A Review on Electric Vehicle Thermal Management System

Ruochong Li

As an important part of national economy, with high consumption of energy, especially petroleum resource, transportation industry has received much attention. Under the pressure of energy shortages and environmental pollution, automakers have to turn their attention to green energy and clean cars. Pure electric vehicles (EVs), hybrid electric vehicles (HEVs) and fuel cell electric vehicles (FCEVs) are more energy efficient and cleaner than conventional vehicles. Therefore, they have received worldwide attention.

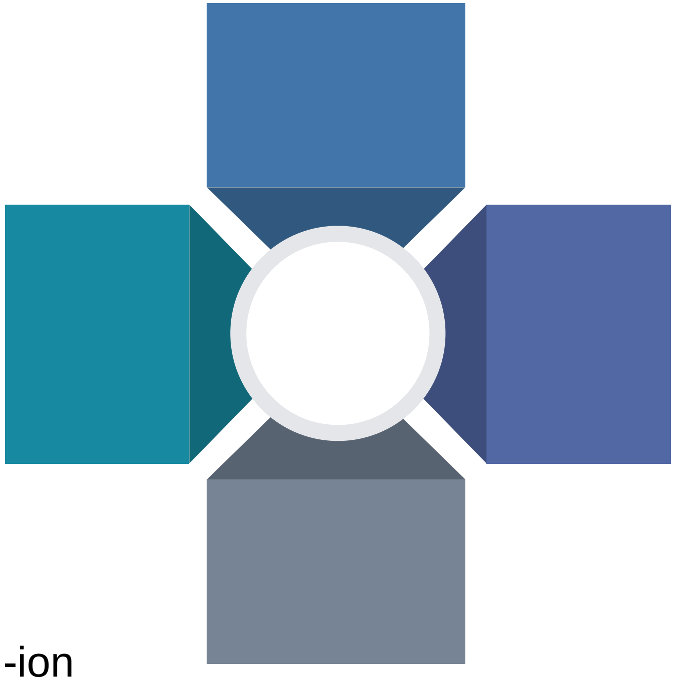
Commonly used vehicle batteries

lead-acid

- Withdrawn from mainstream applications
- Serious environmental pollution

Li-ion

- Strong advantages in energy density, power density and service life
- Environmentally friendly
- High cost



Ni-MH

- Have been the mainstream of commercialization
- The laboratory data lower than Li-ion batteries
- Theoretically there is no improvement.

PEMFC

- does not involve hydrogen-oxygen combustion
- energy conversion rate is high
- performance obviously depends on the amount of water vapor

To ensure battery safety and extend battery life, an efficient battery thermal management system is required. During the charging and discharging process of the battery, a large amount of heat is generated to raise the temperature. Excessive temperature may cause the battery to escape gas or corrode.

In severe cases, it may even cause thermal runaway, causing the electrolyte to decompose and generate a large amount of gas, causing the battery to explode due to excessive pressure.

Temperature related problems

(1) The high temperature caused by the untimely dissipation of heat will reduce the battery cycle performance and even cause safety problems.

(2) The heat generation of the battery cells is not balanced, affecting the dynamic performance and life of the vehicle.

(3) Low-temperature environment battery cold start efficiency is low, battery discharge depth does not match the electric vehicle's power performance, which in turn restricts the application and development of electric vehicles in alpine regions and winter.

Air based battery thermal management system

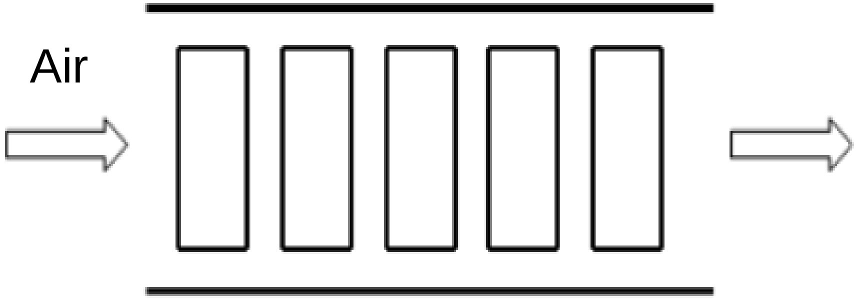
The thermal management of the power battery with is to let the air traverse the battery pack to take away or bring heat to achieve the purpose of heat dissipation or heating.

