Academic Journal of Engineering and Technology Science
ISSN 2616-5767 Vol.3, Issue 4: 62-74, DOI: 10.25236/AJETS.2020.030407

Research on Thermal Management System of Electric Vehicle Power Battery Pack

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ABSTRACT. *Electric cars have the advantages of being more efficient and cleaner than traditional fuel cars. The working performance of electric cars depends largely on the working performance of batteries. As an important factor affecting battery performance, temperature has a great impact on the usability and safety of electric vehicles. In brief summary power battery thermal management necessity and under the premise of system function, the optimal working temperature range from the battery, thermal field, the temperature sensor layout, selection of fan power and the design of battery pack from several aspects such as design key points of power battery thermal management system are introduced, and the different cooling ways were analyzed, provide reference for further research.*

KEYWORDS: *Electric vehicle, Battery, Temperature, Thermal management*

1. Introduction

Electric cars are cleaner and more efficient than conventional gas-powered ones. The working performance of electric cars depends largely on the working performance of batteries. During the working process of the battery, the internal temperature of the battery is constantly changing due to the electrochemical reaction and joule effect that produce heat. In terms of structure, the power batteries for electric vehicles are placed in battery packs in groups, which are restricted by the structure and installation position of the battery packs. The battery packs themselves have difficulty in radiating heat, and the temperature imbalance between individual batteries is serious. At the same time, the change of external temperature will directly cause the change of battery temperature. Therefore, the electric vehicle power battery temperature is a time-varying system. In general, the influence of temperature on the battery is mainly manifested in the following aspects :(1) internal resistance, open circuit voltage, SOC; (2) charge and discharge efficiency; (3) reliability; (4) service life. It can be seen that battery temperature has a great impact on the performance, reliability and service life of electric vehicles. In a word, the battery temperature is affected by itself and the outside, which will affect the normal operation of electric vehicles. In the electric vehicle design stage, we need to consider the reasonable thermal management of the power battery pack to make the battery work at the right temperature, so as to ensure the reasonable operation of the electric vehicle.

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2. Methodology

The research methods of automotive thermal management technology mainly include experimental research and simulation research. Although the experimental research has a long period and high cost, it is true and reliable, and can provide sufficient experimental data for simulation research to verify the accuracy of simulation calculation. At present, different research institutions at home and abroad have built different thermal management test platforms and analyzed the thermal management system through different simulation software.

Tsinghua university has built the first automotive thermal management system test platform in China, which can provide technical support for the technical research of automotive thermal management system, especially fuel cell vehicle thermal management system. Ni jimin et al. from tongji university set up an engine thermal management system test platform, which includes the cab heater, throttle heating device, engine hood, etc. The test platform has the same structure as the whole vehicle. It can study the working characteristics of each component in the thermal management system and conduct thermal performance test under various working conditions of the engine. Tan jianxun of zhejiang university developed a thermal management system test platform for construction machinery. The test platform can accurately measure the thermal characteristic parameters of each component of the system, evaluate the performance of the cooling system of the vehicle, and optimize the matching design of the cooling system of the vehicle.

In addition to the above experimental platform construction, in the simulation technology, domestic and foreign research institutions have also done a lot of work. Computational fluid dynamics (CFD) and computational heat transfer (NET) open up a new way for the research of automotive battery thermal management system, making simulation a very effective research method. Compared with the traditional research methods, simulation has the advantages of pre-research, unconditional limitation, abundant information, low cost and short cycle. Most of the simulation research on the thermal management of automobile battery is the one - and three - dimensional coupling simulation analysis using multiple software. The two methods can be coordinated with each other. In one dimensional applications, the circulation of the airway. The circulation of the coolant, the circulation of the lubricating oil and the structure of the engine, the circulation between them and the interaction between the components are all taken into account. The mutual use of these nodes is controlled by vehicle simulation code, which can provide load, operating conditions and environmental conditions for these one-dimensional nodes. The three-dimensional thermal management system can simulate the interaction between the gas and the structure on one hand, and the interaction between the structure and the coolant on the other hand. Three-dimensional computational fluid dynamics (Fire) is associated with finite element programs (ABAQUS and NASTRAN) and thermally coded BOOST. CFD coding can also be used to study the thermal comfort of passengers.

