

# Comprehensive Analysis of Battery Thermal Management Systems for New Energy Vehicles

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**Abstract.** In recent years, challenges such as energy scarcity and environmental pollution have become more serious, presenting tremendous prospects for creating new energy vehicles and enabling new energy vehicles to develop swiftly. However, the service life of the power battery of new energy vehicles, the battery capacity is too small and the charging time is extended, etc. have become the bottleneck restricting the development of new energy vehicles, and an effective battery thermal management system is a necessary way to solve these problems. This article describes and evaluates the state-of-arts battery thermal management system plan for new energy cars and introduces the working concept of air, liquid, and phase change cooling systems. This study can assist readers in forming a more thorough knowledge of the evolution of battery thermal management technology for new energy vehicles and give researchers suggestions for thinking about crucial technologies.

**Keywords:** New energy vehicle, Battery thermal management, Vehicle thermal management, New energy vehicle thermal management application

## 1. Introduction

With the advancement and development of science and technology, the energy problem has gotten more serious, and people are searching for new ways and means to fulfil the rising energy demand. As a necessary medium of mobility in modern civilization, the vehicle is important to our existence. However, the conventional fuel used to power automobiles, petroleum, is gradually being replaced by hydrogen and electricity. Compared to previous fuel vehicles, the energy efficiency and emissions of our most common electric vehicles have vastly improved, and the cost of energy use has been greatly lowered. However, modern energy vehicles still have significant constraints, such as a lack of battery capacity, a short range, a lengthy charging time, a difficulty with battery service life, and a lack of proper supporting infrastructure. These issues have become the stumbling block to the creation of new energy vehicles.

The power battery serves as one of the three essential elements of an electric vehicle. It consists of a battery module, a battery management system (BMS), a thermal management system, and a mechanical system. It has a substantial impact on the cost, service life, durability, and safety performance of cars and is a huge advancement in tackling these problems.[1]. Temperature is the most crucial parameter of all battery parameters [2]. According to the research [3], the battery temperature in new energy vehicles is frequently too high, which alters the heat dissipation within the power battery, resulting in heat accumulation and thermal runaway, causing irreversible damage to the internal electrode of the power battery, rendering its overall performance ineffective, and drastically reducing the power battery's cycle life. Severely, it may result in safety incidents. Therefore, it is vital to regulate the battery's temperature to stabilise it within an optimal working temperature range, enhancing the battery's service life and safety performance. Consequently, the battery thermal management system (BTMS) was developed.

Generally, the BTMS is a closed-loop regulation system comprised of a thermally conductive medium, measurement and control unit and temperature control equipment, which strictly limits the charging and discharging current and temperature of the battery for maintaining an optimal state. Consequently, the battery system's functionality and durability are guaranteed. The thermal conductive medium is the heat dissipation through the movement of the medium, such as air, liquid, and PCM (phase change materials), after contact with the battery pack. The measurement and control device regulates the temperature control equipment for the appropriate heat treatment by measuring the real-time temperature of the battery system, the electromagnetic module, or even the single cell at various points. Fans are the most common type of temperature control equipment. The purpose of temperature control equipment is to keep the temperature within an acceptable range so that the equipment may operate in an appropriate atmosphere. The primary roles of BTMS are as follows [3]:

Heat dissipation refers to the system's ability to dissipate heat in a timely and effective manner when the battery is at a high temperature., preventing it from becoming out of control due to high temperature and allowing the power battery to keep its optimal state.

Under conditions of low temperature, it is capable of insulating well and heating quickly.

Maintain the temperature equilibrium of the battery pack to avoid the performance of the alternative energy vehicle from being impacted by the disparate temperatures of the individual batteries.

In conclusion, the BTMS regulates the correct temperature of the battery pack. Through the functioning of the BTMS, the battery pack of the new energy vehicle may be charged and discharged in a reasonable temperature range in any environment, allowing the vehicle to operate normally and increase its endurance. The battery heat management system plays an important role in the vehicle's heat management system. The temperature control range for the motor/electronic control system and the battery temperature control system are distinct. The temperature of the motor / electronic control system exceeds the optimal operating temperature (15°C to 35°C) of the batter. Thus, the temperature control of the battery has a significant impact on the thermal management of the vehicle.