According to the flow of air outside the battery pack, it can be divided into two types of heat exchange methods: natural convection and forced convection.

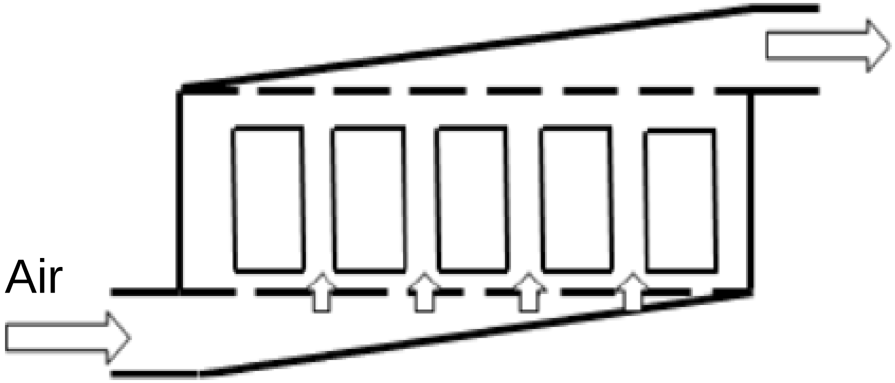
It can also be divided into active and passive thermal management methods depending on whether or not electric vehicles are required to provide auxiliary energy.

Air cooling systems

For air cooling systems, it can be combined with the design of the vehicle's driving characteristics. The heat is taken away according to the natural wind formed by the speed of the vehicle. The battery can also be cooled by forced air circulation through fans and fans. According to the arrangement of the batteries, it can be divided into two types of ventilation: serial and parallel. Studies by Pesaran show that parallel ventilation works better.



serial



parallel

the ACS is simple in structure, light in weight, and low in cost.

Air cooling systems

This kind of battery cooling method is widely used in early electric passenger vehicle, such as KIA Soul EV. At present, this cooling mode is used less and less on passenger cars. At present, more and more are used in **electric buses and electric logistics vehicles**.

The airflow used for cooling the battery pack can be generated by a fan or caused by a vehicle running into a wind.

Air cooling systems

This picture shows the perspective view of KIA Soul EV. We can see that there is an airflow channel above the battery pack to dissipate heat in the battery pack.

Through the air inlet of the air inlet under the vehicle, part of the air inlet of the battery group flows into the cooling channel of the battery group through the air inlet of the battery group, and the exhaust port is discharged through the exhaust port to achieve the purpose of the cooling battery group.

Natural cooling

As for the natural cooling, that is, do not use special heat dissipation measures, so that heating components through their own surface and ambient air heat exchange to heat.

This is the most primitive and the simplest cooling, and is now less widely used. But there are exceptions, that is, Nissan Leaf. However, Nissan's newest generation of Leaf vehicles has also encountered the problem of battery overheating affecting the charging speed of vehicles.

Natural cooling

the battery pack of the first generation Leaf vehicle, which uses natural cooling mode. It can be seen that the battery pack with this cooling method has a more regular and closed appearance, and there is no extra outlet except the current interface.

the battery pack for the latest generation of Leaf models. From the structure, it can be seen that Nissan's new generation of Leaf models still use the weakest and most passive natural cooling.

Air heating system

In a cold environment, the energy and power of most batteries will be reduced, and the performance of the vehicle will be seriously degraded. At this time, it is necessary to consider heating the battery and designing a reasonable air heating system (AHS) to ensure its normal operation. For HEVs, the engine can provide a heat source, but it must be delayed for a certain period of time to heat the battery to the desired operating temperature, so a separate heating device is required. For the BEV, since there is no engine to heat the battery pack, the heat generated by the motor and the heat generated by the electronic appliances with high power in the vehicle can be utilized.

As the ambient temperature increases, the battery size increases, and the battery power requirements increase, conventional ACS cannot meet the cooling requirements. And for heating in cold conditions, AHS is less efficient.

Therefore, in the case of low power and temperature conditions, ACS and AHS are preferred to help reduce the cost of the vehicle. When the power system requires a high-power battery pack and the battery size is large, the ambient temperature is high or low, ACS and AHS can not achieve the desired thermal management effect.