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3. Thermal Management System of Electric Vehicle Battery Pack

3.1 Necessity of Battery Thermal Management

As the main energy storage unit of ev, the performance of battery directly affects the performance of ev. It is necessary to conduct thermal management of electric vehicle battery pack, for the following reasons :(1) the battery group works for a long time in a harsh thermal environment, which will reduce the discharge capacity of the battery and shorten its service life; (2) the uneven distribution of temperature field in the battery pack will aggravate the inconsistency between the performance of each battery module and single battery; (3) the thermal monitoring and thermal management of the battery pack is of great significance to the safe operation of the vehicle.

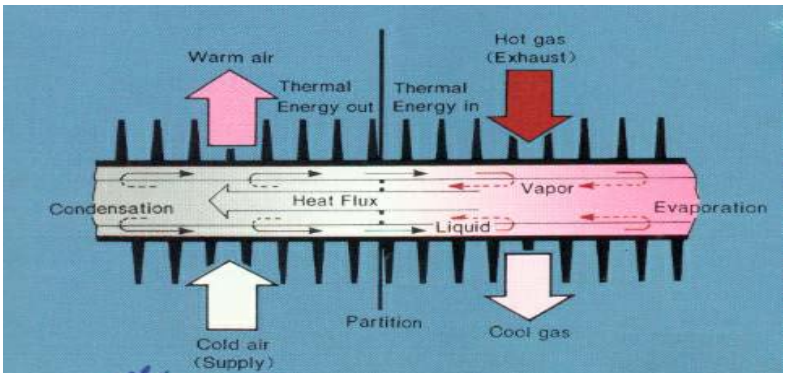

Fig.1 Working principle

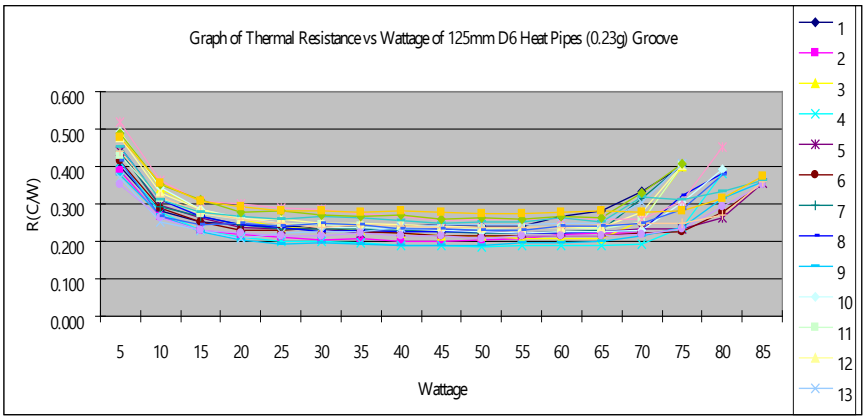

Fig.2 Thermal resistance analysis diagram

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3.2 Functions of Battery Thermal Management System

Battery thermal management system is used to ensure that the battery works in the appropriate temperature range of the whole system, including the battery box, heat transfer medium, monitoring and control equipment and other components.

The thermal management system of battery pack has the following main functions [1] :(1) to ensure the temperature in the battery pack is balanced, so as to avoid the inconsistency between batteries and reduce the performance; (2) effective heat dissipation and ventilation when battery temperature is too high; (3) rapid heating and insulation of battery when the temperature is too low; (4) effective ventilation when harmful gases are produced; (5) eliminate battery failure or explosion risk caused by heat loss.

