Equinox Issue

SCHOLARLY REVIEW ONLINE

How can phase change materials improve vehicle cooling systems for better motor efficiency and thermal management?

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Abstract

Phase change materials, or PCMs, have become an attractive option for improving thermal management in the vehicle industry.With the increasing demand for efficient cooling systems and improved driving ranges in electric vehicles, PCMs offer an innovative approach to managing heat dissipation and improving performance.While PCMs are already applied in industries such as construction, their potential to revolutionize automotive thermal management could lead to advancements in all aspects of the field.They are a perfect option for increasing energy efficiency because of their capacity to collect and release thermal energy. This study explores the application of PCMs in vehicles and assesses their effectiveness in improving cooling systems.

Keywords: Phase Change Materials, Thermal Management, Automotive Cooling Systems, Battery Efficiency, Electric Vehicles, Thermal Energy Storage, Fuel Efficiency, Heat Dissipation

Introduction

In the automobile industry, effective thermal efficiency has emerged as a critical study area in the ongoing drive to improve vehicle performance and efficiency. To maximize longevity and energy efficiency, it is now imperative to balance battery temperatures and engine efficiency due to the integration of several creative ideas for dealing with demanding energy demands in automobiles. One of the most important parts of engineering is thermal management, which is controlling the temperature inside a car's systems to improve performance and safety. Engines generate a lot of heat while they run, and if this heat is not controlled, it can cause overheating, which shortens the engines' lifespan and reduces their efficiency. Particularly modern cars must meet higher standards for performance and efficiency. This calls for solutions for heat dissipation of crucial parts like batteries that are vulnerable to thermal damage. In this regard, Phase change materials present a novel and potentially effective answer to these problems. According to Liang et al. (2021), phase-change materials are compounds that can change their state and release latent heat without altering their temperature. Thermal management and regulation are facilitated by their capacity to absorb, store, and release substantial amounts of thermal energy during phase transitions.

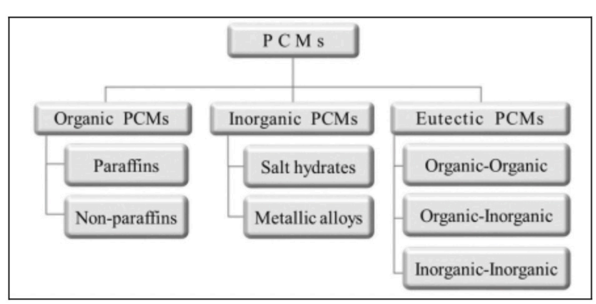
The emphasis of this cutting-edge technology is on battery management in electric and hybrid vehicles, and it has begun to migrate to other automotive applications. To increase energy efficiency, PCMs can be used in the battery thermal management systems of electric and hybrid cars (Wazeer et al., 2022).By addressing problems like excessive power usage and a limited ideal temperature range, such advancements in battery thermal management can help enhance battery longevity (Malik et al., 2016). PCMs have the potential to improve fuel efficiency in diesel engines as well. According to Park et al. (2017), PCMs such as stearic acid can recover around 30% of the thermal energy lost during engine cooling, boosting fuel efficiency and cutting down on warm-up time. By reclaiming lost thermal energy, condensing cooling systems, and increasing thermal conductivity, phase change materials can optimize car cooling systems, which will increase engine efficiency and fuel economy.

This paper aims to showcase the potential advantages of integrating phase change materials into automotive cooling systems and illustrate another approach to optimize engine efficiency and improve thermal management, entering a new era of sustainability. Through an examination of existing uses, advantages, and some difficulties, this research seeks to offer not only a thorough comprehension of phase change materials but also how it can revolutionize the automobile industry.

Phase change materials: Fundamentals

As discussed in the introduction, PCMs are substances that store and release thermal energy through phase transitions, offering high energy storage capabilities and temperature stability (Feng et al., 2022). PCMs can be classified into three main categories: organic, inorganic, and eutectic types with temperature ranges as low (<80 C), medium (80-200 C), and high (>200 C) (Feng et al., 2022).

Figure 1
Categorization of Phase Change Materials



They have a unique capability to absorb and release thermal energy and transition between different states. This energy exchange occurs during the process of melting and solidifying, making PCMs effective mediums for thermal storage and management.

Organic PCMs typically include paraffin waxes and fatty acids, which are often less corrosive and have thermal stability, making them useful for clothing and building insulation (Concept Group LLC, 2024). Inorganic PCMs consist of salt hydrates and metallic alloys. They often exhibit higher thermal conductivity and greater heat storage capacities compared to their organic counterparts, making them suitable for thermal energy management (Concept Group LLC, 2024) Eutectic PCMs are mixtures of multiple components and demonstrate superior performance with broader temperature ranges and improved phase stability compared to single-component PCMs (Sun et al., 2023) The effective utilization of PCMs depends on their thermal and chemical stability, which is crucial for the longevity of any component which uses them in various industries (Tyagi et al., 2022). Researchers have developed PCMs and employed various techniques to address challenges such as low thermal conductivity, supercooling, phase separation and much more (Feng et al., 2022).