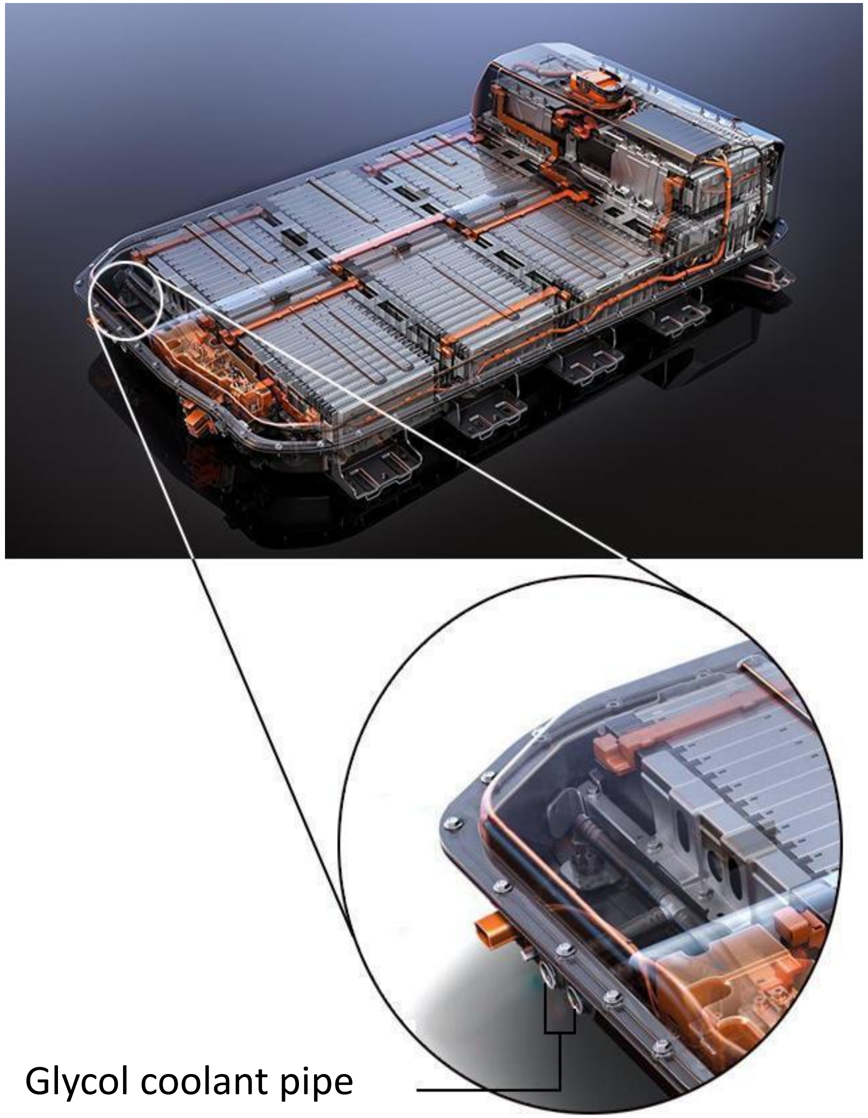
Liquid based battery thermal management system

The use of liquid as a medium for thermal management of power batteries, including liquid cooling systems (LCS) and liquid heating systems (LHS), especially LCS, was developed in the context of ACS not meeting expected results, and can also be divided into active And passive. Active LCS and LHS use the car's own cooling or heating unit, and the battery heat is sent out through liquid exchange. In a passive system, the liquid exchanges heat with the outside air to send the heat of the battery. When the liquid is a medium, a pipeline may be arranged between the battery modules, or a jacket may be disposed around the battery, or the battery cells or modules may be directly immersed in the liquid. When the battery is in direct contact with the liquid, the liquid may be water, glycol, or a refrigerant. In the case of non-direct contact, the liquid must be dielectric and insulated to avoid short circuits.

Liquid based battery thermal management system

We take the Chevrolet Bolt EV model under general group as an example. The battery pack uses Liquid cooled cooling technology. The battery pack is equipped with a coolant interface besides the necessary current interface. The common coolant is ethylene glycol.

