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**Abstract.** With the acceleration of the popularity of new energy vehicles, battery life, driving range, power output and safety stability play an absolute role in new energy vehicles. This article mainly analyzes the classification and characteristics of batteries in new energy vehicles, and reviews four types of heat dissipation technologies for new energy vehicles. This includes air cooling, liquid cooling, heat pipe cooling and phase change material cooling. At the same time, the importance of utilizing waste heat in new energy vehicles and the application of improving the overall energy efficiency of the vehicle are discussed. By rationally utilizing the residual heat from batteries and motors, not only can the working environment of batteries be improved, but also energy can be provided for other vehicle systems, thereby enhancing the overall energy utilization efficiency of the vehicle. The research in this paper provides a theoretical basis for the further development of thermal management and waste heat utilization technologies for new energy vehicle batteries.

## INTRODUCTION

With the increase in oil consumption, and China's traditional energy being extremely dependent on imports, China began to vigorously support the global automotive industry to accelerate its transformation. New energy vehicles, by virtue of their environmental protection, energy-saving and other advantages, gradually become the main force in the automotive market.

Forecasts indicate that the global sales of new energy vehicles (including fuel cell vehicles) are expected to exceed 12 million units in 2025, accounting for about 50% of the global total, with a compound annual growth rate (CAGR) of more than 20%, and the penetration rate is expected to be more than 50% (about 35% in 2023). At the same time, China's electric vehicle ownership will reach more than 50 million by 2029, making it the world's largest market. Among them, the battery system plays a decisive role in the vehicle's driving range, power output, safety and stability. It is worth noting that the waste heat generated by the battery is not worthless. If it can be reasonably utilised, it can not only improve the working environment of the battery, but also provide energy for other systems of the vehicle to enhance the energy efficiency of the vehicle.

In recent years, domestic and international scholars have carried out a lot of research work based on the waste heat utilisation of electric vehicles. Among them, Tan Ran etc. carried out a systematic thermodynamic analysis for the waste heat utilisation method to study the effect of waste heat and ambient temperature changes on the system.

Han Nankui conducted a performance study on heat pumps for electric vehicles using waste heat and analysed the effect of changing the waste heat power and other factors. Therefore, it is necessary to deeply study battery characteristics, on the basis of which to develop advanced waste heat utilisation and heat dissipation technology for new energy vehicles, which is of great significance in promoting the sustainable development of the vehicle industry.

This research focuses on three significant areas: classification of batteries for new energy vehicles, thermal management solutions for power batteries, and effective utilization of waste heat. As for thermal management of power batteries, this study unfolds in five parts—initially examining the principle behind heat generation in power batteries and successively exploring multiple cooling technologies, such as air-based cooling, liquid - based cooling, heat-pipe-based cooling, and phase-change - material-based cooling. In the context of waste heat utilization, two core elements are explored: waste heat recovery from batteries and motors and a comprehensive study of the heat pump air-conditioning system, enabling the development of more effective and sustainable solutions for the new energy vehicle industry [1] [2].

## NEW ENERGY VEHICLE BATTERY CLASSIFICATION

New energy vehicles primarily consist of hybrid electric vehicles (HEV), battery electric vehicles (BEV), and fuel cell electric vehicles (FCEV), among others [3]. As the core component of electric vehicles, the performance of the power battery directly affects the operational efficiency and safety of the vehicle. Batteries generally comprise several key components, including a battery pack, a battery management system, a cooling system, high and low-voltage wiring harnesses, a protective enclosure, and various additional elements. Each battery has its own advantages based on thermal stability, safety, cost, and battery life. As the main types of power batteries, lithium iron phosphate (LFP) batteries and lithium nickel cobalt manganese (NCM) batteries. have high energy density, stable performance, strong safety and long service life, etc., and have become the mainstream batteries widely circulated in the market and used in electric vehicles [4].

### Lithium-ion Batteries

Lithium-ion batteries represent the predominant category of batteries in contemporary usage, characterized by their high energy density, extended cycle life, and minimal self-discharge rate. The disadvantages of Li-ion batteries are poor consistency, poor low-temperature performance, and complex management systems. Lithium-ion batteries encompass both lithium iron phosphate and lithium ternary batteries, with lithium iron phosphate being regarded as a safer option for the positive electrode.