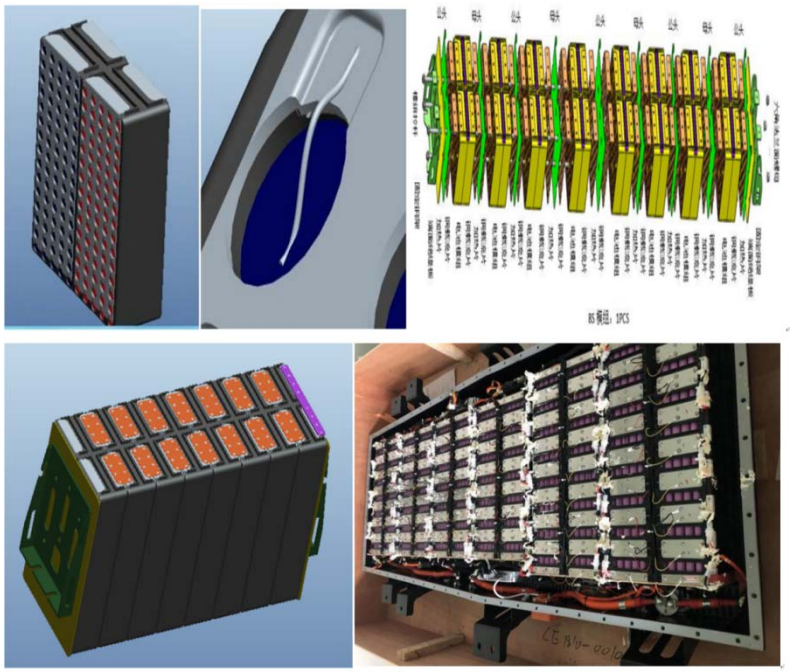

Fig.3 Diagram of battery structure

4. Design Key Points of the Battery Thermal Management System

4.1 Determine the Optimal Operating Temperature Range of the Battery

Under different climatic conditions and different vehicle operating conditions, the battery temperature will vary greatly. The ultimate purpose of thermal management of battery pack is to make the battery work in the optimal temperature

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range.

Understanding the temperature characteristics of the battery is a prerequisite for determining the optimal operating range. The temperature characteristics of the battery refer to the performance of internal resistance, open circuit voltage, SOC and charging and discharging efficiency of the battery under different temperatures [2]. The temperature characteristics of the battery can be obtained by experiment and simulation. If the temperature characteristics of the battery are determined by experimental measurement, the results will be accurate and reflect the real characteristics of the battery. If the use of software such as ADVISOR simulation, the time is short, to some extent can reflect the temperature characteristics of the battery. A certain type of 60 battery charging and discharging efficiency under different temperature conditions is shown in figure 1, we can find that the temperature is higher than 40 ℃ or less than 0 ℃, a significant reduction in the charge and discharge efficiency, so we should at least keep the battery working temperature range between 0 ~ 40 ℃, at the same time the synthesis temperature on the resistance, open circuit voltage, the influence of the SOC to determine the optimal scope of work. Generally speaking, the optimal operating range of the battery is about 25 ° ~ 40 ° c.

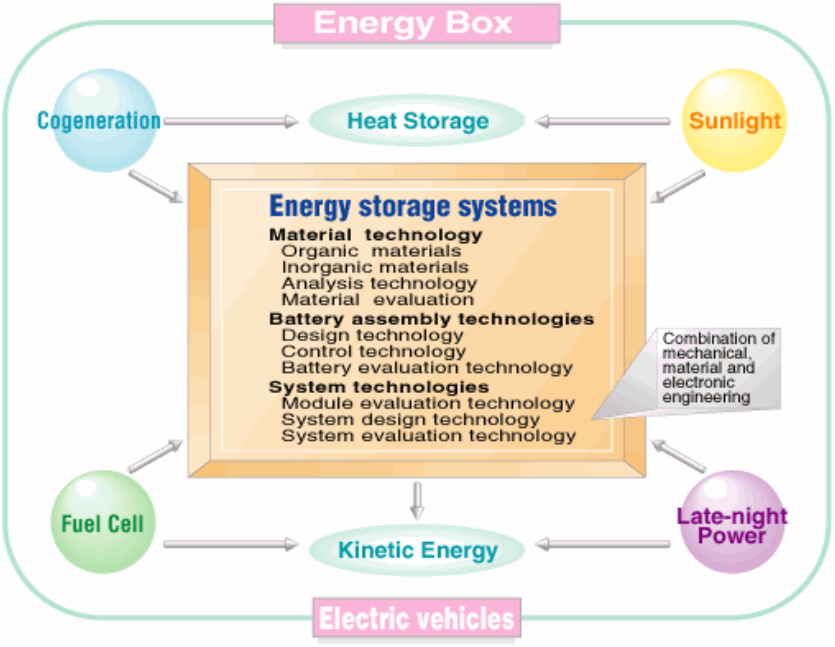

Fig.4 Schematic diagram of energy storage system

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4.2 Calculation of Battery Thermal Field and Temperature Prediction

The battery is not a good conductor of heat, and measuring the temperature distribution on the surface of the battery by temperature sensor alone cannot fully explain the thermal state inside the battery. By calculating the temperature field in the battery by mathematical model, the thermal behavior of the battery can be predicted.