In the inside of the battery pack, in addition to the battery module, a cooling plate is arranged, and the internal flow of the coolant will take away the heat generated by the battery, thus controlling the temperature of the battery.



Heat pipe

The rapid development of heat pipe (HP) technology in recent years has been widely used in many fields. The heat pipe is a high-efficiency heat exchange element that utilizes the phase change of the medium in the tube to absorb and release heat. Since the phase change of the medium in the tube is mainly liquid-gas phase change, and the medium is liquid before the phase change, the application of the heat pipe in the thermal management of the battery is classified as a liquid mode.

Conventional LCS and LHS, as well as new heat management systems such as heat pipes, have good thermal management effects, but at the same time there are negative factors such as complex system, relatively heavy weight, potential liquid leakage risk and difficult maintenance. In the case of large battery size and power or high heat output, and the battery operating conditions are relatively harsh, liquid medium thermal management will have the advantage that ACS and AHS can't match.

PCM based battery thermal management system

Phase change material (PCM) is a substance that has a constant temperature or a small range of variation during phase change but that absorbs or releases a large amount of heat. So far, PCM has been applied in many other fields.

When PCM is used, the battery cells or modules can be directly immersed in the PCM, and the battery can be thermally managed by absorbing and releasing heat when the PCM is melted or solidified.

PCM based battery thermal management system

Li-ion battery pack size and discharge current increase will lead to more prominent thermal problems, especially heat dissipation. When the costs of ACS and LCS and the complexity of the system become more prominent, the thermal management advantages of PCM in the battery become more apparent.

Compared to air and liquid media, the PCM battery thermal management system is simple, does not require additional cooling components and battery energy consumption, and is especially suitable for non-stationary discharge systems.

Cooling method		Cooling principle	Cooling efficiency	Remarks
Natural cooling		Air natural convection	Low	Low cost, small col umn
Air cooling	Passive air cooling	Air convection	General	Used for early electric vehicles
	Forced-air cooling			
Liquid cooling		Liquid forced convection	high	Current mainstream method, complex structure
Phase change cooling / refrigerant direct cooling		Phase change endothermic	Very high	Not widely used

Conclusion

In general, the trend of battery development is always towards higher energy density, while high energy density batteries often require a more efficient and safer cooling scheme. The water cooling scheme has no error in heat transfer capacity, heat transfer consistency, battery pack sealing, NVH and so on. Secondly, water cooling has long been used in traditional cars and has a perfect supply chain. When the design and process of the battery system are stable, the cost can be effectively controlled.

Thanks for listening!

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Abstract: Electric vehicles have great potential and advantages in energy saving and emission reduction, but their performance is restricted by power batteries, and temperature will affect the safety and life of batteries. Therefore, the battery thermal management system is important for the safe and efficient operation of electric vehicles and battery performance. In this paper, the recent research progress of thermal management of automotive power battery is reviewed. The current heat dissipation methods and research status of typical battery thermal management systems such as air cooling, liquid cooling and phase change are analyzed. The research methods and innovations are summarized. The problems faced in battery thermal management research, the future research of power battery thermal management system is discussed.

1 Introduction

As an important part of national economy, with high consumption of energy, especially petroleum resource, transportation industry has received much attention [1]. Under the pressure of energy shortages and environmental pollution, automakers have to turn their attention to green energy and clean cars. Pure electric vehicles (EVs), hybrid electric vehicles (HEVs) and fuel cell electric vehicles (FCEVs) are more energy efficient and cleaner than conventional vehicles [2-6]. Therefore, they have received worldwide attention.

As a key component of electric vehicles, power batteries are particularly important for electric vehicles. Among the commonly used vehicle batteries, lead-acid batteries have long since withdrawn from mainstream applications due to serious environmental pollution; although Ni-MH batteries have been the mainstream of commercialization, the laboratory data of their main indicators are lower than Li-ion batteries, and theoretically there is no improvement. Compared with other types of batteries, Li-ion batteries have strong advantages in energy density, power density and service life, and become the mainstream of current power batteries, but their cost is high, and performance, life and safety are all It is closely related to the ambient temperature. The power generation process of PEMFC does not involve hydrogen-oxygen combustion, so it is not limited by the Carnot cycle, and the energy conversion rate is high; no pollution occurs during power generation, the power generation unit is modular, and the reliability is high. However, the performance of PEMFC depends obviously on the amount of water vapor, while the local dehydration or water condensation due to uneven temperature distribution can cause performance degradation [7].

