

## **Thermal Property Optimization and Engineering Applications of Novel Phase Change Energy Storage Materials**

With the increasing global demand for efficient and sustainable energy solutions, phase change materials (PCMs) have gained significant attention due to their ability to store and release large amounts of thermal energy during phase transitions. PCMs play a crucial role in thermal energy storage (TES) systems, improving energy efficiency in industrial, residential, and renewable energy applications. However, conventional PCMs face several challenges, including low thermal conductivity, phase separation, subcooling, and long-term stability issues, limiting their widespread adoption in practical applications.

To overcome these limitations, researchers are actively developing novel PCMs with enhanced thermal properties and optimized performance. Various approaches, such as incorporating high-conductivity nanoparticles, utilizing composite PCMs, and designing microencapsulated structures, have been explored to improve heat transfer efficiency and durability. Furthermore, the integration of smart materials and advanced encapsulation techniques has enabled better thermal management and control over phase transition behaviors.

The engineering applications of these optimized PCMs extend across multiple sectors, including building energy management, electronic cooling, solar thermal energy storage, and industrial waste heat recovery. In smart buildings, PCMs integrated into walls and ceilings help regulate indoor temperatures, reducing reliance on active heating and cooling systems. In electronics, advanced PCMs provide efficient thermal management solutions for high-power devices, ensuring operational stability and longevity. Moreover, in renewable energy systems, PCMs enhance the efficiency of concentrated solar power (CSP) plants and hybrid energy storage systems, contributing to the transition toward sustainable energy solutions.

This paper explores recent advancements in the thermal property optimization of novel PCMs and their engineering applications. Key factors influencing PCM performance, such as thermal conductivity enhancement, phase stability, and encapsulation techniques, will be analyzed. Additionally, case studies demonstrating successful industrial implementations will be discussed, highlighting the potential of these materials in energy-efficient systems. Understanding the latest developments in

PCM technology is essential for addressing energy challenges and achieving long-term sustainability goals.