State-of-the-arts Thermal Management Systems for New Energy Vehicles

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Abstract. With the rapid progress of automobile manufacturing industry, people's demand for energy is gradually expanding, and smog is gradually appearing in cities. New energy has gradually become a new direction of automobile development, with its dual advantages of not only reducing emissions but also saving energy. Lithium battery is the main component of new energy vehicle, and its temperature will be in the heating process of current input and loss. The average temperature distribution directly affects the service life and functional effect of the battery, and the stability of the battery determines whether it can bear much power. If the car is running, the heat of the battery can't be dispersed in time and the local temperature is too high, the life of the battery will be reduced rapidly, and even more seriously, it will lead to fire. Therefore, in order to make the battery pack of the new energy vehicle heat evenly, and the reliability and safety of the new energy vehicle work continuously and effectively, A battery heat dissipation structure is determined in order to improve the overall performance of the lithium-ion battery. The latest thermal management systems for new energy vehicles are thoroughly examined in this paper.

Keywords: Battery; New energy vehicles; thermal management systems.

1. Introduction

With the rapid development of national economy, people's living standard is gradually rising, and automobiles are also developing rapidly. However, the energy consumption of automobiles accelerates the shortage of energy, and the pollution of exhaust gas to the environment is becoming more and more serious. Faced with the problems of energy and environment, new energy vehicles have been strongly supported by the government for their advantages of energy saving and emission reduction, and have become one of the top ten key promotion areas in "Made in China 2025". New energy vehicle is a new starting point of China's automobile industry [1-3].

As shown in Fig. 1, a battery electric vehicle (BEV) is a car that runs on batteries that can be charged (such as lead-acid batteries, nickel-cadmium batteries, nickel-hydrogen batteries or lithium-ion batteries). It is mostly made up of the power supply system, the electric drive system, and the support system. A power supply, an energy management system, and a charger are all parts of the power supply system. Its main job is to power the motor, keep track of how much power is being used, and control the charger so that the battery can be charged. The electric drive system consists of the electronic controller, power converter, motor, mechanical transmission mechanism, and wheels. It is responsible for converting the electric energy stored in the battery into the kinetic energy of the wheels, and reversing this process when the vehicle slows down or stops. Regenerative braking is the name for this last part.Auxiliary systems include of things like a backup battery, power steering, a GPS system, an air conditioner, lights, a defroster, a windshield wiper, a radio, and a lot more, with the help of these auxiliary devices, the maneuverability of the car and the comfort of the passengers can be improved.