To ensure battery safety and extend battery life, an efficient battery thermal management system is required [8]. During the charging and discharging process of the battery, due to the electrochemical reaction and the internal resistance, a large amount of heat is generated to raise the temperature [9]. Excessive temperature may cause the battery to escape gas or corrode [10]. In severe cases, it may even cause thermal runaway, causing the electrolyte to decompose and generate a large amount of gas, causing the battery to explode due to excessive pressure [11]. And the aged battery may lead to uneven temperature distribution [12]. In short, no matter whether a battery is of any type: lead-acid, Ni-MH, Li-ion and PEMFC, with effective heat dissipation and thermal runaway safety, all require a successful battery thermal energy management system.

Battery thermal energy management, including traditional cooling systems, such as an air thermal management system with an electric fan, liquid thermal management system with water, glycol, oil, acetone or even refrigerants, hear pipe thermal management system and PCM thermal management system have been investigated by many researchers. Thermal energy management for PEMFC also attracted more attention during the last decade. Single PCM is not sufficient for high heat fluxes, such as paraffin wax with large heat storage capacity but low thermal conductivity. To resolve the conflict between large heat storage capacity and low thermal conductivity, many methods have been investigated for increasing the thermal conductivity of PCMs. It is also important to get a stable and stronger battery module to withstand thermo-mechanical effects while in operation [13].

This paper introduces the research background and current status of electric vehicle thermal management system. The principles and applications of typical battery thermal management systems are summarized. The advantages and disadvantages of these are introduced from examples. In addition, the latest research progress of thermal management of automotive power battery is summarized, and the problems faced in current battery thermal management research are summarized. The research direction of future thermal battery thermal management system is prospected.

2 Research progress on battery thermal management

2.1 Battery thermal management performance requirements and classification

Battery thermal management is based on the influence of temperature on battery performance, combined with the electrochemical characteristics and heat generation mechanism of the battery, based on the optimal charge and discharge temperature range of the specific battery, covering materials, electrochemistry, heat transfer, molecular dynamics, etc. The background of the discipline is to solve the problem of heat dissipation or thermal runaway caused by the battery operating under too high or too low temperature, and improve the overall performance of the battery. With the increasing demand for battery power performance in power systems such as electric vehicles, the demand for battery thermal management is becoming more and more urgent. Based on the foregoing analysis, the temperature related problems of the electric vehicle power battery system mainly include the following three aspects:

(1) The high temperature caused by the untimely dissipation of heat when the battery is operated in a high temperature environment and the rapid accumulation of heat generated by the discharge of a large current will reduce the battery cycle performance and even cause safety problems such as direct damage to the battery such as combustion or explosion.

(2) The heat generation of the battery cells is not balanced, the temperature distribution between the batteries of the battery module is not balanced, and the temperature imbalance between the various modules of the entire battery pack of the electric vehicle and the temperature of each battery will reduce the overall life of the battery pack, affecting the dynamic performance and life of the vehicle.

(3) Low-temperature environment battery cold start efficiency is low, battery discharge depth does not match the electric vehicle's power performance, which in turn restricts the application and development of electric vehicles in alpine regions and winter.

The electric vehicle's power performance and cycle life are improved, and the following requirements are imposed on the battery thermal management system [14-15]:

(1) Ensure the optimum operating temperature range of the single cell, avoiding the overall or partial temperature of the single cell, the battery module and the battery pack being too high, enabling the battery to be efficiently dissipated in a high temperature environment, and rapidly heated or insulated in a low temperature environment.

(2) Reducing the temperature difference between different parts of the unit cell, especially the large-size unit cell, to ensure uniform temperature distribution of the unit cell.

(3) Reduce the temperature difference between different battery modules inside the battery pack to ensure uniform temperature distribution inside the battery pack.

(4) Meet the specific requirements of light and compact electric vehicles, easy to install and maintain, reliable and low cost.