#### *Ternary Lithium Battery*

The single lithium ternary battery has a single energy density of 200-300Wh/kg and a system energy density of 160-200Wh/kg, which has become the mainstream choice for pure electric and hybrid vehicles by virtue of its high energy density and moderate cost. Li-ion ternary batteries (NCM) have excellent low-temperature discharge performance and are able to operate normally in environments as low as -30℃. Under the same low-temperature test conditions, the winter range of Li-ion ternary batteries decreases by less than 15%. For example, the discharge capacity of a ternary lithium battery at -10°C is only 83.9% of the rated capacity, which indicates that at low temperatures, the ionic conductivity of the electrolyte exhibits a decline, and the internal reaction of the battery slows down, leading to a reduction in discharge capacity. The material stability of ternary lithium batteries is poor, and usually starts to decompose at around 200℃. Under the influence of high temperature, its electrolyte is easy to burn quickly, and may even lead to spontaneous combustion of the vehicle, thus threatening the safety of people and property.

#### *Lithium Iron Phosphate Batteries*

In contrast, lithium iron phosphate batteries have a monomer energy density of 150-160Wh/kg. Although the energy density is lower, they have better safety, longer life and more cost advantages, so they are also widely used in pure electric and hybrid vehicles [5]. In the context of safety, lithium iron phosphate batteries exhibit considerable advantages when compared to ternary lithium batteries. Specifically, lithium iron phosphate batteries demonstrate enhanced thermal stability in elevated temperature conditions. Its peak electrical heating can exceed 350°C, while the chemical composition does not begin to decompose until temperatures in the range of 500 to 600°C.

## Sodium Ion Batteries

Sodium-ion batteries (SIBs) are regarded as formidable alternatives to lithium-ion batteries (LIBs) owing to their economic advantages, abundant availability of raw materials, and reduced environmental impact. Sodium ion batteries are secondary batteries that utilize sodium ions to move between the anode and cathode to attain electrical energy storage and release, and are allowed to discharge to zero volts due to their non-overdischarge characteristics. As an abundant resource, sodium has far more reserves in the earth's crust than lithium. Therefore, it has the advantage of lower cost. The operational mechanism of sodium-ion batteries closely resembles that of lithium-ion batteries, as both systems rely on the intercalation and deintercalation of ions between the anode and cathode to facilitate energy storage and release. Sodium-ion batteries are moving towards commercialization and practicality as a potential alternative technology.

## Other Types of Batteries

Nickel-metal hydride batteries have nickel-hydrogen oxides at the anode and hydrogen storage alloys at the cathode, and the energy witnessed is lower than that of lithium-ion batteries. This type of battery has the advantages of long life, clean and non-polluting, but there are also shortcomings such as low specific energy, high cost of materials, and poor high-temperature charging and discharging performance, etc., and is currently mainly used in the field of hybrid vehicles, such as Toyota Prius [3].

Lead-acid batteries represent one of the most established forms of battery technology. Comprising lead dioxide at the positive electrode and lead at the negative electrode, these batteries are predominantly utilized in low-speed electric vehicles and electric bicycles. Lead-acid batteries, as an early development of battery technology, have the advantages of mature technology, low cost, easy maintenance and strong reliability, but there are also short life, low energy density and environmental pollution and other shortcomings [3].

Fuel cells generate electricity through hydrogen-oxygen reaction, and these cells exhibit the benefits of elevated energy density and favorable environmental performance, and short charging time, but the technology is not mature enough and the cost is high. Currently, proton exchange membrane fuel cell (PEMFC) is one of the more mature fuel cell technologies, which works on the principle of generating protons and electrons through an oxidation reaction of hydrogen at the anode [5]. Mainly used in Toyota Mirai, Hyundai NEXO and other cars.

## Solid State Batteries

Solid-state batteries are an important development direction for power batteries. Solid-state battery performance has the potential to disrupt current liquid lithium batteries with higher safety, higher energy density, longer low-temperature range, and longer life. Solid-state electrolytes are non-flammable, thermally stable and more chemically stable. However, the manufacturing process is complicated, the material is expensive and the production cost is high.

Semi-solid-state batteries offer significant improvements over traditional liquid batteries by reducing the amount of liquid electrolytes and introducing oxide and polymer composite electrolytes to enhance battery performance and safety. Oxide electrolytes are added mainly in the form of diaphragm coating and positive and negative electrode wrapping, while polymer electrolytes are filled in the battery structure as a framework network [6].In addition, semi-solid-state batteries have been upgraded in anode materials, shifting from traditional graphite system to pre-lithiated silicon-based anode and lithium-metal anode; and the anode materials have been upgraded from high-nickel system to high-nickel+high-voltage system as well as lithium-rich manganese-based anode and so on. The diaphragm portion remains, but is coated with a solid electrolyte for enhanced performance [6]. At the same time, the lithium salt has been upgraded from the conventional LiPF6 to the LiTFSI with better performance. These improvements have enabled semi-solid-state batteries to reach energy densities of more than 350 Wh/kg. However, although semi-solid batteries reduce the amount of liquid electrolyte, the risk of flammability is not completely eliminated as they still contain a small amount of liquid content [6].