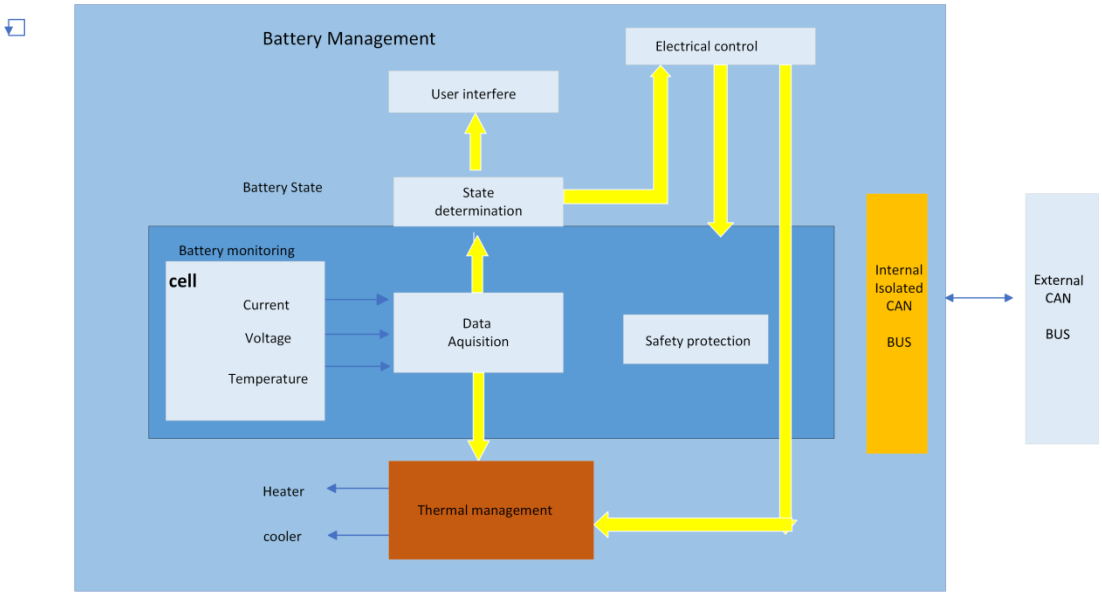


Fig. 1. System diagram of a BEV

Battery, also called secondary battery or storage battery, is powered by reversible electrochemical reaction inside the battery. And when charging, the electric energy is stored in the form of chemical energy [4-6]. Inside the battery. Battery is a key component of new energy vehicles, and its importance is self-evident. The bottleneck of the pool lies in the technical problems of "safety", "low cost" and "large capacity". According to the actual driving situation of new energy vehicles, the following requirements are put forward for the performance of power batteries:

(1) Superior to specific energy. In other words, The battery's mass specific energy and volume ratio measure its power output relative to its size.The larger the energy ratio, the more energy the battery can store and release. Using a battery system with a large specific energy can reduce the quality and volume of the battery can improve the effective load of the automobile and the mileage that can be driven by one charge and discharge. Therefore, The energy density of power batteries is an essential performance metric.

(2) High specific power. That is, mass specific work and volume specific work, that is, what the unit mass or volume of the battery can do. The greater the work ratio, the greater the work done by the battery per unit time, and the acceleration performance and climbing performance of the car are obvious.

(3) Strong adaptability. Power batteries often work under harsh and extreme conditions, such as or fast charging. And charging and discharging conditions under variable discharge conditions, etc., so it is required that the battery still has enough charge and discharge under such conditions. Electricity, have good adaptability to working conditions.

(4) The price is moderate. At present, due to the limitation of technology and material conditions, the cost of power batteries is generally high, For example, for hybrid electric vehicles, the cost of battery pack that only provides power accounts for 1/3 of the whole vehicle. If we can make a technological breakthrough in material cost, the competitiveness of new energy vehicles in the market will be greatly improved.

(5) High charging and discharging efficiency. To meet the needs of the vehicle as a whole, the power battery requires frequent charging and discharging under certain operating conditions.The power demand often requires that the charging and discharging efficiency is large enough.

(6) Good safety performance. Safe and reliable, long cycle life, and try to avoid corrosion, flammability and explosion.

(7) Environmental protection. That is, the process of making, using, recycling and regenerating batteries is environmentally friendly.

In this paper, various battery technologies and corresponding thermal management for BEV application is comprehensively analyzed.

2. Basics of Lithium-ion batteries

Although lithium-ion batteries are all composed of positive plate, negative plate, separator, electrolyte and casing. However, due to the different shapes, sizes, material systems and internal structures of batteries, the performance of various battery products. There are also big differences. According to different shapes, lithium batteries on the market at present can be divided into cylindrical lithium batteries and square lithium batteries [4].

And lithium battery and soft pack lithium battery, each of which has different characteristics and its own application fields. For example, notebook computers mostly use 18650 cylindrical lithium batteries, and mobile phones mostly use soft-pack batteries. And in electric steam Car field, different car manufacturers have different choices. Domestic manufacturers mostly use square batteries and soft-pack batteries. Tesla, a representative American electric vehicle manufacturer, prefers cylindrical batteries.

Soft-package lithium batteries have a similar internal structure and properties to square lithium batteries，but the biggest difference is that the outer packaging is made of aluminum-plastic composite film, which makes the weight of soft-package lithium batteries reduce by 20~40% compared with square batteries with the same capacity. When safety problems occur, soft-package batteries generally only bulge, but are not as prone to explosion as steel or aluminum-shell batteries. Its disadvantages are high cost, poor consistency and easy leakage.

