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DESIGN AND ANALYSIS OF BATTERY THERMAL MANAGEMENT SYSTEMS FOR LITHIUM-ION BATTERIES

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ABSTRACT: Electric vehicles' (EVs) rising profile as a greener substitute for gas-powered vehicles has highlighted the significance of effective battery heat control. Lithium-ion batteries are frequently employed in electric vehicles (EVs) due to their rapid charging capabilities and efficiency. Nevertheless, they may become less durable and unsafe if they become excessively heated. The objective of this research is to develop a suitable model for battery thermal management that allows for the monitoring and regulation of the battery's temperature within a safe range by utilizing passive and active cooling methods. Batteries could be rendered safer, more efficient, and longer-lasting through the implementation of an enhanced thermal management system. This could result in an increase in the number of individuals who use electric vehicles and contribute to the environmental sustainability of transportation.

Keywords:*Electricvehicles, Battery Thermal Management System (BTMS), Lithium-ion batteries, Thermal modeling*

1. INTRODUCTION

The long cycle life, high energy density, and extensive use of lithium-ion batteries have made them the go-to choice for energy storage in a number of sectors, including electric vehicles, portable electronics, and renewable power systems. Improving the safety, performance, and longevity of lithium-ion batteries is crucial for managing and regulating these batteries in light of the increasing demand for efficient and dependable energy storage systems.

The proper management, safety, and oversight of lithium-ion batteries are dependent on a BMS. The primary functions of the BMS are to keep the cells of the battery from being exposed to harmful operating conditions, to avoid thermal runaway, overdischarging, and overcharging, and to ensure that each cell is charged and discharged at the same rate. In order to improve the performance and lifespan of the battery, the BMS efficiently controls its state of charge (SoC) and state of health (SoH). Keeping cells in a steady state is a key function of the BMS. In lithium-ion batteries, many cells are arranged in either a parallel or series configuration. Subtle differences in cell properties might lead to an imbalance between discharge and charge rates. To ensure that the battery lasts as long as possible and has as much capacity as possible, the BMS constantly regulates the voltages of individual cells. If you want your lithium-ion batteries to work as intended and not cause any problems, you need a good Battery Management System (BMS). When it comes to lithium-ion batteries, thermal management is all about controlling and regulating the temperature. This is done to make sure the batteries work safely and efficiently.

Extreme heat or cold can kill batteries or severely reduce their performance or even compromise their safety. Despite the abundance of energy storage methods, one that makes great use of nanofluids is low-temperature thermal energy storage (LHTES), which is highly appealing in thermal systems. Thermostatically, sensible heat thermal energy storage is becoming increasingly common, but LHTES's near-isothermal operation, small size, and higher energy density make it a potentially more promising alternative.

2. COMPOSITE PHASE CHANGE MATERIALS

Power battery temperature management has been enhanced with the development of a new composite phase

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change material (CPCM) containing nanosilica (NS). Battery modules run cooler and last longer when using NS because it increases material stability, decreases CPCM leakage and volumetric variations, and improves cooling efficiency. This new development overcomes significant challenges in the field of effective PCM cooling technology. Two composite phases were evaluated in the experiment.

Batteries employ phase change materials (PCMs) for temperature regulation. Because the phase change material in multi-cell packets had lesser conductivity, the extended cooling duration caused the temperature distribution to be uneven. By decreasing voltage differences and improving temperature uniformity, the higher-conductivity phase change material improved performance in cold environments. For battery packs to keep their cell voltages and temperatures constant, efficient thermal regulation is essential. To enhance heat transfer in lithium-ion battery packs, a PCM composed of CCFSS and paraffin was created. This confirms the efficacy of the composite PCM, which has been proven in both numerical and experimental investigations to exhibit effective temperature regulation. Battery temperature can be affected by variables such as spacing, convection coefficient, and PPI; thus, this composite PCM has potential uses in thermal control of lithium-ion batteries .

