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Research Progress and Prospect of Thermal Management of Automotive Lithium-ion Batteries

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Abstract: As an important energy storage device, lithium-ion batteries are widely used in mobile electronic devices, electric vehicles and other fields. However, lithium-ion batteries generate a lot of heat during the charging and discharging process, and if effective thermal management is not carried out, it will lead to problems such as battery performance, reduced safety and even thermal runaway. Therefore, it is of great significance to study the thermal management strategy of lithium-ion batteries to improve battery performance and safety. This paper reviews the progress of thermal management research on lithium-ion batteries in recent years, analyzes the working principles of active cooling and passive cooling in detail, proposes the application methods of composite cooling, and looks forward to the future research should focus on the research and development of Multiphysics coupling simulation, intelligent thermal management system and new thermal management materials to achieve efficient thermal management of lithium-ion batteries and improve battery performance and safety.

Keywords: Lithium-ion Batteries; Thermal Management; Security Performance; Temperature; Cooling.

1. Introduction

With the rapid development of renewable energy and the expansion of the electric vehicle market, lithium-ion batteries have been widely used as a high energy density, long life and environmentally friendly energy storage devices. However, the large amount of heat generated by lithium-ion batteries during the high-power charging and discharging process will not only reduce the energy conversion efficiency of the battery, but also have a serious impact on the performance and life of the battery. Therefore, the study of thermal management strategies of lithium-ion batteries has become a hot spot and challenge in current research.

In recent years, researchers have conducted extensive and in-depth research on the thermal management of lithium-ion batteries. Wang et al. [1] reviewed the two aspects of battery thermal model development and thermal management strategy, studied the thermal effect of lithium-ion batteries in thermal runaway and response at low temperatures, discussed their thermogenic characteristics and accurate battery thermal analysis, and explored BTM new technology to mitigate battery thermal influences to improve the temperature uniformity of the entire battery pack and extend battery life. Patel R J et al. [2] reviewed the main BTMS, concluding that PCM and heat pipe-based BTMS can provide better thermal management without consuming any power consumption. By studying the influence of cooling conditions and battery pack configuration on battery temperature, Karimi G et al. [3] found that the cooling strategy of distributed forced convection is an efficient and economical method to provide uniform temperature and voltage distribution within the battery pack at different discharge rates. Zhang et al. [4] introduced the thermal management methods used in lithium-ion batteries, discussed their advantages and disadvantages, and put forward the prospects for future development. Yang et al. [5] conducted a review based on previous research, summarized the thermal characteristics of electrical and battery and how they are affected by operating temperature, analyzed the relative advantages and specific uses of different cooling or heating methods, and provided many optimization methods. Wang et al. [6] thoroughly summarized and classified the research progress of battery cooling system and preheating system according to the heat transfer medium, evaluated various thermal management technologies from multiple perspectives, and proposed that it would be a research trend to design a new thermal management system that integrates multiple technologies. Wang et al. [7] proposed a new modular battery liquid cooling system, and studied the influence of coolant flow and cooling mode on the thermal behavior of the battery module through numerical simulation and experiments. Chen et al. [8] reviewed the research progress of PCM-based BTMS and proposed that most pure solid-liquid phase change materials have low thermal conductivity, resulting in a large amount of heat accumulation in harsh operating environments.

Based on the in-depth research on thermal management by many scholars, this paper will summarize and analyze the research progress of lithium-ion battery thermal management, propose the application method of composite cooling, and make a scientific prediction of the possible development direction of the automotive lithium-ion battery industry in the future.

2. Research Progress in Thermal Management of Automotive Lithium-ion Batteries

Lithium-ion battery thermal management refers to controlling and regulating the temperature of the battery to keep the battery operating within a safe temperature range and improve the performance and life of the battery. Since lithium-ion batteries generate a lot of heat during the charging and discharging process, if this heat cannot be effectively managed, it will lead to battery overheating, thermal runaway and even safety accidents. In order to achieve thermal management of lithium-ion batteries, researchers have proposed a variety of strategies and technologies. At present, the thermal management strategy of lithium-ion batteries can be mainly divided into two categories: active thermal management and passive thermal management.

2.1. Proactive Thermal Management

Active thermal management includes liquid cooling, gas cooling, phase change material cooling and other technologies that enable thermal management of batteries through active temperature control.

2.1.1. Liquid Cooling

Liquid cooling is a common and effective thermal management technique for lithium-ion batteries. It absorbs and takes away the heat generated by the battery by circulating the liquid coolant to lower the temperature of the battery and keep the battery operating within a safe temperature range.