Lithium-containing metal oxide (LiMCh, M stands for transition metal) and lithium-intercalated carbon (LixC) are active materials in the positive and negative electrodes of lithium battery, respectively [6]. When the battery is working, lithium ions are embedded or removed in the active materials of the positive and negative electrodes, and spread between the two electrodes through the transmission of electrolyte, while the external circuit connected with the current collector shows equal electron transfer. The figure shows the diffusion during reverse+charge and discharge. During the charging process, the lithium-containing material of the anode is oxidized, and lithium ions are separated and diffused in the electrolyte, and embedded into the lithium-embedded carbon of the anode material through the diaphragm, so that the active material of the anode is continuously reduced during the charging process, and the same amount of electrons and lithium ions show the transfer from the anode to the cathode in the external circuit; During the discharge process, lithium ions are separated from the lithium-intercalated carbon, transported through the electrolyte, passed through the diaphragm and embedded into the positive metal oxide.

During the process of charging and discharging, owing to the battery's operational specifications and the increase of heat generation in the reaction process, the ion diffusion inside the lithium ion battery will change with the change of temperature, which shows that the electrochemical parameters of the battery, such as conductivity, ion diffusion rate and activation energy, will change with the change of temperature [5]. Sometimes, side reactions and excessive reactions will occur, resulting in other substances. Excessive reactions and side reactions should be avoided in actual use.

Research shows that the main parts of a battery's heat source are Joule heat, Qj heat, and reaction heat. Qr, heat from polarization, Qp, and heat from side reactions, Qs. The total heat that the battery gives off is:

$$Q=Qj+Qr+Qp+Qs \quad (1)$$

Qj is the heat made by the battery's ohmic resistance, Qr is the heat made by the chemical reaction going on inside the battery, and Qp is the battery pole. Heat is made by reactions, and Qs is the amount of heat made by the side reaction of a battery.

(1) Joule heat Qj

Since the materials of lithium-ion battery, such as the shell, pole, positive and negative electrodes, diaphragm and electrolyte, have internal resistance, a certain amount of heat, Joule's heat, is generated when current flows through them according to Joule's law. Joule heat is the main source of heat generation in a power cell, and its constant value is positive.

(2) Reaction heat Qr

Throughout the course of lithium ion battery operation， lithium ions and electrons are constantly embedded and de-embedded between the plus and minus electrodes,and the lithium ions and electrons are embedded and de-embedded by the heat generated by this particle transfer is called reaction heat, which is charged and discharged because the reaction is reversible. When the electricity is equal in magnitude and opposite in sign, it is negative when charging and positive when discharging.

(3) Polarization heat Qp

There are three kinds of polarization effects in the process of battery charging and discharging: ohmic polarization caused by ohmic internal resistance, also known as Resistance polarization; Electrochemical polarization due to the moving speed of electrons being faster than the reaction speed of electrodes; Due to lithium The diffusion rate of ions is lower than the electrode reaction rate, resulting in concentration polarization, which will cause. A certain pressure drop, while generating a certain amount of heat, is called polarization heat Qp, and its value is always positive.

(4) Heat of side reaction Qs

In addition, when the lithium battery is overcharged and overdischarged, certain side reactions will occur and heat will be generated. Side effects are predominantly induced by the self-discharge of the battery and the decomposition of electrode materials and electrolyte caused by high temperature. The heat generated by these side reactions is called the heat of side reaction, which is recorded as Qs. Since this part of heat is very small and under normal working conditions of the power battery, overcharge will not occur. Under normal working conditions, overcharging and overdischarging will not occur, so the heat generated by the battery is usually ignored when calculating the side reaction heat. Therefore, the side reaction heat is usually ignored in the calculation of battery heat production, and only Joule heat, polarization heat and reaction heat need to be considered in the actual calculation of battery heat generation.

The second law of thermodynamics states that temperature differences occur whether or not they are within the same item. The heat will naturally move from the part with the high temperature to the part with the low temperature,or between many items. warmed area. Heat can be transferred in three different ways: conduction, convection, and radiation. However, the actual heat transfer process frequently combines several different heat transfer modes. The power battery's heat transfer is as follows for various heat transfer modes. A brief analysis of the process' embodiment is provided.

