Research Status of New Energy Vehicle Thermal Management

Zhihui Zhu *

Institute of International Education, Wuhan University of Technology, Wuhan 400063, China

* Corresponding Author Email: 324293@whut.edu.cn

Abstract. Thermal management of new energy vehicles, as a way to break through the driving range of new energy vehicles and one of the guarantees of safety performance, has been paid more and more attention to. In order to improve the thermal management efficiency of new energy vehicles, the thermal management mode of the whole vehicle should be optimized, so that different parts can work at a suitable temperature, so as to ensure the functional safety and service life of the vehicle. Based on this, this paper analyzes the passenger cabin thermal management system through Positive Temperature Coefficient (PTC) heating air conditioning, heat pump air conditioning and other technologies. This paper introduces the new energy vehicle battery thermal management system from the aspects of direct cooling mode and heating mode, introduces the battery thermal management system through the analysis of flow charts, and introduces the cooling mode of electric control and motor, and pays attention to some cutting-edge research progress, and summarizes the automobile thermal management technology theory.

Keywords: New energy vehicle, thermal management, Battery, Cabin.

1. Introduction

In the era of pure electric vehicles, the energy consumption of batteries has become the focus of car companies and users. At a time when battery materials cannot make major breakthroughs, the driving range needs to be improved by reducing vehicle energy consumption. Thermal management of new energy vehicles plays a crucial role in reducing vehicle energy consumption.

The low temperature performance of the power battery is poor, and the temperature is too low, resulting in a sharp decline in charge and discharge performance, rapid decay of discharge capacity, and slow charging and weak acceleration. At the same time, if the thermal management of the vehicle battery is not handled well, it will even cause a violent chemical reaction inside the battery due to high temperature, giving rise to a large amount of heat and causing thermal runaway, finally leading to battery fire or even explosion, vehicle spontaneous combustion and other serious hazards. Overheating can also drastically reduce battery life and durability. Optimizing the battery thermal management system, providing a healthy reaction temperature for charging and discharging the battery pack, and prolonging the service life of the battery are the focus of research [1]. In addition, the passenger cabin air conditioning system of new energy vehicles is also directly linked to the comfort of passengers, which is a special attention of consumers. However, electric vehicles do not have engines, in the air-conditioning heating link, there is no heat generated by the engine working as a heat source for the whole car heating, so additional heating components need to be added, so that the vehicle energy consumption is too high and lead to a sharp reduction in mileage. The thermal management system of new energy vehicles needs to ensure that the temperature of the battery pack is within the normal range in extreme weather to ensure the normal operation of the battery, and also needs to reduce the energy consumption of the passenger cabin air conditioning system as possible. Therefore, the integrated management of the battery management system and the passenger cabin air conditioning system of new energy vehicles is a trend in the vehicle thermal management system [1]. The heat pump air conditioning technology used by Tesla, BYD and Zeekr reduces energy consumption by about half compared to traditional PTC heating technology, and can use the temperature difference between the coolant and the outside to absorb heat and transfer this heat to the cabin.

A thermal management system of new energy vehicles is mainly divided into a motor, electronic control cooling system, battery thermal management system and passenger cabin air conditioning system to achieve winter cabin heating, summer cabin cooling, battery cooling heating and motor heat dissipation functions. In this paper, the thermal management system of passenger cabins, battery thermal management systems and electric motor thermal management systems are reviewed, explaining how thermal management systems can ensure passenger safety and comfort and improve vehicle mileage.

2. Cabin Thermal Management System

2.1. Introduction to Cabin Thermal Management System

Passenger cabin thermal management system, that is, to cool or heat the passenger cabin to make the temperature of the passenger cabin reach the comfortable temperature of the driver and passengers. The cooling link of new energy vehicles is relatively simple, and the compressor is used for cooling like traditional energy vehicles, but new energy vehicles cannot use engine waste heat to heat the passenger cabin like traditional energy vehicles, so the heating link is more complex, and the analysis of the heating link should be focused on [2].