Research on lithium-ion battery heat management made use of composite phase transition materials composed of graphene and multi-walled carbon nanotubes. Improved thermal conductivity and controlled temperature increase during heat charging were achieved by finding the ideal ratios. An MWCNT/graphene composite with a mass ratio of 3/7 exhibited the best thermal conductivity, enhanced temperature regulation, and promise for efficient thermal management of lithium-ion batteries.

Research on PCM cooling for pouch cells found that it outperformed natural convection by a wide margin. Melting point, thickness of phase transition material, and thermal contact resistance were the primary variables impacting cooling. Performance was improved with an appropriate melting point and reduced thermal contact resistance, and cooling efficiency was further raised with a PCM thickness of up to 3 mm. Future studies should investigate the effects of PCM cooling; the results will help guide thermal management and safety measures. Thanks to their high thermal energy storage capacity, phase change materials (PCMs) allow for precise thermal regulation. Using aluminum and CENG foams speeds up the thermal charging process. Because of improved conduction, which is affected by the viscosity of the thermal interface materials and the phase change material (PCM), aluminum foams with a higher pore density perform better.

The design of thermal batteries for space conditioning is affected by CENG foams' outstanding thermal conductivity, low density, and small pore size. These foams also display amazing thermal charge growth [6]. A new approach to thermal management system heat transfer is proposed in the paper, which makes use of phase transition materials for big battery packs. During high-rate cycling, the pack's inverted cell orientation improves heat distribution and temperature management, in addition to thermoelectric and convection devices. This approach maintains the potential for latent heat storage while also having the potential to increase the range of electric cars and the utilization of technology across platforms.

The thermal efficiency of electrical devices is being studied experimentally with copper foam heat sinks and phase change materials (PCMs). Phase change materials (PCM) kinds and volume fractions affect the basal temperature reduction at different power loads while charging. In many cases, composites made of copper foam perform better than the separate foams. Heat regulation efficiency is dependent on electrical load, melting point, and PCM type. For moderate power levels, RT-35HC/Copper foam works well, whereas RT-54HC/Copper foam excels under higher loads and temperatures.

The investigation demonstrates a phase-change material (PCM) based hybrid battery thermal management system (PLH-BTMS) that employs heat pipelines, liquid cooling, and phase change materials. A surrogate model is developed to minimize temperature fluctuations and enhance heat dissipation during charging and discharging cycles in order to optimize economically. With its enhanced thermal performance and decreased risk of thermal runaway propagation, the PLH-BTMS has become a reliable solution for battery thermal control [9]. Using hybrid techniques and developments in thermal conductivity, this work aims to optimize the design of PCM-based BTMS. We highlight a hybrid BTMS that incorporates PCM and heat pipelines as the optimum approach after considering material selection, setup, and reactivity. Methods for enhancing thermal conductivity are investigated, including the use of porous foams.

A number of factors influence the efficacy of BTMS, including design considerations, melting point, and heat conductivity. To improve the design of BTMS, further research should go into topics such material compatibility, waste heat recovery, 3D printing, PCM melting temperatures, and cost analysis. Cell temperatures remain constant and consistent regardless of environmental conditions thanks to the phase change material and the suggested cell-to-cell cooling architecture of the combined active and passive battery thermal management system.

The enhanced PCM-cooled approach permits a more direct alteration of pack capacity in comparison to traditional systems. Create and evaluate BTMSs that enhance the thermal efficiency and safety of electric vehicle batteries by utilizing Phase Change Material (PCM). This research aims to enhance the thermal conductivity and latent heat properties of phase change materials (PCM) while considering convection, volume, weight, and cost trade-offs . The goal is to create a BTMS that is efficient and effective for future applications. Explore Battery Thermal Management Systems (BTMS) that incorporate Phase Change Materials (PCMs) to provide a uniform distribution of battery temperatures. Several ways to enhance phase change material (PCM) characteristics are being investigated in this research. These include lowering the PCM's melting point, boosting its thermal conductivity, and enhancing its latent heat, among others. Future improvements in the efficiency, volume, weight, cost-effectiveness, and energy usage of BTMS based on PCM are highlighted in the research, along with the significance of hybrid BTMS.