All-solid-state batteries, on the other hand, are a further revolution of liquid batteries, completely eliminating liquid electrolytes and using solid electrolytes, such as oxides, sulfides, or polymers, as the ion-conducting medium

[6]. The solid electrolyte separates the positive and negative electrodes in the configuration of a thin film, replacing the function of a traditional diaphragm. Currently, the advancement of oxide solid-state electrolytes is progressing at a fast pace, while sulfide solid-state electrolytes are regarded as possessing significant potential for future applications, primarily due to their high ionic conductivity. In contrast, polymer solid-state electrolytes face limitations in their applicability, attributable to their relatively low upper-performance threshold. In terms of anode materials, all-solid-state batteries also adopt pre-lithiated silicon-based anode and lithium metal anode; cathode materials are further upgraded to high-performance systems such as ultra-high nickel, lithium nickel manganate and lithium-rich manganese base [6]. Thanks to these improvements, the energy density of all-solid-state batteries can reach 500 Wh/kg, far exceeding that of conventional liquid batteries[6].In addition, all-solid-state batteries significantly improve battery safety by completely removing the liquid electrolyte and fundamentally solving the flammability problem.

Overall, semi-solid-state batteries, as a transitional technology, have made important progress in energy density and safety, but there are still certain risks; while all-solid-state batteries represent the direction of the next generation of battery technology, with higher energy density and safety, and are an important breakthrough point in the future battery field.

## POWER BATTERY HEAT DISSIPATION TECHNOLOGY

During operation, batteries generate a significant amount of heat, particularly under high-power or extreme conditions. The resultant temperature rise can accelerate battery aging and reduce battery lifespan. To address this issue, researchers have developed various thermal management technologies aimed at mitigating battery heat through different cooling methods, thereby extending battery life.

### Heat Generation Mechanism of Power Battery

The primary heat generation mechanisms in power batteries consist of electrochemical reaction heat, resistive (Joule) heating, polarization-induced heat, and heat from parasitic side reactions.[7]. Chemical reaction heat, which is the main source of heat in power batteries, is generated by the chemical reactions occurring inside the battery. During charging, significant chemical reaction heat is produced due to the reactions between the positive and negative electrodes. During operating [7], joule heat is generated when the current passes through the inner resistance of the battery. The amount of Joule heat is related to the battery's operating conditions; for instance, when the battery is under a high load, the current flows for a longer duration, resulting in more Joule heat. Polarization heat arises from the polarization phenomenon of chemical substances within the battery under the influence of an electric field [7]. The magnitude of this heat depends on factors such as the battery's operating voltage, current, and ambient temperature. Side reaction heat refers to the heat released by additional side reactions that may occur during battery usage, apart from the aforementioned mechanisms [7].

Currently, heat dissipation in new energy vehicles (NEVs) may impact battery lifespan, as excessively high battery temperatures can accelerate aging. Therefore, effective thermal management and heat dissipation technologies are critical for the development of NEVs. The primary cooling methods for NEVs which includs air cooling, liquid cooling and direct cooling. Air cooling utilizes airflow to dissipate heat, offering low cost but relatively low cooling efficiency. Liquid cooling, which involves circulating coolant through internal battery channels, provides high cooling efficiency and is the predominant cooling technology in NEVs. Direct cooling employs refrigerants to directly absorb heat through evaporation, offering high cooling efficiency but presenting significant technical challenges.

### Air-cooled Heat Dissipation Technology

The air cooling system is relatively simple, primarily relying on natural or forced convection of air to dissipate heat, making it cost-effective and suitable for large-scale applications. However, compared to cooling methods, for instance, liquid cooling or phase change material cooling, air cooling exhibits lower heat dissipation efficiency. Under high-power discharge or extreme environmental conditions, air cooling may fail to meet the thermal management requirements of battery packs. Additionally, the performance of air cooling systems is significantly influenced by external elements, for example, ambient temperature, humidity, and wind speed. In high-temperature environments, the heat dissipation capacity of air cooling systems can markedly decline.