(5) Effective ventilation when harmful gases are generated, and thermal measurement and monitoring consistent with relevant parameters such as temperature.

2.2 Air based battery thermal management system

The thermal management of the power battery with air as the medium is to let the air traverse the battery pack to take away or bring heat to achieve the purpose of heat dissipation or heating. According to the flow of air outside the battery pack, it can be divided into two types of heat exchange methods: natural convection and forced convection. It can also be divided into active and passive thermal management methods depending on whether or not electric vehicles are required to provide auxiliary energy.

For air cooling systems, it can be combined with the design of the vehicle's driving characteristics. The heat is taken away according to the natural wind formed by the speed of the vehicle. The battery can also be cooled by forced air circulation through fans and fans. According to the arrangement of the batteries, it can be divided into two types of ventilation: serial and parallel. Studies by Pesaran et al. show that parallel ventilation works better [15]. At the same time, the ACS is also affected by the thickness of the runner [16]. Considering the specific requirements of cost and car space, ACS is generally used as the first choice for heat dissipation in electric vehicle batteries [17]. The Toyota Prius battery pack uses a parallel-ventilated ACS as recommended by Pesaran et al. According to NREL's test data, the Ni-MH battery used in the battery pack can operate at 25 ° C and the maximum temperature can be controlled below 45 ° C. The temperature difference is controlled below 5.0 °C [18]. Relatively speaking, the ACS is simple in structure, light in weight, and low in cost.

In a cold environment, the energy and power of most batteries will be reduced, and the performance of the vehicle will be seriously degraded. At this time, it is necessary to consider heating the battery and designing a reasonable air heating system (AHS) to ensure its normal operation. For HEVs, the engine can provide a heat source, but it must be delayed for a certain period of time to heat the battery to the desired operating temperature, so a separate heating device is required. For the BEV, since there is no engine to heat the battery pack, the heat generated by the motor and the heat generated by the electronic appliances with high power in the vehicle can be utilized.

As the ambient temperature increases, the battery size increases, and the battery power requirements increase, conventional ACS cannot meet the cooling requirements. And for heating in cold conditions, AHS is less efficient. For lead-acid batteries, Choi and Yao pointed out that relying on natural convection or forced convection does not effectively solve the problem of temperature rise [19]. For Li-ion batteries, Nelson et al. pointed out that when the battery is in a warm environment [20], it is difficult to reduce the battery temperature of 66 ° C to below 52 ° C by air cooling. Chen et al. found through numerical simulation that the uniformity of the temperature distribution of Li-ion battery has not been fundamentally improved after the intensity of forced convection has increased to a certain extent [21]. Natural cooling, that is, do not use special heat dissipation measures, so that heating components through their own surface and ambient air heat exchange to heat. This is the most primitive and the simplest cooling, and is now less widely used. But there are exceptions, that is, Nissan Leaf. However, Nissan's newest generation of Leaf vehicles has also encountered the problem of battery overheating affecting the charging speed of vehicles.

Therefore, in the case of low power and temperature conditions, ACS and AHS are preferred to help reduce the cost of the vehicle. When the power system requires a high-power battery pack and the battery size is large, the ambient temperature is high or low, ACS and AHS can not achieve the desired thermal management effect.

2.3 Liquid based battery thermal management system

The use of liquid as a medium for thermal management of power batteries, including liquid cooling systems (LCS) and liquid heating systems (LHS), especially LCS, was developed in the context of ACS not meeting expected results, and can also be divided into active And passive. Active LCS and LHS use the car's own cooling or heating unit, and the battery heat is sent out through liquid exchange. In a passive system, the liquid exchanges heat with the outside air to send the heat of the battery. When the liquid is a medium, a pipeline may be arranged between the battery modules, or a jacket may be disposed around the battery, or the battery cells or modules may be directly immersed in the liquid. When the battery is in direct contact with the liquid, the liquid may be water, glycol, or a refrigerant. In the case of non-direct contact, the liquid must be dielectric and insulated to avoid short circuits.

We take the Chevrolet Bolt EV model under general group as an example. The battery pack uses Liquid cooled cooling technology. The battery pack is equipped with a coolant interface besides the necessary current interface. The common coolant is ethylene glycol.