(1) Heat conduction

Heat conduction, also referred to as heat conduction, is the disorder and randomness of small particles of matter, such as molecules, atoms, and electrons. Exercise causes a change in heat diffusion. Heat conduction is dependent on direct contact between objects, and when objects are in contact, heat is conducted. When only heat conduction occurs, components will not undergo any macroscopic displacement. Even though the electrolyte is a fluid within the power battery, its flow is so feeble that it can be solidified. The manner of heat transport within the battery is characterized as heat conduction. Fourier's law (also known as heat conduction and heat flow rate square Cheng) states that the heat flux density passing through every point of an item along the normal direction of an isothermal surface is proportional to the rate of temperature change at that point.

(2) Convective heat transfer

When there is a temperature difference in a fluid, the fluid's macroscopic displacement causes the high- and low-temperature components to merge. Thus, mixing results in heat transfer, also known as heat convection.The difference in temperature is what convective heat transfer is all about.There are two main ways that heat moves from the surface to the outside fluid: heat transfer and heat transfer. Combination of methods. In the battery compartment, convective heat transfer accounts for the moving air on the surface of the power battery to get rid of heat. Convective heat transmission can

also be subdivided into natural convection and forced convection, with natural wind correlating to cold forced air cooling. Natural convection is created by the flow caused by the density change caused by the temperature change of the fluid,forced convection is driven by external factors while natural convection is driven by internal forces.(e.g. natural wind, pump, fan, etc.).

(3) Thermal radiation

Radiation thermique is a kind of electromagnetic wave energy emitted into space as a result of the continuous thermal motion of subatomic particles.

Anything with a temperature above 0K(all objects in nature have a temperature greater than 0K) is in spontaneous and uninterrupted release and absorption of thermal radiation energy. In contrast to thermal radiation does not work like heat conduction or heat convection. It needs direct contact between the objects and has no medium for transmission. Radiative heat exchange takes place between the battery and the box, the air and other batteries in the box. According to Stefan-Boltzmann law, the net radiant heat exchange between the battery and the surrounding objects is proportional to the blackbody radiation constant σ and the fourth power difference (Tw4-TS4) between the surface temperature of the battery and the surface temperature of the environmental objects. Due to the battery system's temperature and temperature difference are relatively small, compared with heat conduction and convection heat exchange, this radiation heat transfer amount is very small in value and can be neglected. Therefore, this paper only discusses the heat conduction inside the battery and the convective heat transmission between the battery's surface and the surrounding air.

3. Thermal management system

The research on battery thermal management system can be traced back to 1980s. With the increasing thermal safety problems of power batteries and the vigorous development of new energy vehicles, the research on battery thermal management system has gradually developed. The National Renewable Energy Laboratory of the United States regards the research on battery thermal management as its main work direction. After 20 years of further research and development, experts and scholars from universities and research institutes at home and abroad have made some research on battery thermal management [7-10].