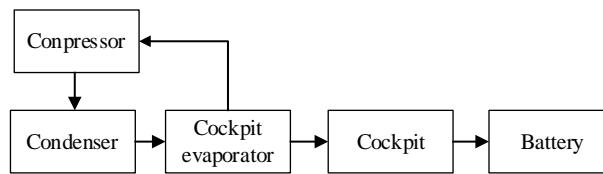
Therefore, the development of an efficient battery thermal management system is the primary focus of the research and development of new energy vehicles by experts in China and overseas. On the basis of the current research status of electric vehicle battery thermal management system technology at home and abroad, including air cooling system, fluid cooling system, phase change cooling technology, multi-system coupling, and other specific heat management technology for batteries in electric vehicles, this paper analyses the constraints encountered in the current process of developing the technology for the thermal management systems of electric vehicle batteries and their future impacts.

## **2. Classification of battery thermal management system**

With the continuous increase of the range of electric vehicles and the continuous expansion of the scope of applications, higher requirements are also put forward for the thermal management system of the battery. The performance and cost of the power system greatly determine the performance, cost and reliability of new energy vehicles. Moreover, the temperature and temperature field of the power battery are often directly related to the life of the battery. A perfect thermal management system can greatly extend the life of the battery, thereby reducing the life cycle cost of the battery and improving the utilization value of the battery.

### **2.1. Air Cooling-based BTMS**

The air cooling system is the earliest system applied in the battery thermal management system of new energy vehicles, as shown in Figure 1



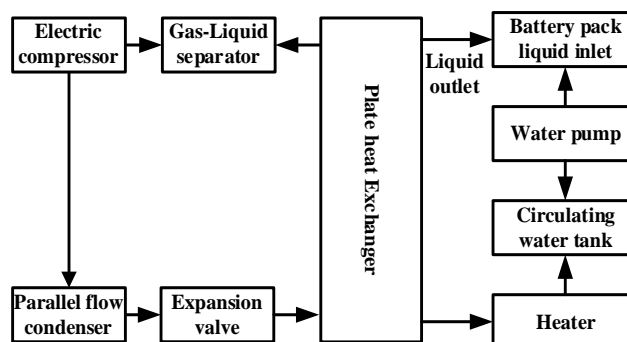
**Figure 1.** Air cooling system structure diagram

Air cooling and heat management system is mainly divided into two types: one is the natural air cooling and heat management system, and the other is the forced air cooling and heat management system. The natural air-cooled heat management system, as the name suggests, is to directly pass the convection of external gases, exchange heat with the inside of the battery shell, take away the hot air inside the battery through the convection, complete the exchange of cold and hot gases, and thus complete the temperature control of the battery pack. The forced air-cooled heat management system relies on thermal fluid simulation analysis to locate the heat distribution area inside the battery and carry out forced heat dissipation. In the forced air-cooling system, the blower box speeds up the air circulation speed inside the battery, so that the heat can be more dissipated. It is also necessary to set up a special air duct inside to discharge the hot gas. At present, there are three main forms of air duct: bottom air duct, tandem air duct, parallel air duct. The most commonly used is the parallel duct.

However, the air-cooling system also has great limitations at present. On the one hand, both thermal convection and heat conduction are susceptible to the temperature inside the battery itself. When the internal operating temperature of the battery is too high, the reduction of temperature is also limited through heat conduction and thermal convection. At this time, not only will not achieve the expected cooling effect, but also pose a certain threat to the safety of battery work. On the other hand, the air-cooling system has a limited area of the heat sink in contact with the outside air, and it is impossible to achieve a suitable heat dissipation efficiency. Most importantly, the heat sink is always exposed to air. As long as the internal temperature of battery is greater than the ambient temperature, the cooling system will continue to work, so that not only the heat dissipation system is overworked, but also can not regulate the temperature within a suitable range, in the paper "Battery Pack Air Cooling System Structure Design and Simulation Optimization Research", to make the internal temperature of the battery uniform and consistent, design a single inlet and four out of the box structure, in the 4 air outlets in accordance with the cycle law to open and close, actively guide the cooling medium through the set runner, Active control of the higher internal temperature of the battery pack.