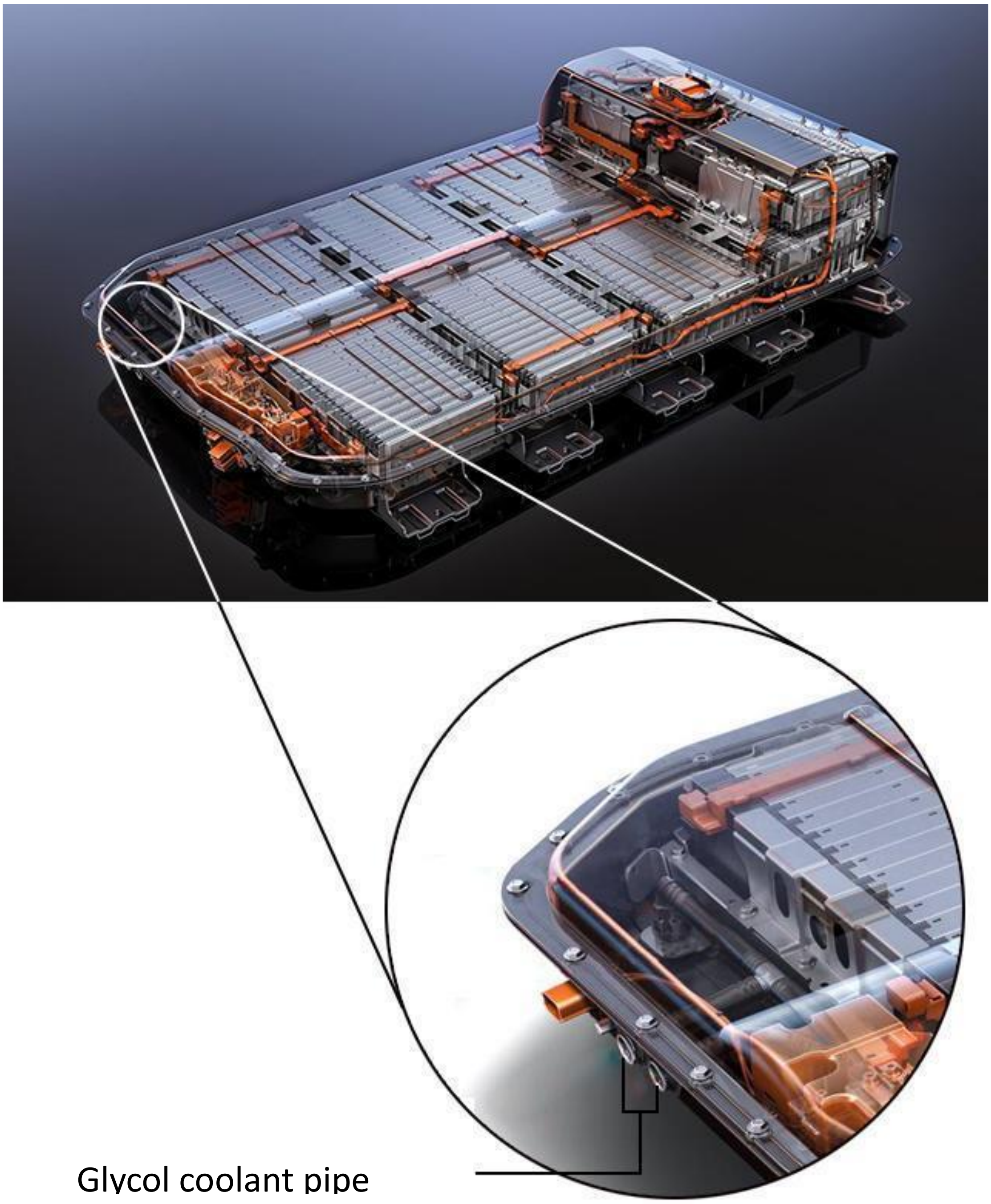

Figure 1 battery pack for Chevrolet Bolt EV

In the inside of the battery pack, in addition to the battery module, a cooling plate is arranged, and the internal flow of the coolant will take away the heat generated by the battery, thus controlling the temperature of the battery.