Liquid cooling technology can be divided into two ways: direct liquid cooling and indirect liquid cooling. Direct liquid cooling refers to the cooling agent flowing directly through the inside of the battery pack to cool the battery by exchanging heat with the battery surface. A common method of direct liquid cooling, shown in Figure 1, is to set up cooling channels in the battery module or battery pack through which coolant flows through the battery, carrying away heat. The coolant can be water, glycol solution or other liquid with good thermal conductivity. Direct liquid cooling has the advantages of fast response and efficient cooling, and can effectively control the battery temperature, but it is more complex in design and manufacturing.

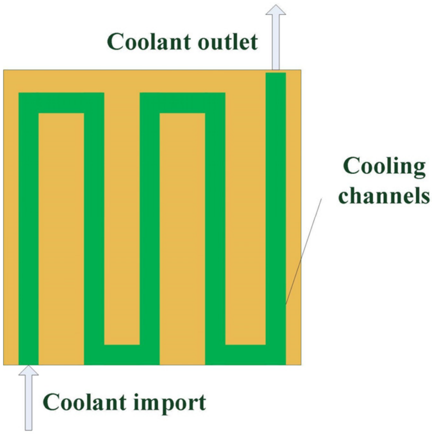

Figure 1. Schematic diagram of direct liquid cooling

Indirect liquid cooling is the isolation of the coolant from the battery by a heat exchanger in which heat is exchanged between the coolant and the battery, as shown in Figure 2. This approach reduces the impact on the internal structure and materials of the battery and is easier to implement in some cases. Heat exchangers are usually made of thermally conductive materials with good heat conductivity and are able to efficiently transfer the heat generated by the battery to the coolant. Indirect liquid cooling reduces the requirements for battery pack design and improves system reliability and maintenance.

Liquid cooling technology has certain advantages in the thermal management of lithium-ion batteries, which can quickly and uniformly absorb and disperse heat, effectively control the temperature of the battery, and improve the cycle life and power output of the battery. However, the design and implementation of liquid cooling systems needs to consider the selection of coolant, the design of circulation systems, leakage and corrosion, so factors such as performance, safety and cost of battery systems need to be considered comprehensively. With the advancement of technology and the increasing demand for electric vehicles and other fields, liquid cooling technology will continue to be widely used and researched in the thermal management of lithium-ion batteries.

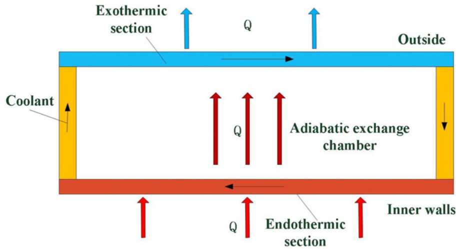

Figure 2. Schematic diagram of heat exchanger operation

2.1.2. Gas Cooling

Gas cooling is a common technique for thermal management of lithium-ion batteries that uses the thermal conductivity of gas to absorb and take away the heat generated by the battery to keep the battery operating within a safe temperature range, as shown in Figure 3. Gas cooling technology mainly includes two ways: direct gas cooling and indirect air cooling. Direct air cooling refers to the direct blowing of cooling gas to the surface of the battery to cool the battery by conducting and convection heat on the surface of the battery. A common direct air-cooling method is to set up an air-cooling channel in the battery module or battery pack, through which the cooling gas is blown over the surface of the battery, taking away heat. Commonly used cooling gases are air, nitrogen, etc. Direct air-cooling technology has the advantage of being simple and reliable, and can quickly reduce the temperature of the battery, but there may be certain challenges in terms of cooling effect and temperature uniformity. Indirect gas cooling is the isolation of the cooling gas from the battery through the heat exchanger, and the heat of the battery is conducted through the heat conductive material in the heat exchanger. The cooling gas is exchanged with the thermally conductive material in a heat exchanger before the heat is taken away. This approach reduces the impact on the internal structure and materials of the battery, while improving the cooling effect and temperature uniformity.

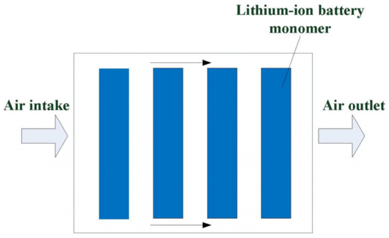

Figure 3. Air-cooled **schematic**

Indirect gas cooling technology usually needs to be implemented in combination with a circulation system and a heat exchanger to allow the cooling gas to circulate and thus achieve effective cooling of the battery. R. Mahamud et al. proposed a reciprocating air flow method, which reduces the maximum temperature of the battery pack by 1.5 ° C and the temperature difference between cells by 4.0 ° C compared with unidirectional flow. The temperature comparison analysis is shown in Figure 4.