Air cooling dissipates heat generated by batteries through airflow, which can be achieved via natural convection or forced convection. Convective cooling technology involves the use of thermally conductive materials at the bottom of the battery pack to conduct heat, while utilizing airflow along the sides of the battery pack for heat dissipation [7]. This technology offers advantages such as high heat transfer efficiency and excellent stability, effectively reducing the operating temperature of batteries, thereby extending their lifespan and enhancing safety. Furthermore, convective cooling technology provides isolation and vibration-damping functions, helping to prevent issues such as short circuits or wear between batteries [7].

## Liquid Cooling Technology

Liquid cooling demonstrates superior cooling performance compared to air cooling, as it relies on the continuous circulation of a heat transfer medium to achieve efficient heat dissipation. Heat transfer media can be categorized into direct-contact and indirect-contact types. The former includes substances such as mineral oil, which can directly interact with heat sources to absorb and transfer heat, while the latter encompasses water and specialized coolants. By circulating coolants (e.g., water or ethylene glycol solutions) through liquid cooling plates or pipes, the high temperature yielded by the battery is absorbed and removed, thereby reducing the temperature of battery. The principle of liquid cooling technology involves injecting the coolant into the interior of the battery pack and dissipating the high temperature transit aluminum cooling tubes [7]. Commonly used coolants include mineral oil, synthetic oil, and water-based coolants [7]. Among these, mineral oil exhibits excellent thermal conductivity and high-temperature resistance but poses certain environmental concerns. Synthetic oil, on the other hand, offers better environmental compatibility and high-temperature stability, while water-based coolants are characterized by their non-toxicity, harmlessness, and environmental friendliness [7].

## Heat Pipe Cooling Technology

Leveraging the high thermal conductivity of heat pipes, the heat manufactured by batteries are rapidly transferred to a heat sink for dissipation. The heat pipe heat sink is a core component of power battery heat pipe cooling technology, primarily consisting of heat pipes, fins, and fans [7]. The heat pipes function to transfer the internal heat of the battery to the heat sink, while the fins serve as critical components to increase the heat dissipation domain and enhance cooling efficiency. The fans are employed to accelerate airflow, thereby improving the heat dissipation performance of the heat sink [7]. Heat pipes exhibit strong heat transfer capabilities and enable cyclic heat transfer processes, making them widely applicable in industrial fields. However, further research is still required in areas such as cost control, structural optimization, and material selection [8].

## Cooling Technology of Phase Change Materials

Utilizing the heat absorption characteristics of phase change materials (PCMs) during their phase transition process, the temperature of batteries can be effectively controlled. Phase change materials are substances that can absorb or release large amounts of heat within a specific temperature range. When heat from the battery is transferred to the PCM, the liquid portion of the PCM absorbs heat and expands, transitioning into a gaseous state, while the solid portion releases heat and contracts [7]. With advancements in materials science, a wide variety of phase change materials have been developed, including organic PCMs, inorganic PCMs, and microencapsulated PCMs, among others [9].

# WASTE HEAT UTILIZATION

Waste heat utilization refers to the recycling of waste heat generated by automobiles into effective energy. In conventional fuel vehicles, the heat mainly comes from the combustion process of the engine. In the process of converting chemical energy into mechanical energy, an engine generates a large amount of waste heat. This waste heat is usually lost to the environment through cooling systems and exhaust systems. In new energy vehicles, the source of heat is more diversified, mainly including batteries, motors and electronic control systems. The effective utilization of residual thermal energy in new energy vehicles plays a crucial role in enhancing overall energy conversion efficiency, prolonging operational endurance, and minimizing energy expenditure. Through the implementation of intelligent thermal management systems and waste heat recovery technologies, the vehicle's energy utilization framework can achieve comprehensive optimization. This approach not only improves the thermodynamic efficiency of power systems but also contributes to sustainable energy conservation in automotive engineering applications.

## Battery Motor Waste Heat Utilization

Battery charging and discharging will generate heat, and heat pumps or hot spot conversion technology can be used to convert waste heat and lung heat into interior heating or for battery preheating. The waste heat in the electric drive system can be used to increase the battery temperature in winter to increase the driving range, and the use of waste heat to provide heating to reduce the heat provided by the battery energy to increase the driving mileage, and can reduce the battery aging and increase the battery life. New energy vehicles mainly use PTC heating in low-temperature environments, which requires most of the electricity. Taking 2000kw PTC as an example, the power consumption for 1 hour of operation is 2 KWH, and the comprehensive energy consumption of new energy vehicles is 15kWh/100 km, so the PTC will lose 13-14 km of mileage in one hour. Lee's experiments show that due to the lower efficiency of PTC heaters, the driving range of electric vehicles is reduced by up to 50%[10]. Torregrosa et al. found that almost all existing pure electric vehicles use PTC electric heaters for heating, and the PTC electric heating power is generally greater than 2kW, and the efficiency is less than 1, which can lead to a 24% reduction in the operating range of battery-powered vehicles [11]. According to Farrington and other studies, electric vehicles can reach a range of more than 300km, but when the heating and cooling system is running, the range is reduced by about 40 percent [12].