The internal temperature field of lithium ion battery is calculated as the average density. Is the specific heat of the battery; Is the thermal conductivity of the battery in three directions; Q is the rate of heat generation per unit volume. The heat generation rate of the battery can be obtained by selecting a special calorimeter, while the thermal conductivity of the battery in different directions can be obtained by using the finite element method.

4.3 Selection of Heat Transfer Medium

The heat transfer media commonly used in battery thermal management systems include air, liquid and phase change materials.

Air cooling is the easiest way, simply letting air flow over the surface of the battery. The advantages of air cooling are as follows :(1) simple structure and relatively small weight; (2) there is no possibility of leakage; (3) effective ventilation when harmful gases are produced; (4) low cost. The disadvantage is that the heat transfer coefficient between it and the battery wall is low, and the cooling and heating speed is slow.

Liquid cooling is divided into direct contact and indirect contact. Mineral oil can be used as direct contact heat transfer medium, water or antifreeze can be used as a typical indirect contact heat transfer medium. To cool the battery, liquid cooling must be carried out through heat transfer facilities such as water jacket, which reduces the heat transfer efficiency to some extent. The main advantages of liquid cooling mode include :(1) high heat transfer coefficient between it and the battery wall, fast cooling and heating speed; (2) small volume. The main disadvantages are: the possibility of leakage; Relatively large weight; Complex repair and maintenance; Need water jacket, heat exchanger and other parts, the structure is relatively complex.

Phase change material (PCM) cooling is a relatively new cooling method. PCM can directly absorb heat from the outside, thus cooling the battery. Phase change materials have simple cooling structure, high efficiency and high cost.

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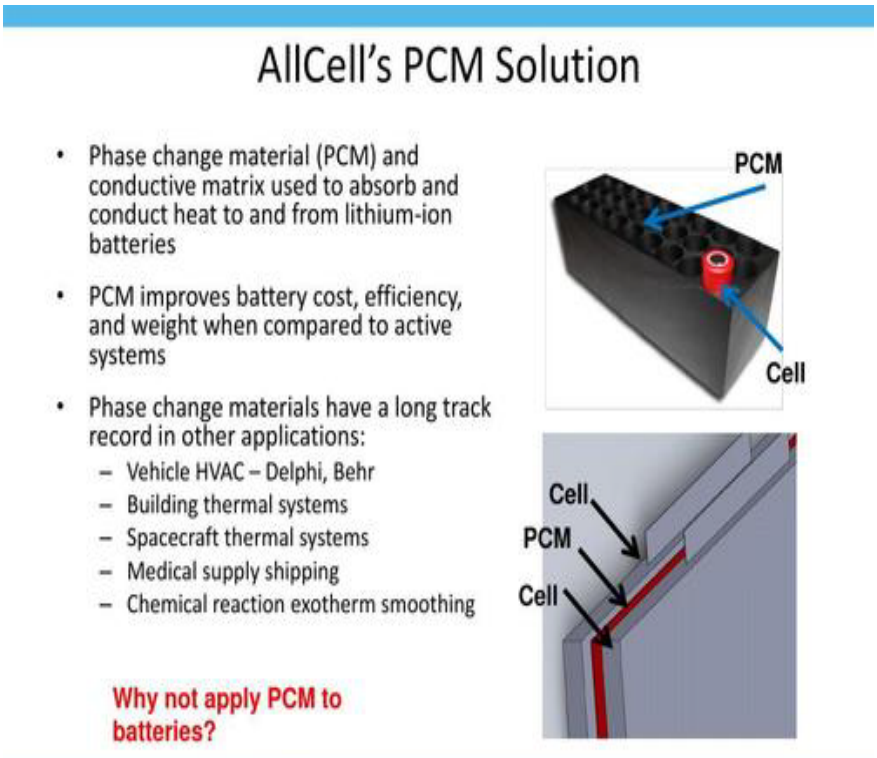

Fig.5 AllCell's PCM Solution

4.4 Selection of Number of Temperature Sensors and Temperature Measuring Points

The more number of temperature sensors, the more comprehensive the temperature measurement, but it will also increase the cost of the system. Considering that the temperature sensor may fail in the long working process, the number of temperature sensors in the whole system should not be too small. In the design of thermal management system, the number of temperature sensors can be adjusted according to the specific requirements.

