Thermal Management System Based on Phase Change Material & Heat Pipes for Electric Vehicle Batteries

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ABSTRACT

As Electric Vehicles (EVs) continue to gain popularity, the demand for high- performance and efficient battery systems becomes increasingly critical. Ensuring the optimal thermal management of lithium-ion batteries is essential to maintain their safety, reliability, and longevity. This project focuses on the development of an innovative Thermal Management System (TMS) for EV batteries using Phase Change Materials (PCM) and Heat Pipes. The project aims to design, fabricate, and test a prototype Thermal Management System based on PCM and heat pipes. Through experimental testing and computational simulations, the performance of the system will be assessed under various operating conditions. Ultimately, this research contributes to the advancement of EV battery technology by addressing the critical issue of thermal management. By developing a robust Thermal Management System that combines Phase Change Material and heat pipes, this project offers a promising solution to enhance the safety, longevity, and energy efficiency of electric vehicle batteries.

Keyword : *- Battery Thermal Management System, Phase Change Material, Heat pipes, EV Battery Technology*

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1. Introduction.

S Introduction to Battery Thermal Management System (BTMS) Up to now, many researches have reported various types of BTMSs for EVs, in which the selection of cooling mediums, the thermal design of cooling systems and the assessment of cooling effect became focused. In general, air, liquid and phase change materials (PCMs) as coolants were more considered; occasionally two or more mediums were combined to improve the cooling effect. Among the above methods, air cooling can be passive/active, parallel/series or natural/forced, and most widely used due to its low cost, availability and easy installation. In fact, even using air forced cooling still cause the non-uniform temperature distribution especially for a large-scale battery pack in EVs. Liquid cooling usually uses water, glycol or insulated oil as the common coolants, has higher heat transfer coefficient and offers greater cooling capacity than air cooling. However, some additional equipment such as pumps, tanks, heat exchangers and valves have to be installed in EVs to cause more occupied space, weight and requirements for leakage protection and complicated maintenance. Furthermore, the relatively high pressure drop across the liquid-cooled heat exchangers will lead to significant increased energy consumption and cost of the system. The drawbacks of the above BTMS makes it very difficult to meet the thermal requirements for power batteries working at various complex driving conditions. Thus, in demanding for highly efficient and low-energy consumption BTMS [4].

1.1 Problem Statement

High working temperature in the battery can cause a thermal runaway, decrease in battery capacity, and reduce the discharge cycle this has been a big obstacle for adaptation of Electric Vehicles (EVs). Therefore, a thermal management system is needed to maintain the temperature of the battery in all the working conditions

1.2 Proposed System Architecture

The proposed Battery Thermal Management System (BTMS) architecture aims to address the challenges of efficient cooling and temperature regulation for electric vehicle (EV) batteries by integrating multiple cooling strategies, advanced sensors, and intelligent control systems. This architecture seeks to optimize battery performance, enhance energy efficiency, and ensure the safety and longevity of EV batteries..

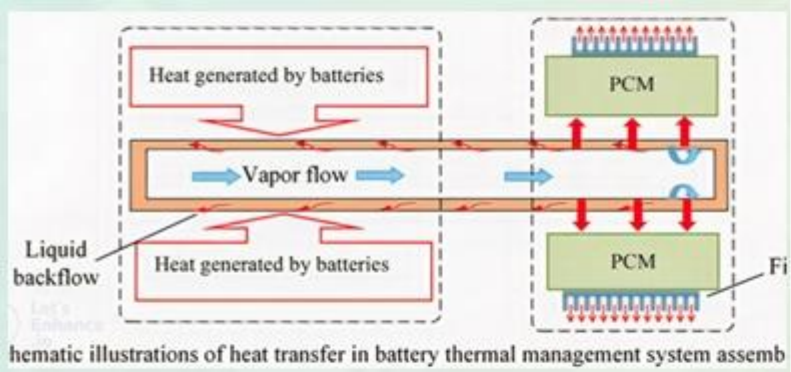

Fig – 1 Block diagram

2. Components.

Hardware

i. Phase Change Material
ii. .Battery 12v
iii. Heat pipes
iv. Resistance 50 Ohm
v. Temperature Sensors