In a temperature environment, the high-temperature auxiliary PTC element of the motor can be used to heat the crew cabin, which reduces the loss of battery power to a certain extent [13]. The motor will generate a significant amount of heat during operation., which can reach more than 60℃at high load or high speed, and the heat of the motor coolant is transferred to the heating system of the crew cabin through the heat exchanger. Insufficient heat is provided by the PTC heater as an auxiliary heat source. At the same time, the waste heat emitted by the battery can also be used to provide heat to the coolant of the battery through the heat switch, taking full advantage of the waste heat of the motor battery, reducing the power consumption of the PTC heater and improving the energy consumption of the vehicle. In short-distance driving (such as in the city form), the battery motor waste heat and PTC heater work together; During long trips, the battery and motor waste heat are sufficient to further reduce the power of the PTC heater. A multi-heat source collaborative heating system is constructed by combining motor waste heat with battery waste heat and air conditioning system.

## Heat Pump Air Conditioning System

The working principle of a heat pump essentially reverses the refrigeration cycle of an air conditioning system. In this process, high-pressure refrigerant first undergoes pressure reduction through an expansion valve. Subsequently, the refrigerant absorbs heat from the ambient air via isothermal evaporation in the evaporator. The resulting low-temperature, low-pressure gaseous refrigerant then enters a compressor where it is pressurized into a high-temperature, high-pressure vapor. This heated refrigerant subsequently flows into the condenser, where it releases thermal energy through condensation, effectively transferring heat into the passenger compartment for heating purposes [14]. The heat pump system uses ambient heat and vehicle waste heat, and the heat efficiency ratio (COP) is much higher than that of traditional PTC heating. However, when the ambient temperature is low, due to the physical properties of the refrigerant or the existing technical capabilities are not perfect, there is insufficient heating capacity and low energy efficiency ratio. For this situation, the current solutions are mainly: For example, the use of refrigerants with better heating effect under low temperature environment, such as R744, R32, etc. to replace the refrigerant with low heating efficiency, or the use of compressor to replenish the air and increase the enthalpy technology to enhance the work efficiency of the heat pump air conditioning system [14]. For example, using refrigerants that are better at heating at low temperatures, such as R744, R32, etc., replace the refrigerant with low heating efficiency, or use the compressor to replenish the air enthalpy technology to improve COP of the heat pump [14].In addition, the use of waste heat recovery technology to rationally utilize the waste heat generated by the motor or battery in the vehicle driving process can not only optimize the energy utilization efficiency of the vehicle, but also has certain advantages in development cost, and is favored by major car companies [14].

## CONCLUSION

In summary, the crucial point of heat dissipation technology and waste heat utilization of new energy vehicles has become a vital factor in improving the overall vehicle performance. Currently, fluid-based cooling is one of the mainstream cooling methods. Moreover, ventilation-based cooling, cooling by phase-change materials, and cooling via heat pipes also have great development potential. In terms of thermal dissipation, different cooling methods play various roles.

The thermal energy produced by the battery during operation is an important aspect. The heat emitted from the battery is able to be managed in different ways. For example, in the energy-using efficiency of the vehicle system, cooling methods can affect how this heat is handled. Under low - low-temperature conditions, waste heat utilization becomes more significant. Residual heat from the battery and motor can be recovered to effectively improve the energy-using efficiency, reduce battery loss, extend battery life, and increase the driving range. Especially, using the unutilized heat from the battery and motor to assist the PTC heater can significantly reduce power consumption and increase the driving range.

Future research should further explore suitable heat dissipation material solutions and waste heat recovery technologies to establish a more efficient and environmentally friendly thermal management system for new energy vehicles. Integrating heat dissipation technologies with waste heat utilization can form an integrated thermal management solution, which is conducive to enhancing energy efficiency and driving range, and promoting the popularization and sustainable development of new energy vehicles.

## AUTHORS CONTRIBUTION

All the authors contributed equally and their names were listed in alphabetical order.

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