## 2.2. Liquid Cooling-based BTMS

Compared to the limitations of air-cooled thermal management systems, water-cooled thermal management systems have the potential for more efficient applications. Figure 2 shows the internal structure of the liquid cooling and thermal management system.



**Figure 2** Structure diagram of liquid cooling system

By observing the working structure diagram of the liquid cooling temperature control system, the working principle of the liquid cooling temperature control system is analyzed. The main components

of the liquid cooling temperature control system liquid cooling are the compressor, the refrigerator and the water pump. The compressor is the starting point of the cooling performance, and the heat transfer capacity of the whole system is determined by the action of the compressor. Compressors play an important role in the overall liquid cooling and thermal management system. The freezer is the middle part of the whole system, which acts as a coolant and exchanges heat with it [4]. The amount of internal heat transfer directly affects the temperature of the whole system and has a critical impact on the performance of the whole system. The freezer is the working core of the whole working system. The role of the water pump is to regulate the flow of coolant. In many cases, the higher the coolant flow, the better the heat transfer performance of the system.

There are two common systems for liquid cooling and thermal management. One is an indirect liquid cooling and thermal management system and the other is a direct liquid cooling and thermal management system. The internal components of the electronic battery are not in direct contact with the refrigerant, but conduct heat through the copper cold plate connected to the refrigerant, and the liquid circulates to remove the heat and lower the temperature. A fan is needed to carry heat away from components not covering the heat shield because the heat shield only covers part of the heating element, not pure liquid cooling. With direct cooling, the inside of the battery or the entire battery is directly immersed in a coolant that circulates to dissipate heat.

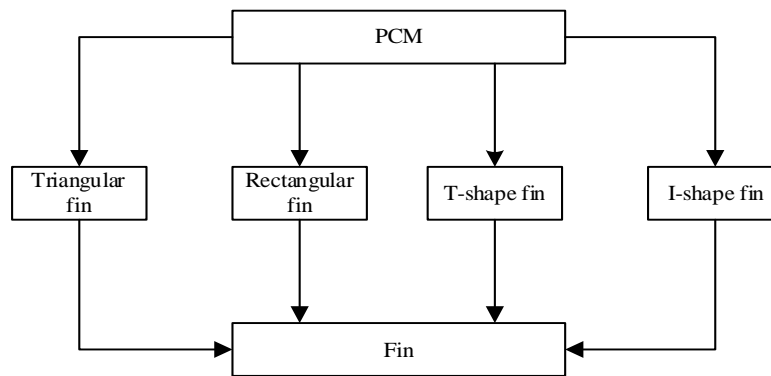
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Modern engines demand more power than before, so they have higher compression ratios. The higher the compression ratio, the greater the effect of battery temperature control in the engine. In many ways, air-cooling technology is difficult to meet the specific needs of today's engine systems. Therefore, liquid cooling and thermal management systems are gradually becoming the main applications of battery thermal management systems.

### **2.3. Phase Change-based BTMS**

Being a newer system than liquid cooling and thermal management systems, phase change cooling systems are gradually being pursued in the automotive industry's search for new energy sources to enable a wide range of applications. The first thing that needs to be explained is the working principle of a phase change cooling system, the phase concept. A phase denotes the state of existence of a substance that has exactly the same composition and properties and has a clear interfacial separation from other surrounding substances. Macroscopically, matter exists in three states: gas, liquid, and solid. A phase transition, as the name suggests, is the transition of a substance from one phase to another through a broad temperature platform and apparent endothermic and exothermic phenomena. This process is called combat.