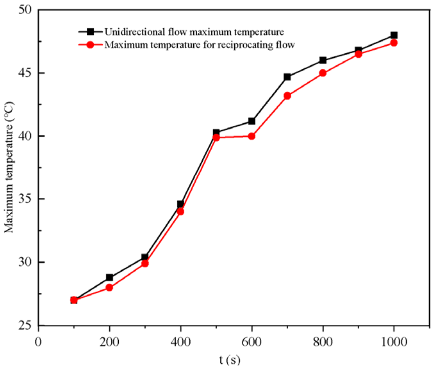

Figure 4. Reciprocating flow versus unidirectional flow maximum temperature

Gas cooling technology offers certain advantages, such as fast heat transfer, flexible design and easy implementation. However, there are some challenges in gas cooling technology, such as controlling temperature uniformity and the effect of gas flow on the inside of the battery. When designing and implementing a gas cooling system, factors such as cooling effectiveness, energy consumption, safety and cost need to be considered. With the continuous improvement of battery performance and safety requirements, gas cooling technology will continue to be studied and applied in the thermal management of lithium-ion batteries. Further research and innovation will help optimize the performance of gas cooling systems and drive the development and application of lithium-ion battery technology.

2.1.3. Phase Change Material Cooling

Phase change material cooling uses latent heat absorption and release during the phase change process to regulate temperature. Phase change materials have the property of changing the state of matter (solid to liquid or liquid to solid) in a specific temperature range, and this phase change process is accompanied by the absorption or release of latent heat. Specifically, the principle of phase change material cooling is as follows:

Latent heat absorption: When the temperature exceeds the phase transition temperature of the phase change material, the phase change material changes from a solid state to a liquid state, a process called a phase change. During a phase change, the phase change material absorbs heat because during the change of state of matter, the phase change material uses energy to destroy and reorganize its molecular structure. The heat absorbed in this process is called latent heat. Phase change materials absorb and store the heat generated by the battery while absorbing latent heat, thereby reducing the temperature of the battery.

Latent heat release: When the temperature is lower than the phase change temperature of the phase change material, the phase change material changes from liquid to solid, releasing the latent heat previously absorbed. In this process, the phase change material releases the stored heat into the surrounding environment, allowing the battery temperature to be regulated and controlled.

Through this process of latent heat absorption and release, the phase change material can maintain the temperature stably within a certain temperature range, so that the operating temperature of the battery is kept within a safe and suitable range. The advantages of phase change material cooling technology are precise temperature control, high energy efficiency and small size. It is worth noting that the selection and design of phase change materials is an important aspect of phase change material cooling technology. The phase change temperature of the phase change material should match the operating temperature range of the battery, and factors such as the thermal stability, cycle life and thermal conductivity of the phase change material need to be considered. Therefore, the research and optimization of phase change materials is still an important direction for the development of phase change material cooling technology.

2.2. Passive Thermal Management

Passive thermal management is to improve the heat dissipation performance of the battery by optimizing the structure and materials of the battery, such as designing heat sinks and increasing thermal conductive materials.

Heat sinks are a commonly used passive thermal management technique that is typically made of highly thermally conductive materials such as aluminum or copper. The heat sink is attached to the surface of the battery and accelerates heat dissipation by increasing the heat dissipation surface area and improving the heat conduction efficiency. The heat sink quickly transfers the heat generated inside the battery to the external environment by exchanging heat with the surrounding environment.

A thermal pad is a material used to improve heat conductivity and typically consists of a thermally conductive filler and a binder. Thermal pads can be used inside the battery module or at the contact surfaces of the battery pack to achieve rapid heat conduction and dispersion by filling the contact gap and improving the heat conduction performance.

3. Application Strategy of Thermal Management Technology - Composite Cooling

In addition to the above single lithium battery thermal management technology, a variety of thermal management technologies can also be compounded, learning from each other's strengths, which can effectively overcome the shortcomings of a single thermal management technology, give play to their respective advantages, and achieve better thermal management effects. At present, most active and passive thermal management technologies are used in combination.