The most obvious environmental element affecting the performance of electric car battery packs is severe heat. What the battery heats up depends on two factors: the rate of discharge and the surrounding temperature. For passive cooling to work, particularly at low discharge rates, fatty acids like capric acid are used as phase change materials (PCMs) to keep the batteries cold. This method is more cost-effective than paraffin wax and has a higher heat absorption efficiency. When conditions are difficult and the discharge rate is large, it may be required to use an auxiliary liquid cooling system to maintain the appropriate temperature.

Graphene nanoplatelets (GNP) combined with paraffin-based composites can enhance the temperature management capabilities of a battery cell. The inclusion of 7% GNP improves thermal conductivity and delays the temperature increase during discharge. Because of this, at lower ambient temperatures, battery protection lifetimes are prolonged while maintaining the right latent heat melting properties for industrial applications.

Figure 1a shows the schematic diagram of the experimental system and the preparation of the battery module based on CPCM-NSx. Using a milling machine, six holes with a diameter of 18.5 mm were bored into the CPCM-NSx. Next, six 18650 Lithium-ion power batteries from a commercial source were utilized to fill these spaces, each with a 2 Ah capacity. One cell was connected in series and six cells were joined in parallel using laser spot welding equipment, resulting in a 1S × 6P structure (Fig. 1b). Additionally, the battery module was charged and discharged with a precision of ± 0.01% using a BTS-5V30A-NTF battery testing apparatus. The Agilent 34970A Data Acquisition system was linked to two T-type thermocouples that were fastened to the center surfaces of two cells in the battery module.

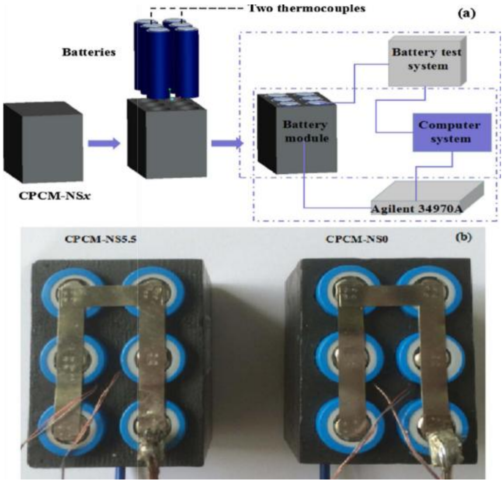

Fig. 1.(a) Schematic diagram for the preparation of the battery module and the experimental system; (b) Photos of the CPCM-NS5.5 and CPCM-NS0 modules.

3. THERMAL MANAGEMENT WITH LIQUID COOLING

Thermodynamic model of a battery pack for an electric car that makes use of cooled liquid channels. Consideration of heat production, heat transport, and individual batteries is made in the model. The simulation findings demonstrate that temperature and non-uniformity are worsened by high discharge/charge rates. Both are enhanced by raising the liquid discharge rate.

The peak temperature can be reduced by increasing the interface area with the channel wall, but the problems with uniformity are made worse . On the other hand, bigger heat exchange surfaces between batteries do enhance uniformity to some extent. A new method for controlling the temperature of lithium-ion batteries, based on AgO nanofluid, is presented in the research. The correct temperature and consistency are guaranteed.

The impacts of discharge rate, concentration of nanofluid, and flow velocity are investigated using numerical analysis. As the velocity and concentration of the nanofluid increase, the maximum temperature and its corresponding variations decrease. With a 7C discharge rate, the temperature is controlled below 305.59 K and the differential is kept below 1.07 K under optimum conditions. By contrasting 18650 and 21700 battery packs, we can see the advantages of the latter.