Battery pack in the battery temperature distribution is not uniform, the theory of finite element analysis and experiment of using infrared thermal imaging or real-time multi-point temperature monitoring method can analyze and measure the battery, the battery module and monomer battery thermal field distribution, decided the number of temperature measurement point, find out the optimal temperature measurement point in different areas. At the same time, during the design of the battery thermal management system, the temperature sensor should not be blown by cold wind, so as to improve the accuracy and stability of temperature measurement.

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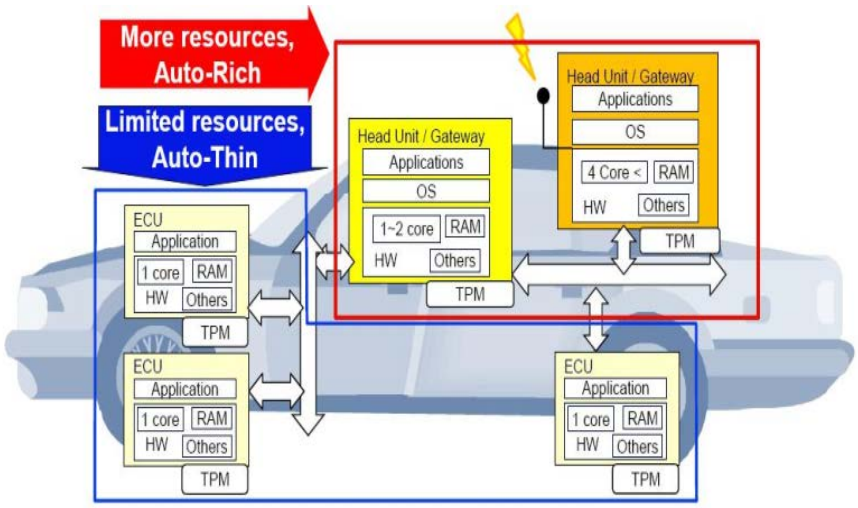

Fig.6 Automobile control software and operating system

Fig.7 BMS management system

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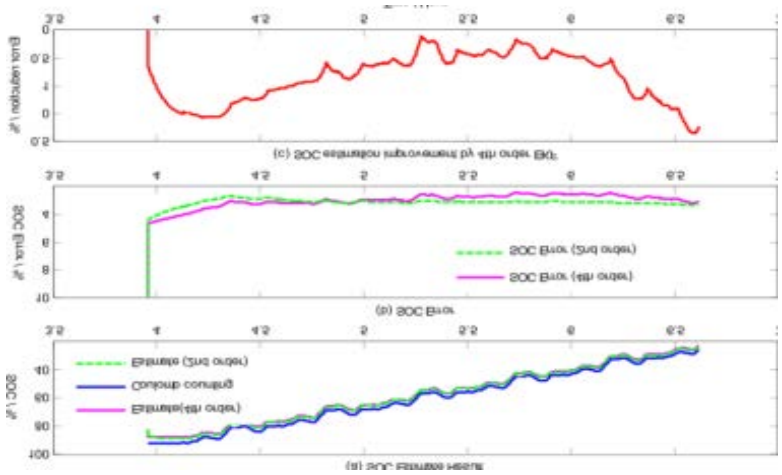

Fig.8 System modeling and state estimation

4.5 Selection of Fan Power and Heating System Power

For the battery heat management system which USES air as the heat transfer medium, the selection of fan power will affect the efficiency of the system. The power consumption of the fan can be estimated by the methods of experiment, theoretical calculation and fluid mechanics by estimating the pressure drop and flow rate. When the flow resistance is small, can consider the choice of axial flow fan; When the flow resistance is large, centrifugal fans are more suitable. At the same time, the size and cost of the fan should be considered. The heating system also needs to choose the appropriate power according to the corresponding demand.

4.6 Design of Battery Pack

The design of the battery pack is very important for the battery thermal management system. Whether the design of the battery pack is reasonable will directly affect the selection, installation and work efficiency of the battery thermal management system. Before the design of the battery pack, the space requirements of the vehicle and other devices such as BMS should be fully considered, and the design should be integrated with the specific cooling mode and the number of batteries. The thermal characteristics of the battery pack were simulated with ANSYS software, and the structural design of the battery pack was improved according to the analysis results. Meanwhile, the fluid mechanics analysis for air cooling could be carried out with FLUENT software to determine the optimal air duct design.