3.1. Cooling system

3.1.1 Ventilation and cooling system

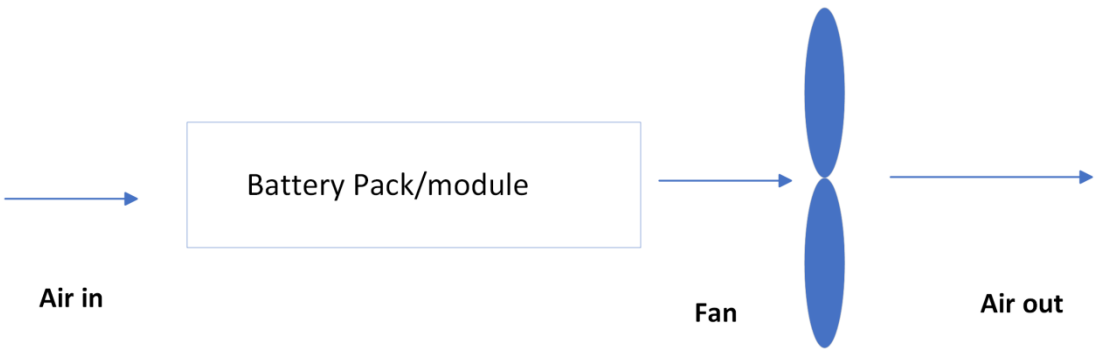


Fig. 2. Schematic diagram of natural convection cooling

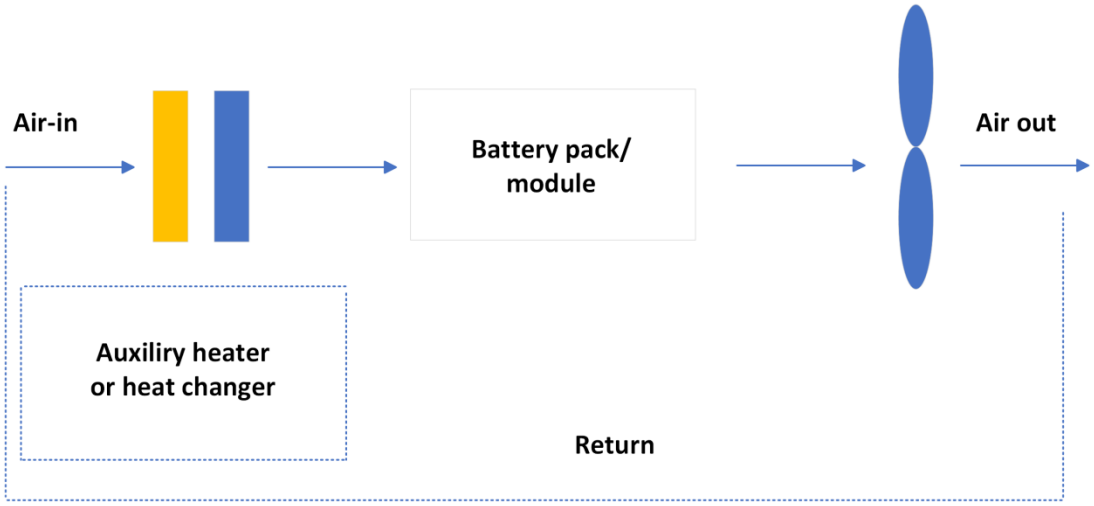
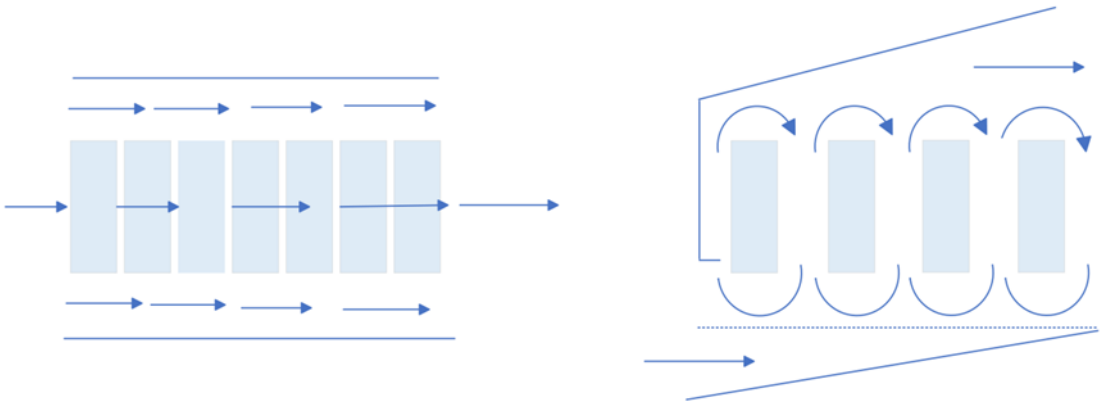


Fig. 3. Schematic diagram of forced convection cooling

There are roughly two types of ventilation, the first is natural ventilation cooling, and the second is forced convection cooling, as shown in the Fig. 2 and Fig. 3, respectively. Natural convection cooling relies on introducing natural wind from the outside to achieve the effect of cooling the inside of the battery pack. General special design is adopted to increase the heat dissipation area of the battery to achieve the heat dissipation effect. The forced cooling system is responsible for the forced air conditioning. such as the electric fan and the auxiliary evaporator of the automobile air conditioning system. With the increasing requirements of the market for the power performance of electric vehicles, The quantity of on-board power batteries is increasing, as is their energy and the compactness of their organization. No longer can natural air conditioning meet the needs. Forced air cooling has clear advantages for controlling the maximum battery pack temperature, but if the battery box and gas channel structure are not scientifically built, it is simple to cause the temperature between monomers. The phenomena of extreme dissimilarity. Current research on air cooling technologies focuses mostly on enhancing the air flow field. Fig. 4 depicts the fundamental circulation structure of ventilation, which is often separated into serial and parallel components.