2.1.1 PTC heating air conditioning

PTC is a semiconductor thermistor used in electric vehicles. As shown in Figure 1, when the temperature increases, the resistance value increases, the current flowing will decrease, and the heat generated will decrease. When the temperature decreases, the resistance value decreases, the current flowing will increase, and the heat generated will increase, which plays the role of automatic power regulation. At the same time, the biggest feature of a PTC heater is its safety, when the fan fails, the current through the PTC heater will decrease with the increase of temperature, and the power will drop sharply. At the same time, the current vehicle PTC heater will be used in combination with the coolant, the heat generated by the PTC thermistor will be exchanged with the coolant, and the passenger cabin will be heated through the coolant, and the heat can be better controlled according to the temperature setting of the passenger.

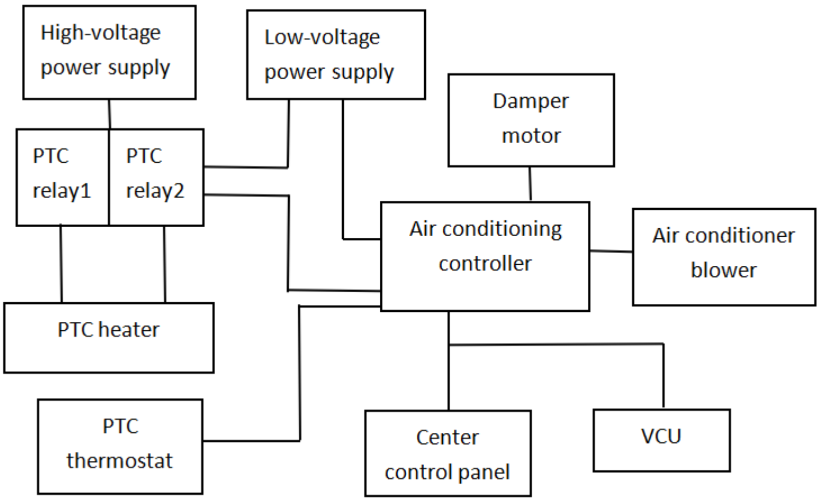

Fig. 1 PTC heating air conditioner

PTC heating also has obvious disadvantages. Heating through the resistance wire has a low utilization rate of heat energy, and the flow of coolant will also lose heat energy to the outside heat radiation. The power consumption of electric vehicles is large, which has a great impact on the driving range of pure electric vehicles. At the same time, due to the different working conditions of the cooling mode and the heating mode, the vehicle that uses the PTC thermistor to heat the air conditioner needs to be equipped with an additional compressor, which is used for refrigeration as the ordinary air conditioner, and the demand for space is large.

2.1.2 Heat pump air conditioning

The function of heat pump air conditioning is to absorb the heat of low temperature heat source and transfer it to high temperature heat source. As shown in figure 2, in electric vehicles, heat pump air conditioning is mainly composed of electric compressors, internal heat exchangers, external heat exchangers, throttle mechanisms, four-way directional valves and other devices. During heating, the refrigerant enters the compressor through the four-way directional valve to compress into high temperature and high pressure gas, enters the internal heat exchanger to heat the passenger cabin [3], and then passes through the throttle device, the pressure decreases after expansion, becomes a low temperature gas-liquid mixture, absorbs heat in the external heat exchanger and evaporates into low temperature and low pressure gas, and finally the refrigerant flows into the compressor to enter the next cycle. When the heat pump air conditioner works, it relies on the power provided by the battery to drive the compressor expansion machine to do work and promote the coolant to run in the pipeline. Because the heat pump air conditioner can use coolant to heat exchange with the outside world, its power consumption is smaller than that of the PTC thermistor, and it has less impact on the driving range of pure electric vehicles. By changing the flow direction of the working medium using the four-way reversing valve, the heating mode can be changed to the cooling mode. It is used as a condenser in summer cooling and as an evaporator in winter heating [4]. At the same time, the thermal management integration of new energy vehicles based on heat pump air conditioning can also heat and insulate batteries.