The two parameters of the phase change material index phase change latent heat and phase change temperature, essentially describe the type of environment to which the material can adapt. The greater the latent heat of the phase change, the greater the material's ability to maintain a constant ambient temperature so that improve temperature control performance.



**Figure 3** Structural diagram of the phase change cooling system

In natural and industrial applications, there are many types of materials that undergo phase transitions due to endothermic and exothermic effects. In the art, however, it mainly affects materials with a narrow temperature range and high latent heat during the phase transition. If the material itself has good thermal conductivity, it can be used for more temperature control applications.

Phase change materials used in thermal management systems typically meet several requirements. First, the high thermal density and large latent heat of the material; second, high thermal conductivity, fast endothermic and heat release process, and most importantly good stability, decomposition is not easy and secondary reaction with the environment. It is hardware and has a long service life to avoid damage effects to the system [6].

Phase change materials are currently being initially applied in battery management systems for electric vehicles. Lithium-ion battery thermal management systems also have certain requirements for phase change materials. The phase change temperature should be as low as possible to adapt to the optimal operating temperature range of the lithium-ion battery. And the material should determine the form, before and after the phase change, it is best not to appear liquid gaseous phase; If the latent heat of the material is large, the system's ability to maintain a constant temperature will also be enhanced; The material also needs to have good insulation to prevent the risk of insulation leakage in high-voltage systems. At the same time, the mass density of the phase change material should not be too high, which is used to reduce the impact on the energy density of the battery pack.

### 3. Comparison and research of mainstream battery thermal management

#### 3.1. Comparison of battery thermal management technologies

For the power battery thermal management system itself, with the continuous increase of module capacity and battery capacity density, the deterioration of the battery thermal environment and the contradiction of the harsh requirements for battery performance are becoming increasingly prominent, and it is imperative to develop and apply more efficient cooling technology.

As shown in Table 1, the air-cooling structure is simple and the cost is low, but the cooling rate is slow and the cooling efficiency is too low to meet the increasing energy of the battery heat dissipation demand. Therefore, most of the small pure electric vehicles with simple structure and small battery quantity use air-cooled thermal management technology.

Phase change cooling technology has excellent heat transfer effect and low cost, which is the most potential development direction in the future, but it is also due to the relative lack of technical maturity, which has not been applied on a large scale in the market.

Medium and large electric vehicles such as SMART EV require high battery life, the number of batteries required, and the need to generate high-power charge and discharge during operation, they need to use active liquid cooling and heating thermal management technology. In this regard, the thermal management scheme of liquid-cooled battery will increasingly become the mainstream heat treatment scheme in the market due to its high heat transfer efficiency, good stability and mature technology [7].

**Table 1** Characteristics of mainstream heat treatment schemes

Project	Features and Performance				Situation of application	Representative models	
	Controversiality	Efficiency	Costing	Temperature uniformity			
Air cooling system	Easy	Low	Low	Poor	A small number of applications	Active air cooling system	Passive air cooling system
						Toyota Prius Honda Insight Volkswagen-Golf Tesla Model-s	Nissan Leaf BAICE 150 Jianghuai iEVS
Liquid cooling system	More difficult	High	High	good	Mainstream applications	SMART EV BMW i3 Chevrolet Bolt Chevrolet Volt	
PCM	Easy	High	Lower	good	Not in the market application	/	

### 3.2. State of Art BTMS

According to research [8], the optimal temperature range for lithium-ion batteries widely used on the market today is the range of 15 to 35 ° C, and its performance will vary with temperature, so we need to understand how the battery produces heat and how to dissipate heat is extremely important. Take lithium-ion batteries as an example, the heat production inside lithium-ion batteries is a complex process, and it is necessary to first understand how the speed of electrochemical reactions changes over time and temperature. and the flow of its internal current. In 1985, D BEMARDI proposed a computational model of heating power, which provided a theoretical basis for the heat generation model of lithium ions. Based on the hypothesis of heat uniformity of objects inside the battery, the model proposes to simplify the heat production of the battery into two sources: "chemical reaction heat" and "ohm heat" [7].

