The task of maintaining temperature equilibrium within battery cells, integrating thermal dynamics with vehicle architecture, and aligning with emerging technologies are all integral components of this field. Effective battery thermal management is not merely a technical pursuit; it is a fundamental pillar supporting the ongoing electric mobility revolution. It plays a pivotal role in ensuring performance, safety, and fostering innovation. From addressing thermal challenges to propelling technological progress, thermal management is indispensable for a cleaner, more efficient and sustainable automotive future. This review concludes with an invitation to researchers, engineers, manufacturers, and stakeholders to contribute to the continued advancement of electric mobility by presenting the current scenario through bibliometric analysis.

Looking forward to the future of battery thermal management, it is poised to be a field ripe with emerging trends and bold innovations. As the electric vehicle revolution continues to gain momentum, we anticipate a fusion of technologies that will redefine efficiency, safety, and sustainability. One such promising trend is the integration of artificial intelligence and machine learning into thermal management systems. These intelligent systems have the potential to make real-time adjustments, optimizing performance and safety while adapting to dynamic conditions. Concurrently, material science is also making significant strides, with new materials being developed that enhance thermal conductivity and insulation.

overall, the pursuit of effective battery thermal management is more than an engineering challenge—it is an endeavour that aligns science, technology, and innovation. It is about creating an electric mobility experience that is not bound by rigid scenarios but flows seamlessly with each note of power demand and heat generation striking a perfect chord in the symphony of harmonious, consistent performance.

References

- 1) Wang, L.; Nian, V.; Li, H.; Yuan, J. Impacts of electric vehicle deployment on the electricity sector in a highly urbanised environment. *J. Clean. Prod.* 2021, 295, 126386.
- 2) Luo, Y.; Wu, Y.; Li, B.; Mo, T.; Li, Y.; Feng, S.-P.; Qu, J.; Chu, P.K. Development and application of fuel cells in the automobile industry. *J. Energy Storage* 2021, 42, 103124.
- 3) Manzetti, S.; Mariasiu, F. Electric vehicle battery technologies: From present state to future systems. *Renew. Sustain. Energy Rev.* 2015, 51, 1004–1012.

- 4) Fotouhi, A.; Auger, D.J.; Propp, K.; Longo, S.; Wild, M. A review on electric vehicle battery modelling: From Lithium-ion toward Lithium–Sulphur. *Renew. Sustain. Energy Rev.* 2016, 56, 1008–1021.
- 5) Eldho Aliasand, A.; Josh, F.T. Selection of Motor foran Electric Vehicle: A Review. *Mater. Today Proc.* 2020, 24, 1804–1815.
- 6) Klerk, M.L.D.; Saha, A.K. A Comprehensive Review of Advanced Traction Motor Control Techniques Suitable for Electric Vehicle Applications. *IEEE Access* 2021, 9, 125080–125108.
- 7) Ahmad, A.; Khan, Z.A.; Saad Alam, M.; Khateeb, S. A Review of the Electric Vehicle Charging Techniques, Standards, Progression and Evolution of EV Technologies in Germany. *Smart Sci.* 2018, 6, 36–53.
- 8) Sun, X.; Li, Z.; Wang, X.; Li, C. Technology Development of Electric Vehicles: A Review. *Energies* 2020, 13, 90.
- 9) Wu, G.; Zhang, X.; Dong, Z. Powertrain architectures of electrified vehicles: Review, classification and comparison. *J. Frankl. Inst.* 2015, 352, 425–448.
- 10)A. Babapoor, M. Azizi, G. Karimi, Thermal management of a Li-ion battery using carbon fiber-PCM composites[J], *Appl. Therm. Eng.* 82 (2) (2015) 281–290.
- 11)J. Wang, Q. Huang, X. Li, et al., Experimental and numerical simulation investigation on the battery thermal management performance using silicone coupled with phase change material[J], *J.Energy Storage* 40 (490) (2021), 102810.
- 12)T. Wu, Y. Hu, X. Liu, et al., Effect analysis on thermal management of power batteries utilizing a form-stable silicone grease/composite phase change material [J], *ACS Appl.Energy Mater.* 4 (2021) 6233–6244.
- 13)Yu, Z., Zhang, J., & Pan, W. (2023). A review of battery thermal management systems about heat pipe and phase change materials. *Journal of Energy Storage*, 62, 106827.
- 14)Dzikowski, P. (2018), “A bibliometric analysis of born global firms”, *Journal of Business Research*, Vol. 85, pp. 281-294.
- 15)Strozzi, F., Colicchia, C., Creazza, A. and Noe, C. (2017), “Literature review on the ‘Smart Factory’ concept using bib