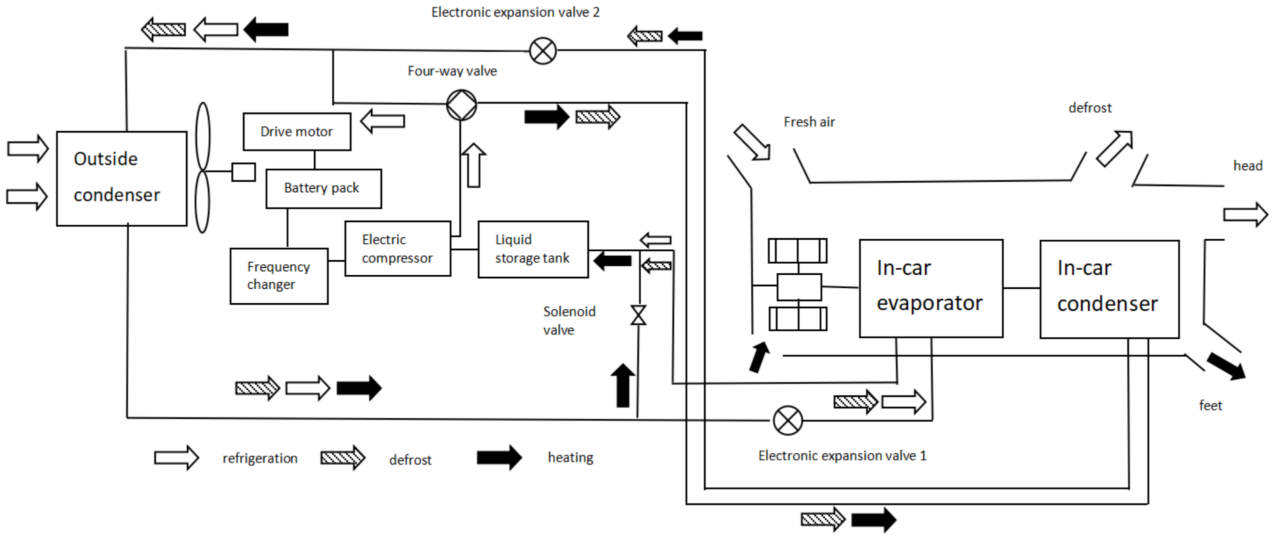

Fig. 2 Schematic diagram of heat pump air conditioning

Heat pump air conditioning also has drawbacks. The choice of heat pump air conditioning coolant is more stringent. On the one hand, the coolant needs to be able to evaporate and absorb heat at different outdoor temperatures, and the winter temperature in the high latitude area will be as low as minus 30 degrees Celsius, at this time the heat pump air conditioning heating effect is poor. At the same time, the high temperature and high pressure gas running in the pipeline after the refrigerant is compressed has higher requirements for the coolant pipeline. Therefore, the current research mainly focuses on the use of auxiliary heaters, waste heat recovery and other technologies to improve the performance of heat pump systems in winter, and design a new circulation loop to solve the problems of heat pump defrosting and windshield defogging [5].

3. Battery Thermal Management System

3.1. Battery Thermal Management Cooling System

From an electrochemical point of view, the heat generated by lithium-ion batteries mainly comes from four aspects: reaction heat Q1, Joule heat Q2, polarization heat Q3 and side reaction heat Q4 [6]. The total heat generated by the battery can be expressed as:

$$QM=Q1+Q2+Q3+Q4 \quad (1)$$

In general, the cooling mode of new energy batteries is mainly divided into three categories: air cooling, liquid cooling and direct cooling. Air cooling is the use of outdoor natural wind or cooling air in the cabin to exchange heat on the surface of the new energy battery, and liquid cooling through an independent cooling pipeline through the coolant to heat exchange cooling of the battery. Direct cooling systems cool the battery directly through coolant.

3.1.1 Air Cooling System

In early new energy batteries, because of their small energy density, the heat accumulation of the battery is not large, so there is more use of air cooling mode for battery heat dissipation. Air cooling is divided into two categories, natural air cooling and forced air cooling. Natural air cooling is cooled by natural wind, and forced air cooling is cooled by a fan.

Models that use air cooling systems such as Wuling Hongguang miniEV and Nissan Leaf are all low-power models that generate limited heat. The use of the air cooling method for cooling, air cooling system structure is relatively simple, and the cost is low, and the maintenance cost is also low. However, the disadvantages are obvious. Because the natural wind can take away less heat through the heat exchange, the heat exchange efficiency is low, and it will lead to uneven internal and external temperature of the battery, which has an impact on the performance of the battery, and it is difficult to accurately control the temperature of the battery. At the same time, the condensed water on the surface of the battery should not be dried, and there is the possibility of erosion and pollution inside the battery [7].