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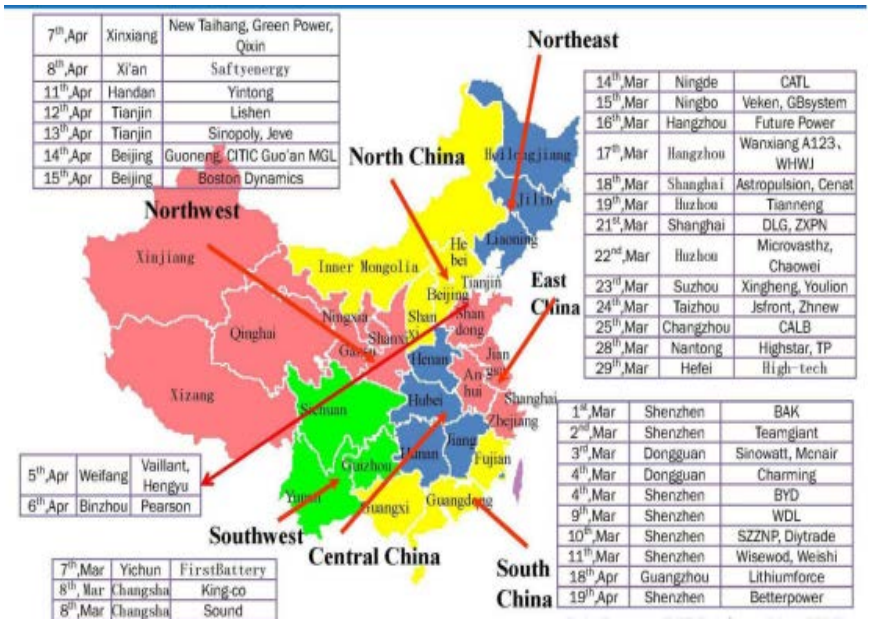

Fig.9 China market distribution

5. Comparison of Several Cooling Methods

5.1 Air Cooling

Air cooling according to the cooling mode is divided into natural convection cooling and forced air cooling, according to the battery ventilation mode is divided into serial and parallel cooling mode.

Natural convection cooling USES the strong air convection when the car is running to cool the battery pack. However, in order to cool effectively, special design of battery shape or battery package is needed, or special materials are selected to increase the heat dissipation area of the battery. Forced air cooling USES an auxiliary or built-in evaporator to provide cold air and is cooled by installing a fan to create a forced airflow. The fan is usually installed at the outlet of the exhaust channel, as shown in figure 2.

Parallel and serial cooling way the difference between two kinds of cooling ventilation way, principle that serial ventilation cooling, air from left to right in turn pass through each monomer battery, the air flow in the process of continuously heated, so the right side of the cooling effect is inferior to the left, left and right sides of the battery within the battery pack because of temperature difference among different cooling effect. In the parallel ventilation mode, the air enters from the

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lower end of the battery pack, flows through the channels between individual batteries and flows out from the upper end, so the temperature between individual batteries is more uniform. However, the parallel ventilation method needs to design the space between the channels of the batteries and the inclined Angle of the collector plate reasonably, so as to find out the best scheme of flow velocity uniformity.

5.2 Liquid Cooling

Liquid cooling USES liquid as the heat transfer medium. Liquid cooling USES the flow of water or coolant in the water jacket to take away the heat generated by the battery pack, and then cools the coolant through the radiator, so as to keep the battery pack temperature in a reasonable range.

Compared with air cooling, liquid cooling has better cooling effect and better adaptability to the change of external temperature, but it requires special design of water jacket and installation of radiator, which requires more space in the car.