In 2001, Honda's SATO N et al. confirmed this lithium-ion model through continuous experimentation on the basis of D BEMARDI. Based on this model, they divided the heat generation of the battery into four parts, two of which were the chemical reaction heat and ohmic heat proposed by D BEMARDI, and the polarization heat and the side reaction heat [8]. In the paper they explain these four parts, the heat of chemical reaction is the heat absorbed or released by the reaction between the chemicals in which the battery works; Ohmic heat is the heat produced from the internal strength of the battery; Polarization heat is the heat generated when the potential of a battery deviates from the equilibrium value when an electric current passes through the electrodes; Side reaction heat is the heat produced by the inner discharge of the battery and the decomposition of the electrolyte.

In 2003 Thomas and Newman argued that lithium ions generate heat through reversible entropy, resistance dissipation, relaxation of cell concentration gradients, and chemical reactions [9]. Since Newman et al. [4] have later undertaken comprehensive modeling of electrochemical systems, many

mathematical methods have now been used to understand the physics of LIB systems. The thermal models of existing batteries rely on various studied physical mechanisms, which can be divided into models of electrical heat, electrochemical thermal patterns and thermal runaway patterns. In the above studies [8], The heat generated by lithium-ion batteries during charging and unloading is not released appropriately, and battery temperature may increase with heat build-up, which can negatively affect efficiency, the lifetime and safety performance of the battery. It will also result in a loss of battery capability and power. There is also thermal runoff, thermal runaway is a serious phenomenon that accelerates with increasing temperature, which will lead to a rise in temperature and gas that may explode the battery. This is a serious safety performance problem for new energy vehicles on the market now. To avoid the above lithium-ion battery thermal issues, new energy vehicles need to maintain the battery within the appropriate temperature range and temperature uniformity of the BTMS. Batteries that tend to be stacked have higher energy density than previous packages increase mileage and recharge batteries with higher currents reduce charging time making the role of the BTMS more important because the battery generates a lot of heat.

A number of battery thermal management strategies have been developed, most of which are active cooling and heating systems based on thermally conductive media, such as air cooling, liquid cooling active cooling systems, and passive cooling systems such as phase change materials [8]. At present, these battery thermal management technologies have been used in new energy vehicles on the market. In 1999, Pesaran et al. showed that in order to ensure the effective operation of the battery pack, new energy vehicles must have a BTMS, because of the specific design requirements of the car, the battery heat dissipation system with air as the heat transfer medium was selected at that time [10]. In 2001, they discussed active cooling, liquid and air cooling, and thermal management of different types of batteries.

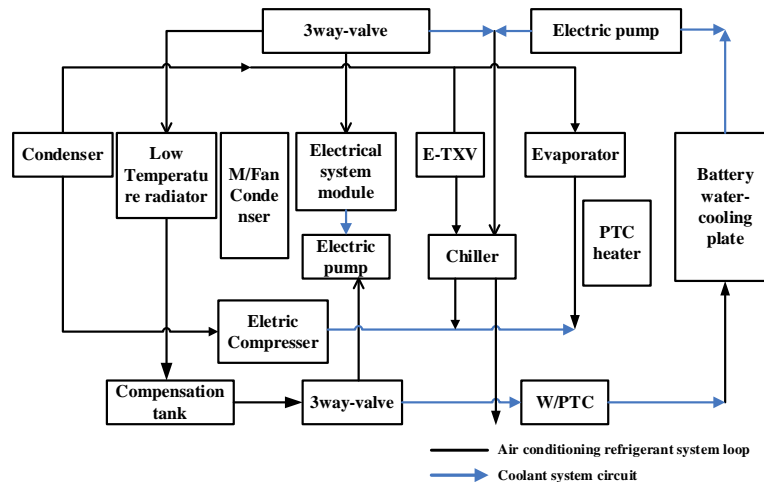
At the 2007 North American International Auto Show in Detroit, Chevrolet unveiled the first Volt electric vehicle [10], with a T-layout, laminated structure, and 288 battery cells installed side by side, with a total capacity of up to 16KWh. All of its liquid cold plates are connected in parallel, adopting a mosaic liquid cooling system with a well-designed particle structure and a dual main channel type. From Figure 1-3, it can be seen that the blue main channel is responsible for the inflow of liquid and the red main channel is responsible for its outflow. The cooling system realizes the output of warm water at low temperatures, and the output of cold water at high temperatures to control the cells in the battery system to maintain the best operating temperature model Experimental results prove that it has excellent heat dissipation performance. The Volt electric vehicle has laid a good foundation for future power battery thermal management system products.