The need of maintaining a consistent temperature for the Li-ion battery packs used in PHEVs, EVs, and HEVs is emphasized. We look at indirect cooling for PHEV Li-ion pouch cells using liquid and aluminum cooling technologies. By using finite element analysis to predict cell temperature distributions under different cooling configurations, the benefits of dual cold plate cooling in boosting the cooling capacity for cell terminals and busbars are shown .

The importance of BTM technology for electric and hybrid vehicles should not be overstated. In addition to exploring several behind-the-meter methods including systems based on phase transition materials, air, and liquid, the review also examines the impact of temperature on battery performance. Our primary objective is to enhance the performance of liquid-based systems in terms of heat transfer efficiency.

We will also investigate potential uses for heat pipes and their interactions with other thermal management systems in vehicles. Propose a lightweight and compact liquid-cooled battery thermal management (BTM) system to regulate the temperature of Li-ion batteries when they are being operated at a high discharge rate. A new thermal conductive structure (TCS) is designed with three curved contact surfaces to enhance the system's performance, and its structural features are investigated in detail. A decrease in both weight and temperature variations is achieved by the produced TCS.

Furthermore, we look into a concurrent TCS setup.Standardize flow rates and keep the battery pack's temperature steady. A vapor chamber and fin assembly comprise a thermal management system for cylindrical Li-ion battery packs that employs water or air-forced cooling techniques. The research found that the most effective way to manage temperature was with a system that combined a vapor chamber with water cooling. Aside from extensive testing, this approach provides a more space-efficient, dependable, and watertight cooling option for cylindrical Li-ion batteries. Improving the vapor chamber's cooling efficiency utilizing various refrigerant kinds and compositions is the focus of future research.

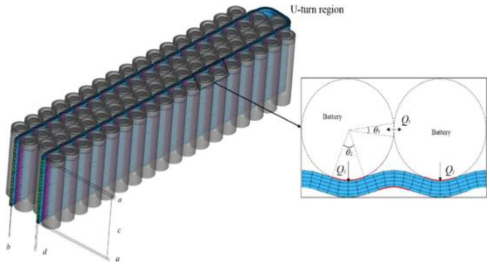

Fig.2.Schematicofthesimulatedlithium-ionbatterymodulegeometryandthenumerical mesh.

A high energy density requires that the required battery module be fully loaded with batteries. With a minimum of batteries per module, you may achieve ideal heat homogeneity and user-friendliness. This research examines a battery module that contains 7118650 type lithium-ion batteries, with the Tesla Model S serving as a point of comparison. A serpentine tube encircling the batteries is seen in Fig. as the cooling channel. 2.

4. THERMAL MANAGEMENT WITH AIRCOOLING

Electric car lithium-ion battery packs employ a reliability design approach that includes cell redundancy and thermal imbalance as critical components. Thirdly, it builds models for reliability, degradation, and multiphysics. The analysis concludes that a 6 × 5 parallel-series design is the best system architecture for improving non-monotonic dependability due to heat effects after looking at multiple redundancy techniques. Furthermore, the impact of cellular organization and freezing circumstances is investigated. Thanks to Battery

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Thermal Management Systems (BTMS), electric vehicles (EVs) and hybrid electric vehicles (HEVs) are able to maximize their efficiency, particularly when it comes toair-cooling operations.

It highlights the advantages of improved efficiency, evaluates new developments, simulates and tests the architecture of air-cooling battery thermal management systems, and determines the effects of heat generation on powertrains. Improving air-cooling battery thermal management systems should be a focus of future research and solutions.

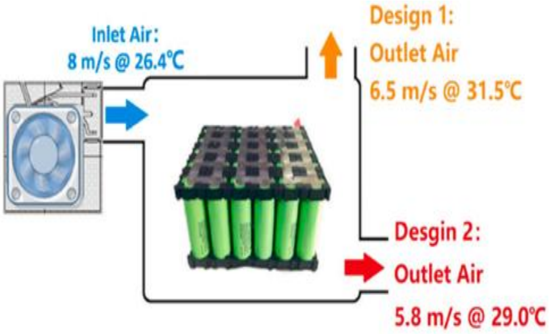

Fig.3.BTMSdesignswithdifferentoutlets:Design1:upperoutlet;Design2:bottomoutlet.