2.1 Phase change Material

Phase Change Materials (PCMs) are substances that absorb and release thermal energy during the process of melting and freezing, making them ideal for thermal management applications. When the temperature rises, PCMs absorb excess heat and melt, storing the thermal energy as latent heat without a significant rise in temperature. Conversely, when the temperature drops, the PCM solidifies, releasing the stored heat. This unique property helps maintain a stable temperature in systems like electric vehicle (EV) batteries, improving efficiency, safety, and longevity by preventing overheating and reducing temperature fluctuations.

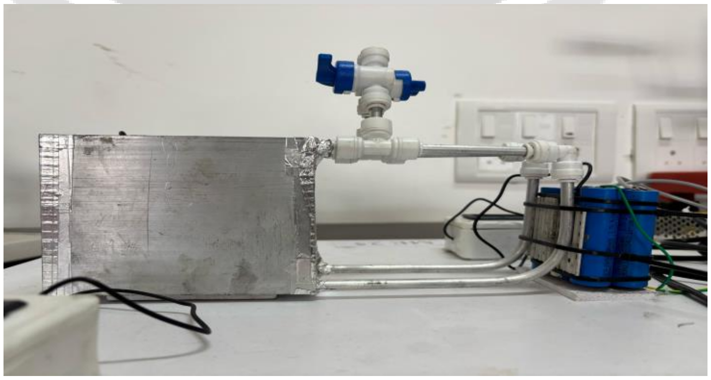

Fig – 2 Bluetooth Module

2.2 Heat Pipes

Heat pipes are highly efficient thermal conductors that transfer heat using the principle of phase change. They consist of a sealed, evacuated tube containing a small amount of liquid (often water or a specialized fluid) and a wick structure on the inside. When heat is applied to one end of the heat pipe, the liquid inside evaporates and travels to the cooler end, where it condenses back into a liquid, releasing the absorbed heat. The condensed liquid is then returned to the heated end via capillary action in the wick. Heat pipes are used in various applications, including electronics, spacecraft, and electric vehicle (EV) battery thermal management, because they can rapidly transport heat over long distances with minimal temperature difference. They are particularly effective when combined with Phase Change Materials (PCMs) to help stabilize the temperature of EV batteries, ensuring safe and efficient operation.

Fig – 3 Heat Pipes

3. Modal

A **model** in the context of heat pipes and thermal management systems refers to a mathematical or computational representation used to simulate and predict the behavior of heat transfer, phase change, and temperature gradients within a system. These models incorporate principles of thermodynamics and fluid dynamics to analyze parameters such as heat transfer rates, temperature distribution, and the flow of liquid and vapor inside the heat pipe. They are critical for designing and optimizing thermal management systems in electric vehicle (EV) batteries, helping engineers predict system performance, minimize overheating, and improve overall energy efficiency. Additionally, physical prototypes and experimental testing validate these models to ensure real-world applicability.