Phase change materials show potential for significant improvement in emissions reduction and overall energy efficiency by thermally buffering vehicle systems to account for better thermal management and heat transfer throughout the vehicles (Jankowski et al., 2014).

The effectiveness of PCMs as thermal management tools is reliant on their excellent thermal properties, including latent heat capacities, melting temperature and thermal conductivity. PCMs have a high latent heat capacity, enabling them to store and release substantial amounts of energy during phase changes, making them reliable for thermal energy storage. High thermal conductivity is essential for the efficient transfer of heat throughout the vehicle, minimizing response times to sudden overheating of essential components.

Role of PCMs in automotives

PCMs have emerged as a promising solution for battery thermal management systems (BTMS), especially in electric vehicles and hybrid cars. PCMs can passively absorb and release heat, maintaining battery temperatures within optimal operating ranges without external power (Sun et al., 2020; Dolla & Fetene, 2024). While paraffin wax is commonly used, its low thermal conductivity limits effectiveness during rapid charging. Integrating highly-conductive additives like expanded graphite or heat pipes can significantly enhance performance (Dolla & Fetene, 2024).

In electric vehicles, PCM-based BTMS can increase driving range without charging and address issues like high power consumption (Malik et al., 2016). These materials can contribute to a substantial reduction in cooling system volume and hangover, potentially improving engine efficiency (Kim et al., 2010). Phase change materials can reduce cooling system size by up to 35% and engine warm-up time by 60%, improving fuel economy (Kim et al., 2010). Furthermore, microcapsule phase change material (MPCM) slurry can be used as engine coolant instead of water, improving thermal conductivity and reducing pumping consumption (Li et al., 2017). PCMs in radiator pipelines contribute to temperature regulation and energy efficiency, improving radiator performance in vehicles (Kumar et al., 2023). Another aspect of phase change materials is nano-enhanced phase change materials in a battery thermal management system that can maintain cell temperature below 46 C even at hot ambient temperatures (Jilte et al., 2020).

Phase change materials in vehicle cooling systems have loads of advantages. Phase change materials in vehicle cooling systems can be cheaper and easier to operate (Ianniciello et al., 2018).They help reduce weight, consume less energy and also produce lower local greenhouse gas emissions helping improve sustainability (Liu et al., 2012). Using phase change materials in vehicle cooling systems can reduce energy consumption by up to 30%, improve temperature uniformity, and delay temperature drop at cold stops, making it promising for heat transfer in EVs (Akbarzadeh et al., 2021). Adding graphite to PCMs can increase their thermal conductivity by up to 70 W m-1k-1, which can improve the performance of battery thermal management systems. For example, some commercially available passive thermal management systems using wax and graphite can increase the driving range of an electric scooter from 30 km to 55 km (Malik et al., 2016).

Phase change materials, if integrated properly, can revolutionise thermal energy management in vehicles. They can regulate temperatures while also integrating conductive properties. They enhance efficiency, reduce energy consumption and improve performance.

Challenges of using phase change materials in vehicles

PCMs offer potential benefits for thermal management in electric vehicle batteries and other vehicle engines but they also present disadvantages. Disadvantages of phase materials in vehicles include liquid leakage, phase separation, and supercooling problems (Wu et al., 2021). Another one of the challenges associated with using PCMs in vehicles is their inherently low thermal conductivity. This limitation can hinder rapid thermal responsiveness, reducing efficiency in situations requiring quick temperature regulation.(Singh et al., 2019).

Long-term stability and degradation represent significant concerns when implementing PCMs in the automotive industry. Due to repeated uses, PCMs must maintain their thermal properties to ensure consistent performance, which can lead to performance degradation. Some inorganic PCMs may exhibit corrosive behaviour towards various materials used in vehicle construction, undermining safety and can be a potential obstacle in structural integrity (Singh et al., 2019).Thus, ensuring that PCMs are non-corrosive and chemically stable is essential for their integration into automotive designs.

Integrating PCMs into vehicle cooling systems can also lead to significant cost implications as they are very expensive(due to a lack of mass production), while they do provide advantages in thermal management, the initial costs for their acquisition and installation can be counter productive.

Conclusion

Phase change materials can potentially revolutionize vehicle efficiency and performance over the next decade, effective thermal management proves to be a crucial aspect in the automotive industry. Throughout the paper, all aspects of PCMs were considered, how they can help increase fuel efficiency, and reduce the size and weight of cooling systems. Applications such as the use of stearic acid in diesel engines and the integration of graphite to enhance thermal conductivity showcase the benefits of these materials.

However, the implementation of PCMs can also pose various challenges such as low thermal conductivity, potential for liquid leakage, phase separation, high costs and cooling problems. Despite this, the future appears to be promising for this product. Ongoing development along with the rapid advancement of material sciences will be important to overcome the obstacles. Embracing new technologies in PCMs will be vital in meeting the growing demand for performance and stability in vehicles, integrating such innovations while also improving potential flaws is essential and of the utmost importance.

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