At the same time, the air-cooled mode can also be divided into serial air duct air-cooled mode and parallel air duct air-cooled mode. The difference is that there is no angle between the serial air duct and the battery, and the volume occupied is small, but the natural wind cannot flow through the gap between the batteries, and the cooling effect is poor. There is an angle between the parallel air duct and the battery, and the natural wind energy flows through the gap between the batteries, and the heat transfer effect is better, but the volume is larger.

3.1.2 Liquid Cooling System

The liquid cooling mode uses the coolant to cool the battery by heat exchange. It is divided into two ways of using the coolant as silicone oil or castor oil that can directly contact the battery cell and using the coolant as water or glycol for cooling in the cooling pipe. The core components of the liquid cooling system are the compressor, Chiller and water pump. The compressor provides the conditions for refrigeration, compresses the coolant, and determines the heat transfer capacity of the entire system. Chiller acts as a heat exchange between the refrigerant and the coolant, exchanging heat from the high temperature coolant to the low temperature refrigerant, and then compressing the refrigerant to start the next cycle. The amount of heat transfer in the Chiller determines the temperature of the coolant. The pump determines the flow rate of the coolant, and the greater the flow rate, the better the cooling effect [7].

The advantage of the liquid cooling system is that the heat transfer coefficient is high, and the heat transfer rate is fast, which can achieve accurate temperature control. At the same time, the temperature equalization of the battery is better, which has little impact on the performance. The disadvantage is that the system has higher requirements for sealing performance and higher costs. At present, the research of liquid thermal management systems focuses on the optimization design of flow channel geometry [8], enhanced heat transfer with different cooling media [9], flow rate and flow direction control, etc.

3.1.3 Direct Cooling System

The direct cooling mode is a refrigeration evaporator built into the battery. As shown in Figure 3, under the action of the compressor, the refrigerant sends the compressed refrigerant into the evaporator inside the battery, directly absorbing the heat inside the battery and taking it away. The cooler is then cooled through a condenser, changing from a gas to a liquid again, and the heat is dissipated to the surrounding environment. After that, the refrigerant enters the evaporator through the expansion valve to complete a complete cycle [10]. Refrigeration technology involves the principle of evaporation and latent heat, which directly takes away the battery heat.

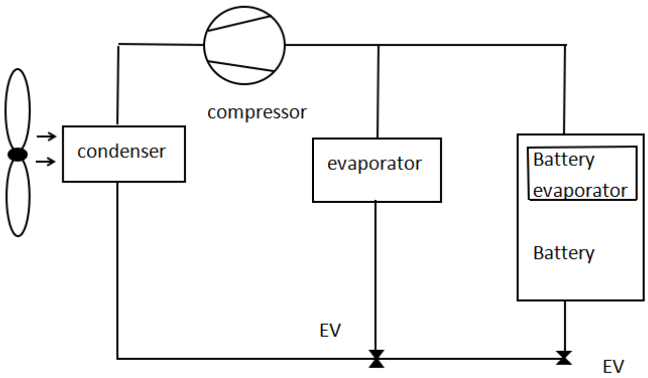

Fig. 3 Principle of direct cooling system

The structure of a direct cooling system is compact and has high cooling efficiency and low cost because there is no liquid heat exchange step. However, the refrigerant will undergo gas and liquid changes in the pipeline, which has higher requirements for system control, and the temperature equalization of the battery is poor, which has higher requirements for high pressure and sealing.

3.2. Battery Thermal Management Heating Management

3.2.1 Electric Heating System

The mode of the electric heating system is relatively simple, that is, it uses a part of the energy from the battery, uses the resistance wire to heat the liquid in the pipeline, and then heats the battery through the heated liquid. This model has a very simple structure and low cost. However, its disadvantage is that the discharge performance of the battery is very poor at low temperatures, and the heating speed of the liquid is very slow, and the power consumption is large. There is a feedback process in the heating system, but the initial condition makes it difficult to start the system. At the same time, the system will occupy a part of the battery power, and thus will have an impact on the vehicle's power performance.