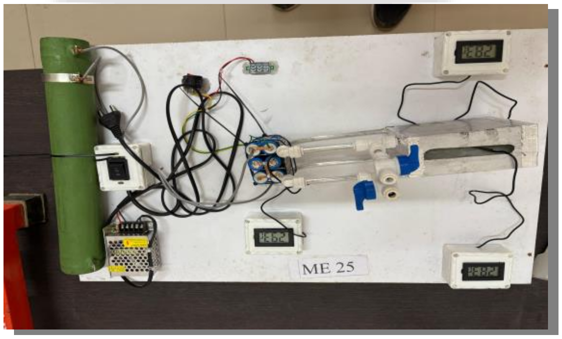

Fig – 4 Modal

4. Advantages.

1. **High Thermal Conductivity**: Heat pipes provide highly efficient heat transfer with minimal temperature difference, making them ideal for managing heat in compact systems like EV battery packs.
2. **Compact and Lightweight**: Their design is space-efficient and lightweight, essential for applications where weight and space are critical, such as in electric vehicles.
3. **Passive Operation**: Heat pipes work without external power sources or moving parts, relying on natural phase change processes, which makes them energy-efficient and reliable.
4. **Rapid Heat Distribution**: They quickly transport heat from hot spots to cooler areas, ensuring uniform temperature distribution and preventing overheating.
5. **Scalability**: Heat pipes are versatile and can be scaled to meet various thermal management needs, from small electronics to large battery systems.
6. **Long-Term Durability**: With no moving parts, heat pipes are durable, require minimal maintenance, and have a long lifespan, making them ideal for long-term applications.

5 Application

- **EV Battery Thermal Management**: Heat pipes regulate battery temperature, ensuring safety and efficiency.
- **Electronics Cooling**: Used in laptops, smartphones, and LEDs to dissipate heat from processors and components.
- **Spacecraft and Satellites**: Maintain thermal stability in space by transferring heat efficiently between hot and cold areas.
- **Industrial Heat Exchangers**: Improve energy efficiency in power generation, HVAC, and refrigeration systems.
- **Solar Thermal Systems**: Transfer heat in solar collectors for efficient water heating and energy storage.
- **Renewable Energy Systems**: Manage heat transfer in geothermal and other renewable energy applications.

6 Result and Discussion.

The results of the experimental testing and simulations demonstrated that the Thermal Management System (TMS) using Phase Change Materials (PCMs) and heat pipes effectively maintained the battery temperature within the optimal range, enhancing safety and efficiency. The PCM absorbed excess heat during high-power operations, while the heat pipes efficiently distributed the heat, preventing overheating and thermal runaway. The system exhibited consistent performance, extending battery lifespan by minimizing temperature fluctuations and improving thermal uniformity. Compared to traditional cooling methods, this combined approach was energy-efficient, as it operated passively without external power sources. However, challenges such as the low thermal conductivity of the PCM and its volume expansion during phase change were identified. Despite these limitations, the TMS showed significant potential for improving the safety, reliability, and longevity of EV batteries, with opportunities for further optimization in future designs.

7. Conclusion.

Battery thermal management systems are crucial for electric vehicles (EVs) to ensure the safe and efficient operation of lithium-ion batteries, which are sensitive to temperature variations. Phase change materials (PCMs) and heat pipes are two innovative technologies that can be used in combination to create an effective thermal management system for EV batteries. The developed Battery Thermal Management System will provide more compact size without the need for an external power supply to cool the battery. The thermal properties of PCM during the discharge process and cycle tests play important role of increasing natural convection and heat conduction in the PCM structure, thereby increasing the efficiency of heat dissipation and reducing the risk of failure in a passive thermal management system using PCM. The utilization of cooling system of PCM and heat pipes can increase the effectiveness of thermal management in battery of electric vehicle.

8. Future Work.

The future scope of this project encompasses several promising avenues for further research and development. One key area is the exploration of alternative PCMs with higher thermal conductivity and lower melting points to enhance the efficiency of thermal management systems. Additionally, investigating different concentrations and combinations of heat pipe fluids could yield even better performance, providing a more tailored approach to specific battery types and usage scenarios. The integration of advanced materials, such as graphene or nanocomposites, into the heat pipes or battery casing could further improve thermal conductivity and overall system efficiency. Another significant aspect is the development of real-time monitoring and adaptive control systems for the BTMS, allowing for dynamic adjustments based on the battery's operational state and environmental conditions. Moreover, long-term testing under various real-world conditions is crucial to assess the durability and reliability of the proposed system, ensuring its practical applicability in automotive and other high- demand applications. Collaborations with industry partners could also facilitate the translation of these innovations from the laboratory to commercial products, contributing to safer and more efficient electric vehicle technologies.

9. Reference.

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