The heat transfer efficiency between a battery cell or module and a liquid is related to the thermal properties of the liquid, such as thermal conductivity, viscosity density, and flow rate. At the same flow rate, most direct contact liquids (such as mineral oil) have much better heat transfer efficiency than air. Better than oil viscosity, resulting in slower flow rate, the effective heat transfer coefficient is only 1.5 to 4 times higher than air [22].

The rapid development of heat pipe (HP) technology in recent years has been widely used in many fields [23-25]. The heat pipe is a high-efficiency heat exchange element that utilizes the phase change of the medium in the tube to absorb and release heat. Since the phase change of the medium in the tube is mainly liquid-gas phase change, and the medium is liquid before the phase change, the application of the heat pipe in the thermal management of the battery is classified as a liquid mode. The application of heat pipes in battery thermal management is mainly heat dissipation. It was first applied to the cooling of space equipment batteries such as artificial satellites. Later, it was gradually applied to electric vehicle power battery systems as battery heat problems became more and more prominent. Wu et al. studied the heat dissipation effect of heat pipes in Ni-MH and Li-ion batteries [26], and proposed to install aluminum in the heat pipe condensation end when designing the heat dissipation of a cylindrical Li-ion battery with a capacity of 12AH. A method of enhancing heat transfer, such as fins and fans. Jang and Rhi designed loop heat pipes for thermal management of Li-ion batteries [27]. Experiments have shown that battery temperatures can be kept below 50 °C. They believe that heat pipes are suitable for future EV and HEV battery thermal management.

Conventional LCS and LHS, as well as new heat management systems such as heat pipes, have good thermal management effects, but at the same time there are negative factors such as complex system, relatively heavy weight, potential liquid leakage risk and difficult maintenance. In the case of large battery size and power or high heat output, and the battery operating conditions are relatively harsh, liquid medium thermal management will have the advantage that ACS and AHS can't match.

2.4 PCM based battery thermal management system

Phase change material (PCM) is a substance that has a constant temperature or a small range of variation during phase change but that absorbs or releases a large amount of heat. So far, PCM has been applied in many other fields. The PCM for the electric vehicle battery thermal management system was first proposed by Al-Hallaj et al. [28] and patented by Al-Hallaj and Selman [29]. When PCM is used, the battery cells or modules can be directly immersed in the PCM, and the battery can be thermally managed by absorbing and releasing heat when the PCM is melted or solidified.

Li-ion battery pack size and discharge current increase will lead to more prominent thermal problems, especially heat dissipation. When the costs of ACS and LCS and the complexity of the system become more prominent, the thermal management advantages of PCM in the battery become more apparent. Khateeb et al. [30] modeled the Li-ion battery pack for electric scooters and used PCM for thermal management with good results. Then they carried out experiments and compared the heat dissipation effects of various cooling systems on the basis of the above. Finally, the effect of PCM/foam aluminum was the most obvious, which was 17.5 °C lower than the maximum temperature under natural convection cooling [31]. Duan and Naterer used electric heating to simulate battery discharge characteristics, and conducted experimental analysis on battery PCM thermal management under constant heat generation rate, heat production rate, ambient temperature and periodic ambient temperature, further verifying the feasibility and efficiency of PCM [32]. Compared to air and liquid media, the PCM battery thermal management system is simple, does not require additional cooling components and battery energy consumption, and is especially suitable for non-stationary discharge systems.

2.5 Conclusion

The cooling efficiency of their cooling system is summarized as follows, and their cooling efficiency is gradually improved.

Table 1 cooling methods commonly used for batteries

Cooling method		Cooling principle	Cooling efficiency	Remarks
Natural cooling		Air natural conve ction	Low	Low cost, small c olumn
Air cooling	Passive air cooling	Air convection	General	Used for early electric vehicles
	Forced-air cooling			
Liquid cooling		Liquid forced convection	high	Current mainstream method, complex structure
Phase change cooling / refrigerant direct cooling		Phase change endothermic	Very high	Not widely used

In general, the trend of battery development is always towards higher energy density, while high energy density batteries often require a more efficient and safer cooling scheme. The water cooling scheme has no error in heat transfer capacity, heat transfer consistency, battery pack sealing, NVH and so on. Secondly, water cooling has long been used in traditional cars and has a perfect supply chain. When the design and process of the battery system are stable, the cost can be effectively controlled.

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