(a) Serial ventilation (b) Parallel ventilation

Fig. 4. Circulation structure of ventilation.

In the structure of serial ventilation, the cooled air will enter the inside of the battery box from one side of the battery box, and then flow out from the air outlet after passing through the outer the outside of the battery.As the chilly air circulates inside the container, its temperature gradually increases, the difference in temperature between the air and the batteries keeps getting smaller. This makes it harder for the batteries in the back row to get rid of heat, which causes the temperature of the battery pack to be spread out unevenly. The longer the flow channel, the more noticeable the difference. The problem is fixed by the parallel heat dissipation structure. In the parallel flow channel, cooling air enters the battery box from the bottom of one side. The flow guide plate helps the air flow evenly into

each row of batteries to exchange heat. Each row of batteries has the same cooling air temperature. This makes the battery pack's temperature distribution much more even. Many researchers have dug deeper into the parallel cooling structure and looked at how the distance between the batteries, the angle of the deflector, the speed and temperature of the air, the number and location of the air outlets, and other factors affect the cooling effect of the system， and made corresponding improvements.

3.1.2 Liquid cooling

According to the mode of interaction between the coolant and battery, liquid cooling technology for power batteries can be classified as direct contact or indirect contact. Direct contact liquid cooling technology is to immerse the whole battery pack in insulating and high thermal conductivity coolant. In ethylene glycol, mineral oil, etc., the key of this technology lies in the insulation between battery and liquid to prevent short circuit. Non-contact liquid cooling technology is widely used at present, and its basic structure and working principle are shown in the figure, namely. A water jacket in contact with a single battery is embedded in the battery box, and an external water pump is used as a power device to drive the water jacket. The cooling liquid flows and a substantial amount of heat is taken out of the battery box into the heat exchanger, and the high-temperature liquid acts as a cooling fan. After lowering the low temperature, re-enter the battery box to dissipate the heat of the battery, so as to achieve the cooling of the battery.

3.1.3 Cooling of phase change materials

Al-Hallaj and Selman first proposed the use of phase change in power lithium battery pack at the beginning of this century [7]. The basic principle of the system is that all single cells are immersed in the phase change materials, and the phase change materials are processed by. In a specific temperature range, the phase change material absorbs or releases heat with a change in its physical form, thus achieving. For the purpose of cooling or heating the battery pack, its basic structure is shown in the Fig. 5.

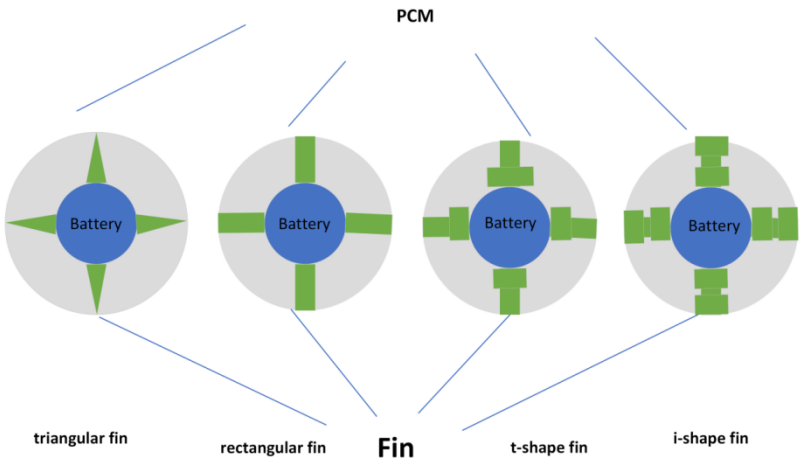


Fig. 5. Different structures of cooling of phase change materials

4. Summary

In this paper, the differences in material system, structure and production technology of lithium-ion battery are expounded. The batteries' thermal theory is discussed, this provides a theoretical foundation for the development of the single-cell thermal model described below. Then, different types of ventilation, such as natural ventilation cooling and forced convection cooling are discussed. Meanwhile, liquid cooling and the phase change materials-based cooling system are analyzed.

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