In the early days, Japanese hybrid car manufacturers Prius and Insight used serial ventilation to cool the battery packs. Among them, Pesaran et al. use serial ventilation and parallel ventilation for cooling [11].

Xiao Yanhui [12] et al. of Shanghai Jiao Tong University compared the heat dissipation effects of the two air cooling forms of fork row and trapezoidal arrangement, and concluded that the trapezoid layout is better than the row of forks, and the temperature difference between the batteries can be effectively controlled within 5 °C.

Since 2000, After Al-Hallaj [13] et al. first proposed electric vehicle power batteries based on phase change materials, PCM cooling technology for lithium batteries has received extensive attention and research in the study of battery thermal management systems [14].

In 2014, Rao, ZH [14] and others studied the heat transfer law of power batteries based on phase change materials through numerical simulation methods, and the study showed that the low temperature battery was pre-heated to the same temperature increase, and the preheating time required for air was much greater than that of the PCM, and the thermal conductivity of the PCM was increased, which could effectively improve the temperature uniformity in the preheating process.



**Figure 4** Integrated vehicle heat dissipation management system

**Table 2** Comparison of three major cooling technologies

Thermal management technology	Air-cooling	Phase change cooling	Liquid cooling
merit	Low cost low technical difficulty	Low cost High efficiency	The technology is more mature High efficiency
shortcoming	Less efficient	The technology is immature	The cost is higher
Direction of development	Reduce the temperature variation between the cells	Increasing the thermal conductivity Improved packaging	Improve cold plate arrangement Improve thermal conductivity efficiency

**3.3. The system coupling of battery thermal management and vehicle thermal management**

The previous article mainly introduces the general structure and method of the battery thermal management of new energy vehicles, but in practical applications, battery thermal management should be combined with research as the first branch of the vehicle thermal management, and vehicle thermal managing is a complex coupling system. The vehicle thermal managing of new energy vehicles mainly includes three major systems: motor temperature control, battery temperature control and occupant cabin temperature control, and requires different thermal management modes and control strategies under different operating conditions [15], in 2015 Due to the short mileage and small battery capacity of electric vehicles listed a few years ago, the three major systems are generally independent and the thermal management efficiency is low. With the gradual attention of the world to the lack of oil energy, especially China has introduced many policies to encourage the new energy vehicle industry, the thermal management research of new energy vehicles has developed rapidly in recent years, and the third generation of temperature control system for vehicle thermal management has been formed, as shown in Figure 4 [16].

The appropriate working temperature of the new energy vehicle power battery usually needs to be controlled in the exact range of 15 ° C ~ 35 ° C to help improve the stability and life of the battery. The battery air-cooling technology, liquid-cooling technology and phase change cooling technology introduced in the second section are the cooling and cooling technology of the vehicle in high working conditions and high temperature environments, and the heating scheme of the battery is also required to ensure the battery discharge efficiency in the low temperature environment or when the vehicle is started.

For example, in the third generation of vehicle thermal management scheme, for the heating needs of the battery at low temperature, in addition to the individually set water heating PTC, it can also be heated by the water temperature of the motor temperature control system: because the suitable system temperature of the motor is higher than the appropriate working temperature of the battery, the water temperature of the motor system can flow into the battery at low temperature for battery preheating to achieve the purpose of reducing energy consumption. Therefore, under the existing technical conditions, the connection between battery thermal management and vehicle thermal management will become more and more close, and technicians will also pay attention to the requirements of battery thermal management to meet the functional requirements of motors, DCDC, chargers and air conditioners in the process of vehicle thermal management, combined with the endurance characteristics, operating power, safety performance and durability of important components during the driving period of the vehicle to test, and set up an integrated management system. Thus, improving the quality of battery thermal management.