An active air-cooling Battery Thermal Management System (BTMS) prevents the battery pack from overheating during normal draining operations. According to the figure, Design 1 had better cooling effectiveness in terms of both the maximum temperature differential and the peak temperature.

5.HYBRID THERMAL MANAGEMENT

An electric vehicle's rectangular Li-ion power batteries are efficiently cooled by a serpentine-channel cold plate shaped like a U. The simulation findings reveal that a 5-channel configuration along the longitudinal axis achieves the optimum cooling performance, with a 26°C decrease in maximum temperature compared to a 2-channel width configuration. This is after examining channel amount, arrangement, and refrigerant inlet temperature.

The design of cold plates for thermal management of lithium-ion batteries is constrained by the maximum allowed channel number and inlet temperature, which are established by efficiency and safety standards . Keeping electric car lithium-ion batteries (LIBs) within their ideal operating temperature range is a critical function of battery thermal management systems (BTMS). A battery thermal management system based on L- and I-shaped heat pipes was designed and evaluated. Resistant to high thermal loads, the system was able to keep temperatures below 55°C, generate less than a 5°C temperature differential, and transfer over 92.18 percent of the heat it generated. A heat conduit and liquid cooling system work together to thermally regulate lithium-ion batteries. From the battery, heat is transferred to the cooling terminals via ultra-thin heat pipes, which evaporatively spread the heat. This system's cooling efficiency is tested using 3 Ah and 8 Ah battery packs with different cooling durations, and then compared to other BTM systems and natural convection. In order to control the battery temperature within a specified range, the research offers an affordable combination of moist cooling, fan cooling, and natural convection.

Enhanced control of hybrid electric vehicles' battery modules' temperatures. The idea is to use heat ducts in conjunction with air conditioning and ambient air ventilation to create a smart thermal management system. A nonlinear model predictive controller adjusts the fan and compressor speeds to maintain a constant battery temperature. Under varying conditions, the simulation demonstrates that the system can disperse heat (up to 1135 kJ) and successfully regulate temperature.

The system's power consumption is tested under different scenarios and modes of operation. LiFePO4 battery cell thermal management system makes use of liquid cooling and phase change material (PCM). The simulations validated the modeling of non-uniform heat generation and evaluated the impacts of pipe orientation, coolant velocity, and ambient temperature. The device demonstrated successful cooling at 45°C ambient temperature, maintaining a battery temperature range of 47.6°C to 4.5°C. The results of the cycle tests verified this.

expanded PCM percentage and heat dissipation, especially around the electrode tabs. Improving battery thermal management in extreme environments while maintaining cooling efficiency and reducing energy consumption was achieved by adjusting the coolant velocity during charging . Put the many BTMSs used by EV batteries into

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distinct groups. We go over the benefits and drawbacks of several BTMS alternatives, including those that utilize Vehicle Cabin Cooling (VCC), including PCM cooling, heat pipe cooling, and thermoelectric element cooling, and those that don't. The long-term goal is to develop better BTMS that can handle the growing heat load of electric vehicle batteries .

The heat generated by lithium-ion batteries is controlled via a sandwich configuration that includes a battery, a phase change material (PCM), and a heat pipe. Together, experimental data and a lumped thermal model shed light on the mechanisms that relate battery temperature with phase change. Heat pipelines maintain a low temperature in the battery over cycles by recovering latent heat from the phase change material (PCM). Additional phases, such as solidification, stable states, sensible heat, and latent heat, are recognized. Picking the ideal PCM melting point and heat transfer coefficient for the condenser will help you strike a balance between energy efficiency, module density, and safe temperatures.