3.2.2 Waste Heat Heating System

When the new energy vehicle starts, the electric machine generates heat. This amount of heat is small compared to traditional internal combustion engine vehicles, but if utilized, it can be used to heat the battery. For example, in the thermal heating system developed by Tesla, the cabin liquid glycol heating cycle device is connected to the drive motor and the power electronics glycol cooling cycle valve to obtain heat, through the motor high temperature cooling circuit and the battery pack low temperature circuit, or through the chiller heat transfer, the waste heat will be used to heat the battery.

This heating method can recover the heat that will be dissipated, but the disadvantage is that the time is slow and the heat energy recovered is not much.

3.2.3 Heat Pump Battery Heating System

The heat pump battery heating system is the result of the integration of the battery thermal management system and the passenger cabin thermal management system, which can obtain heat from the low temperature heat source to the high temperature environment. A heat pump heats the battery by passing compressed high temperature and high pressure material through a pipe, as shown in Figure 4 [1].

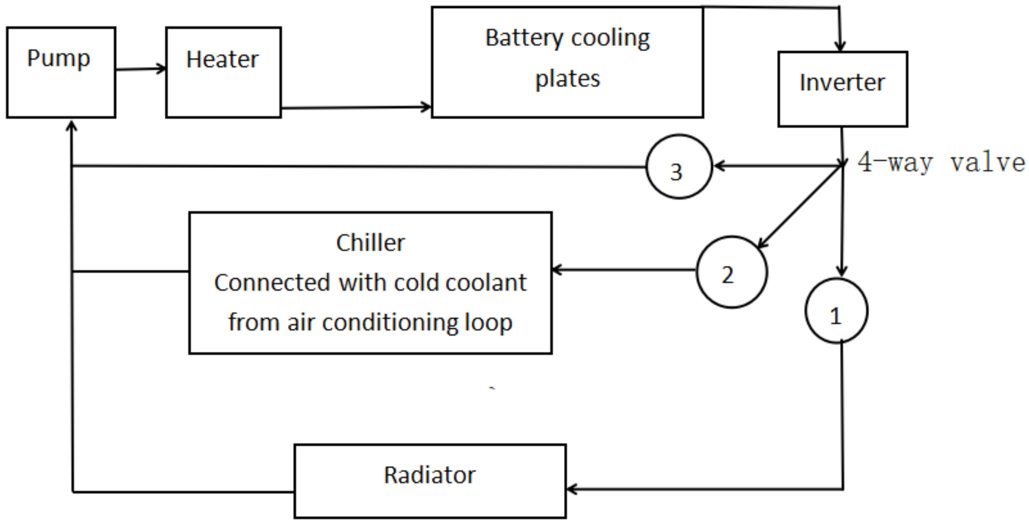

Fig. 4 Flow chart of heat pump battery heating system

The heat pump battery heating system has high requirements for pipelines, and the heating effect is not good in low temperature environment. However, as an auxiliary heating system, it can greatly reduce the impact of the system on the driving range of new energy vehicles.

4. Thermal Management of Motor and Electronic Control System

Because the motor and various electronic control components will generate heat when the new energy vehicle is working, a large part of the motor is converted into thermal energy in the process of converting electrical energy into mechanical energy. When the temperature is too high, it will seriously threaten the service life of the motor and control system and the reliability of operation. Therefore, it is necessary to cool the motor and electronic control to ensure its good work. Among them, air cooling and liquid cooling are the most widely used in automobiles.

A variety of electric motor thermal management methods are summarized in including air, liquid, heat pipes, and hybrid cooling. Air cooling is straightforward and offers a simple structure but the cooling performance may not be sufficient. Moreover, a cooling fan is usually linked to the motor shaft which consumes energy and cannot be directly controlled. Liquid cooling is effective; however, it consumes energy to run the coolant pump and radiator fan. On the other hand, liquid cooling adds more weight and complexity due to the cooling lines. Heat pipes can operate passively in the presence of a temperature gradient; however, they have heat transfer limitations due to the capillary limit, fluid properties, operating temperatures, etc. [11].