In the research of composite air cooling of phase change materials, P. Qin et al. [10] designed a thermal management system for phase change materials and forced air convection composite, and the maximum temperature of the battery pack decreased by 16°C and the maximum temperature difference by 1.2°C compared with single passive thermal management at 3C charge-discharge ratio. The thermal management system of heat pipe composite phase change material designed by W. Wu et al. [11] controls the maximum temperature of the battery pack below 50°C at a discharge rate of 5C. In the research of composite liquid cooling of phase change materials, Y. Zheng et al. [12] designed a thermal management system based on liquid cooling and combined with phase change materials, composite phase change materials mainly play an auxiliary role in absorbing part of the heat, and the study found that under the 8C discharge rate, the maximum temperature of the battery can be controlled at 38.69 °C, and the temperature difference is 2.23 °C. Therefore, combining the phase change material with heat management methods such as air cooling, liquid cooling or heat pipe cooling can give full play to the high phase change latent heat of the phase change material, and at the same time make up for the low thermal conductivity of the phase change material, but the composite method increases the quality of the thermal management system and the structure becomes complex. Therefore, it is necessary to develop a corresponding thermal management strategy according to the specifications and operating environment of the battery pack, combined with economic benefits.

4. Conclusion and Future Directions

In summary, the research on thermal management of lithium-ion batteries has made some progress, but still faces challenges. From the analysis of the advantages and disadvantages of active cooling and passive cooling, the design concept of composite cooling in the lithium-ion battery thermal management system can achieve the optimal effect without considering the cost. Future research should focus on multiphysics coupling simulation, intelligent thermal management system and the development of new thermal management materials to achieve efficient thermal management of lithium-ion batteries and improve battery performance and safety.

(1) Multiphysics coupling simulation: By establishing a more accurate heat conduction model, combining electrochemical reactions and changes in the internal structure of the battery, multiphysics coupling simulation is carried out, which helps to reveal the mechanism in the thermal management process of lithium-ion batteries and guide the design of thermal management strategies.

(2) Intelligent thermal management system: the use of sensors, control algorithms and artificial intelligence technology to achieve real-time monitoring and intelligent control of battery temperature, which can adjust the working mode of thermal management system according to battery working status and environmental conditions, and improve the effect of thermal management.

(3) Research and development of new thermal management materials: The development of new materials with high thermal conductivity, phase change characteristics or adjustable heat dissipation performance can provide more flexible and efficient thermal management solutions.

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References

[1] Wang Q, Jiang B, Li B, et al. A critical review of thermal management models and solutions of lithium-ion batteries for the development of pure electric vehicles[J]. Renewable and Sustainable Energy Reviews,2016,64.W.-K. Chen, Linear Networks and Systems (Book style). Belmont, CA: Wadsworth, 1993, pp. 123–135.

[2] Patel R J, Rathod K M. Recent developments in the passive and hybrid thermal management techniques of lithium-ion batteries [J]. Journal of Power Sources,2020,480.

[3] Karimi G, Li X. Thermal management of lithium-ion batteries for electric vehicles[J]. International Journal of Energy Research, 2013,37(1).

[4] Xinghui Z, Zhao L,Lingai L, et al. A review on thermal management of lithium-ion batteries for electric vehicles[J]. Energy,2022,238(PA).

[5] Yang S, Ling C, Fan Y, et al. A Review of Lithium-Ion Battery Thermal Management System Strategies and the Evaluate Criteria[J]. International Journal of Electrochemical Science, 2019, 14(7).

[6] Wang Z, Du C. A comprehensive review on thermal management systems for power lithium-ion batteries[J]. Renewable and Sustainable Energy Reviews,2021,139.

[7] Wang H, Tao T, Xu J, et al. Cooling capacity of a novel modular liquid-cooled battery thermal management system for cylindrical lithium ion batteries[J]. Applied Thermal Engineering, 2020,178.

[8] Chen J, Kang S, E J, et al. Effects of different phase change material thermal management strategies on the cooling performance of the power lithium ion batteries: A review[J]. Journal of Power Sources,2019,442(C).

[9] MAHAMUD R, PARK C. Reciprocating air flow for Li-ion battery thermal management to improve temperature uniformity [J]. J Power Sources, 2011, 196(13): 5685-5696.

[10] QIN P, LIAO M, ZHANG D, et al. Experimental and numerical study on a novel hybrid battery thermal management system integrated forced-air convection and phase change material[J]. Energ Convers Manage, 2019, 195: 1 371-1 381.

[11] WU W, YANG X, ZHANG G, et al. Experimental investigation on the thermal performance of heat pipe-assisted phase change material based battery thermal management system[J]. Energ Convers Manage, 2017, 138: 486-492.

[12] ZHENG Y, SHI Y, HUANG Y. Optimisation with adiabatic interlayers for liquid-dominated cooling system on fast charging battery packs[J]. Appl Therm Eng, 2019, 147: 636-646.