Figure. shows what's required for the exam. Parts of 4(a) included heat ducts, copper holders, and aluminum plates. The 173 x 125 × 45 mm measurements of the metal panels used as battery simulators are accurate. The four 14 mm-diameter holes drilled into the top of the plate were filled with four heaters to produce heat. This image shows the dimensions of the copper holder. Dimensions of 90 mm × 40 mm x 30 mm are possessed by 4(b). Both the inlet and outflow tubes were 12.7 mm in diameter. The recirculating bath was cooled by cycling the coolant between the input and output tubes. A case in point. A look at Figure 4(b) reveals the configuration of the heat pipes fastened to the top surface of the aluminum plate. To make the aluminum plate, two plates were placed side by side. Figure. displays just one metal plate.

Part 4(c). The heat ducts are shown in the illustration. 4(d) came in two different shapes: L-shaped and I-shaped. Two halves of an L-shaped pipe, 60 mm long and 7.5 mm wide, comprised the condenser and the evaporator. The length of the other section was 124 mm. A copper holder was fastened to the condenser side of the heat conduit. An evaporator and a condenser, the two parts of the I-shaped heat conduit were shown in the picture; the former was 124 mm long and the latter was 15 mm wide. paragraph 4(e).

Following the evaporator's removal of surface heat from the aluminum plate, the condenser transferred that heat to the copper container. The water in the recirculating bath was heated by the copper holder. Eight heat pipes were located on the upper floor, and eight more on the lower level. Every single one of the heat ducts was squeezed in an effort to enhance thermal contact.

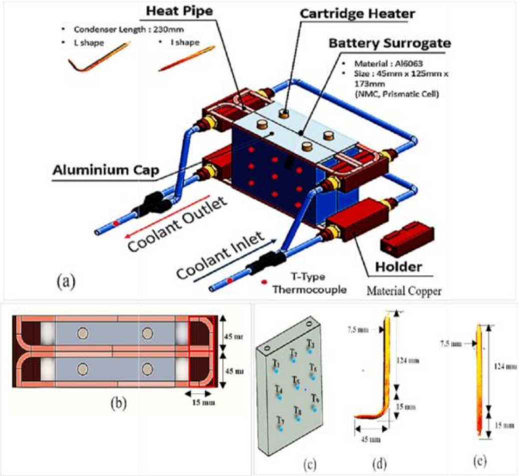

Fig. 4. (a) Test section (b) Arrangement of the heat pipe (c) Location of thermocouples on the aluminium plate (d) L- shaped heat pipe (e) I-shaped heat pipe.

6. CONCLUSION

Phase change materials (PCM) and battery thermal management systems (BTMS) are crucial for electric car battery packs, as shown by the extensive research. Through these inquiries, many significant challenges and advancements in the field are uncovered. Researchers are now working to enhance the thermal properties of PCM materials, including their thermal conductivity and latent heat. When it comes to battery packs, these advancements make temperature dispersion possible, which is crucial for optimal performance and extended life. The research uncovered a plethora of state-of-the-art cooling methods, including heat pipes, wet cooling, channeled liquid cooling, and sophisticated thermal management systems. The complex temperature

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management issues with electric vehicle batteries have real solutions in these methods. Innovative solutions are being developed through the use of hybrid BTMS, which integrate several cooling methods with state-of-the-art materials like as graphene, nanosilica, and copper foam. For demanding situations in particular, these hybrid systems are tailor-made to meet the specific thermal demands of battery packs, which should lead to increased efficiency and safety. An important area of research is the development of multi-physics models and redundancy mechanisms to guarantee the dependability of lithium-ion battery packs. In order to reduce complex heat effects and ensure dependable performance, these solutions are necessary. The importance of continuous research and development is highlighted by the continuous advancements in battery thermal management. Researchers are considering a lot of variables, including convection, weight, cost, and weather, to find the best thermal management systems for EVs and hybrids. These studies highlight the significance of heat regulation in electric car battery packs when considered collectively. They demonstrate a commitment to enhancing battery performance, safety, and longevity by implementing state-of-the-art PCM-based technologies, sophisticated cooling methods, and tactics centered on reliability. These developments are critical to the sustainability and broad acceptance of electric and hybrid vehicles, which are on the rise.

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