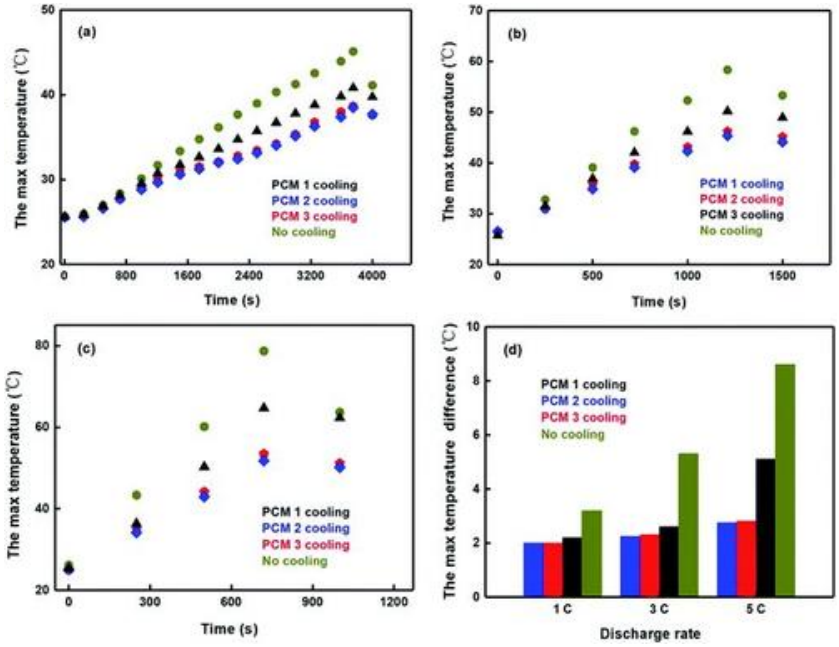

Fig.10 Cooling analysis diagram

5.3 Phase Change Material Cooling

Phase change materials of the cooling system is in a module between monomer battery pack phase change materials, rely on the melting solidification latent heat of

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phase change materials to work, using the refrigerant liquid (such as water, liquid ammonia and freon liquid) under low pressure, low temperature of the gasification process or solid or sublimation process under low temperature melting process, object to be cooled from gasification of latent heat, heat of fusion and latent heat of sublimation, in order to achieve the purpose of cooling. At the same time, it can store the heat generated during discharge in the form of latent heat, and release it when charging or working in a very cold environment, which is one of the most effective ways of heat dissipation.

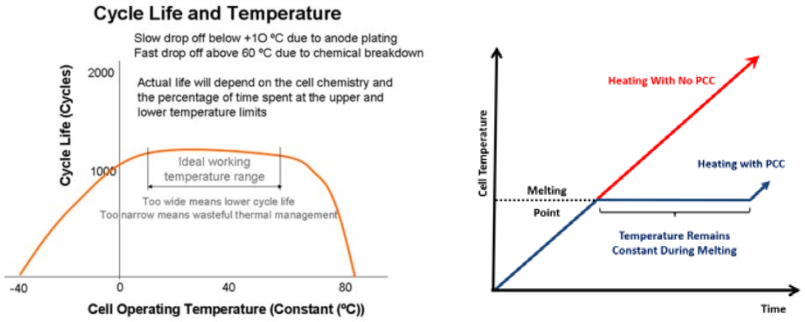

Fig.11 Cycle life and temperature

6. Conclusion

Energy crisis and environmental pollution are two major problems facing the world today. Electric vehicles have the advantages of energy saving and environmental protection, and become the inevitable trend of future automobile development. In the working process of ev batteries, over-charging and over-discharging often occur due to the long charging and discharging time, which not only affects the performance of the battery and shorten the battery's service life, but also reduces the driving distance of ev and reduces the cost performance of the vehicle. At the same time, if the operating parameters (such as voltage, current, temperature, residual power, etc.) of single battery and whole battery pack cannot be accurately collected in a timely manner, it will also affect the vehicle optimization control strategy, reduce the safety performance of battery, and even cause the car explosion. The battery of electric vehicle will be operated in a harsh thermal environment for a long time, which will shorten the battery life and reduce the battery performance. Therefore, the influence of temperature on battery performance and service life should be considered comprehensively to determine the optimal operating temperature range of the battery. Therefore, the thermal monitoring and thermal management of battery pack is of great significance to the safety of vehicle operation. This paper summarizes the improvement of thermal management system from the aspects of control system, material design, thermal management mode, heat pipe technology and research mode.

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The thermal management of electric vehicle power battery is a comprehensive proposition, covering many aspects. It is not only related to the battery management system, but also related to the mechanical design of the vehicle and the design of the vehicle control system. Through the reasonable design of the battery thermal management system, make the battery work in the appropriate temperature range, not only for the use of electric vehicles is of great significance, but also for the safety of electric vehicles is crucial, so in the design of electric vehicles must pay full attention to the battery thermal management system, and reasonable design.

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