#### 4. Conclusions

With the transformation of the world energy situation, the automotive industry is now actively formulating countermeasures and striving to transform and upgrade to a green manufacturing and high-quality development industry. As one of the supporting industries of the new energy vehicle industry, the importance of the battery thermal management and vehicle thermal management industry is self-evident. As shown in Table 2, the advantages and disadvantages of the three major cooling technologies of battery thermal management are compared.

Air-cooled systems use air to absorb and dissipate heat from the battery pack, although they are less applied due to the limitations and efficiency of their own technology, and there is still much room for improvement. When there is a temperature imbalance among the cells in the battery system, the chemical reaction and self-discharge reaction rate of the battery will also be uneven, which will lead to differences in cycle life, capacity and internal resistance between the battery cells. The smaller the temperature change, the better the overall consistency of the pool and the longer the lifespan. At present, the level of air-cooling technology can control the range of temperature of the battery cell at 5-10 degrees Celsius, and it is one of the worthiest directions for the air-cooling system to optimize in the future by adjusting the spacing between the batteries, emission methods and other structural adjustments to improve the heat dissipation effect and reduce the temperature difference among the cells.

Phase change cooling uses the transformation of the liquid phase and the solid phase of the material to carry out heat absorption and exothermic heat, which is developing rapidly as an emerging technology and a good prospect, and is expected to be applied on a large scale in the future. The selection criteria for PCMs applied to battery thermal management systems include: (1) the melting point is within the ideal operating temperature range; (2) High latent calorific value, high specific calorific value, high thermal conductivity; (3) The volume change before and after the phase change is small; 4) There is no supercooling phenomenon during solidification, or the supercooling degree is very small; (5) Stable, not easy to decompose, non-toxic, non-flammable and explosive; (6) Can be supplied in large quantities and at low cost. One of the keys to its technical optimization is to improve the thermal conductivity of phase-change materials, thereby improving heat transfer efficiency and enhancing the uniformity of temperature distribution between batteries; At the device level, because the density and volume of the material before and after the phase change, the pressure deformation of the container is required, and the encapsulation method of the phase change material and its combination with the battery are studied in depth to achieve comprehensive optimization of mechanical properties, heat transfer performance and reliability [13].

Liquid cooling system like the traditional engine through the coolant for heat exchange to achieve heat dissipation purposes, its own high stability and high efficiency, as well as its still broad optimization space, has gradually become the mainstream heat treatment solution in the market. An

important factor driving the continuous iteration and development of liquid cooling technology is to increase the efficiency of thermal conductivity. And to improve the thermal conductivity, there are usually the following schemes: (1) increase the contact zone between the cold plate and the battery cell; (2) Improve the thermal conductivity of the interface between the cold plate and the battery cell; (3) Improve the thermal conductivity of the cold plate itself (material); (4) Adjust the runner design to improve the heat transfer effect of the fluid itself; (5) Different cold plate layout schemes. Cold plate materials, the current main use is aluminum alloy, copper thermal conductivity is better, but the cost is much more expensive, so it is not the mainstream direction, in the field of non-battery packs have applications; For increasing the thermal conductivity efficiency of the thermal interface, it is mainly to do work on the thermal interface material, from the previous air medium, to the later thermal pad, and then to the current thermal conductive adhesive, the thermal conductivity effect is constantly improving. After the above two points are confirmed, the focus of future cold plate optimization will be to improve the contact zone between the cold plate and the battery cell, adjust the runner design, and improve the effect of the fluid itself.

We can expect, the battery thermal management system in the future will be combined with the motor temperature control system and the passenger compartment temperature control system to create an integrated and intelligent vehicle thermal management system, and develop and build a more efficient and energy-saving thermal management system.

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