Tian et al. proposed an integrated thermal management system for electric vehicles that integrates internal thermal comfort, battery cooling and motor waste heat recovery. The system makes full use of the advantages of heat pump technology. The two heat exchanger sides of the heat pump system are connected in parallel with the heat exchanger branch respectively, and the coupling with the heat pump technology is realized through the opening and closing of different circulation branch solenoid valves in winter and summer. The results show that Percentage of Cooling Capacity Reduction (PCCR) ranges from 26.3%-32.1% and waste heat recovery ranges from 18.73%-45.17% after the battery cooling circuit is opened [12] (Figure 5).

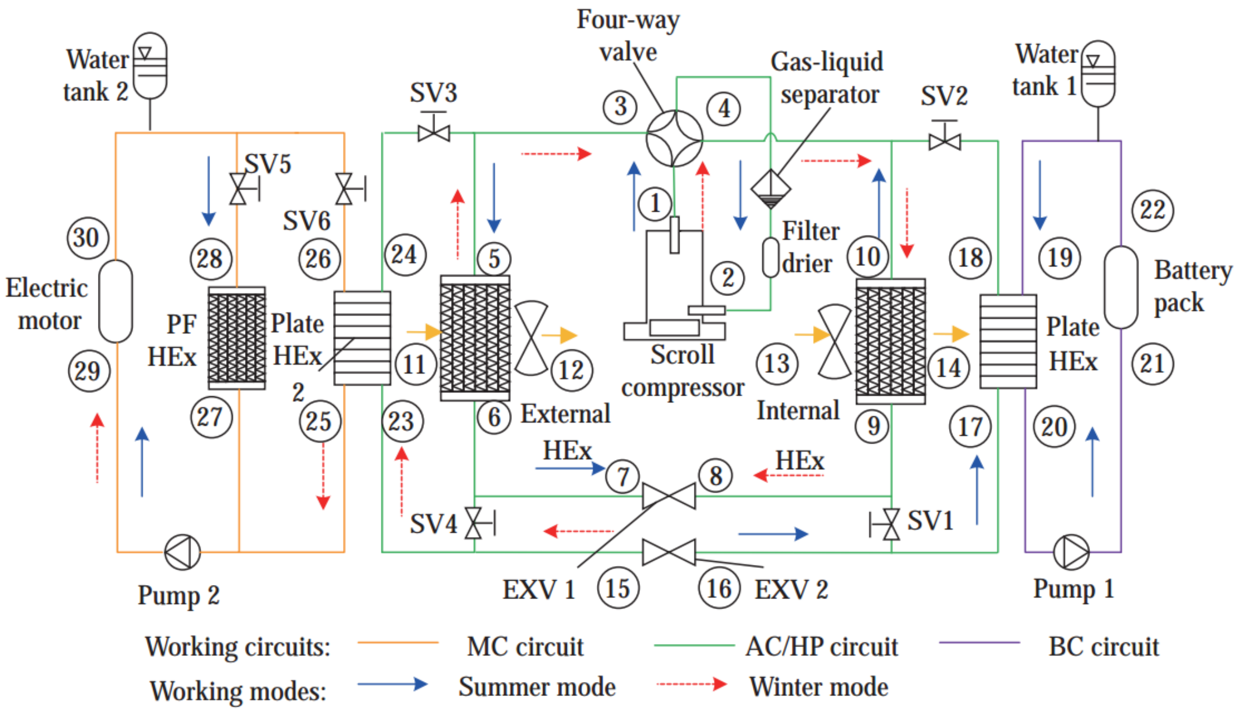

Fig. 5 Schematic of proposed Electric Vehicle Thermal Management System (EVTMS) [12]

5. Conclusion

This paper summarizes the research status of passenger cabin thermal management system, battery thermal management system and electric motor thermal management system, and explains that the thermal management of new energy vehicles is related to the comfort and safety of consumers. At present, the thermal management of new energy vehicles still has problems such as too many management modules, redundant systems and not timely handling of emergency situations. In the future, it is of great significance to optimize the thermal management capability of new energy vehicles, reduce the energy consumption of new energy vehicles, and improve the driving range, explore the integrated integration of the thermal management system of the vehicle thermal management system. Furthermore, an integrated control framework combined with the potential characteristics of the thermal inertia of the system should be established, and thus, consumers' concerns about the safety of new energy vehicles through new technologies can be eliminated.

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