A Review on Nano-PCM based Thermal Energy Storage for Various Applications

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Abstract

Heat storage applications benefit greatly from phase change materials' (PCMs) high energy storage density at a practically constant temperature. The melting points of various materials vary, thus they have lately attracted a lot of interest for use in heating and cooling buildings and providing clean hot water. This study begins with a comprehensive explanation of phase transition materials, including how they function, the many forms they may take, and their defining characteristics. Recent computational and experimental studies have shown that nanoparticles are extremely helpful for enhancing the thermo-physical properties of PCMs, allowing Nano-PCMs, primarily Nano-paraffin, to have a significant positive influence on thermal concepts at the economic, ecological, and effectiveness levels.

Keyword: Thermal systems enhancement; Nano-enhanced PCMs; Nano-enhanced PCMs applications; latent heat; thermal management

I. Introduction

Since thermodynamics works extensively and continuously with rules to optimize thermal systems and collect as much energy as possible, heat transfer has long been considered one of the most essential things that humans depend on to survive. In addition, the current evolution makes it especially important to make greater efforts and implement novel techniques for energy enhancement and savings; otherwise, extreme energy losses will occur, making this field one of the most influential on the global economy and the environment. [1]

Controlling thermal energy ensures a healthy and prosperous living, and this is receiving a lot of attention since heat is one of the most chaotic kinds of energy while also being our primary requirement and comfort sensor. As a result, researchers all around the globe are working to find better ways to insulate buildings and incorporate renewable energy into thermal systems. [2].

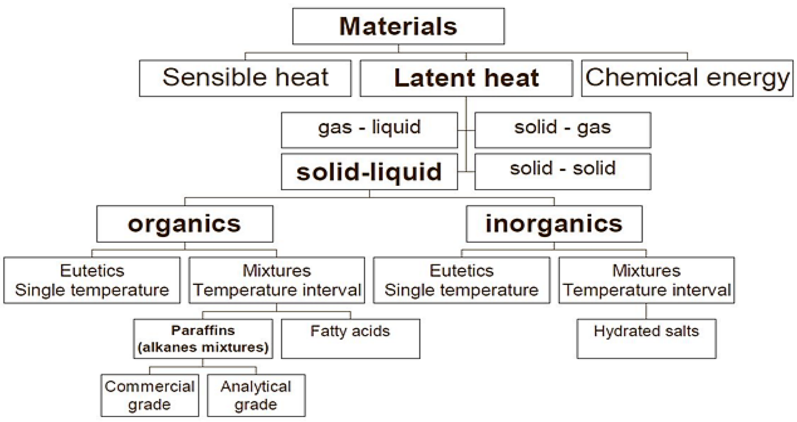

Figure 1: Classification of PCM

A "phase change material" (PCM) is the substance having a high heat of fusion that may store and release huge quantities of energy by melting and solidifying at a particular temperature. Since PCMs absorb or release heat during their phase transitions, they are considered "latent heat storage" (LHS) devices. [3]

When compared to more traditional methods of the thermal energy storage that rely on water, PCM has three key benefits:

a) The ability of water to store thermal energy is greater than its capacity to store sensible energy. Because of this, less space for storage is necessary. Only if only minimally beneficial temperature changes can be established is there any real benefit.

b) Charging and discharging at same temperatures.

c) Emissions of carbon monoxide and hydrocarbons from the backup power unit's burners may be decreased.

The four major drawbacks of PCM as compared to more traditional methods of water storage are:

a) More expensive investments

b) The solid form of PCM has poor heat conduction, limiting the maximum power that may be generated during discharge. This is the primary limiting factor for the maximum size of the storage modules.

c) There is a lack of expertise with thousands of the charge-discharge cycles over a lengthy period of time.

d) Possible solution instability and encapsulation material degradation.

A. Nano-PCM Applications

Increasing the efficiency of thermal systems using nano-enhanced phase change materials has been shown to have many benefits, including cost savings, improved efficiency, and reduced environmental impact, according to recent studies.

Thermal Management: Numerical and experimental research into novel uses of nano-PCMs in the built environment is being conducted with the goal of striking a balance between thermal comfort and energy consumption. The incorporation of nano-PCMs into PV panels significantly improved the system's electrical output by lowering its operating temperature.

Thermal Storage: In the thermal transmission industry, thermal storage systems that can accommodate latent heat are widely dispersed, and incorporating nano-PCMs into these systems may provide significant benefits. Use of nano-enhanced phase change materials (PCMs) in thermal storage systems has been the subject of a number of studies, with a focus on the potential benefits of storing sun renewable energy. By providing economic benefits, environmental support, and high-quality energy, freely-available, clean thermal energy that can be absorbed and stored by nano-enhanced PCMs and released via phase transition when required may totally revolutionize thermal industrial systems.

II. Literature Review

(Ali et al., 2022) [4] Check to see whether the TES employs a mixture of hot and cold "heat transfer fluids" (HTFs) for downward-inner heating and upward-outer cooling. Results reveal that in SCD mode with a constant load, the liquid percentage (20%) does not change over time, indicating that equilibrium between melting & solidification (charging & discharging) has been achieved. To bridge the gap between reactor provided energy & grid power demand while keeping the reactor running at the "full rated capacity" under the changing load, the proposed TES system may track daily variations in grid demand. As predicted, the proportion of PCM that is liquid changes from solid to liquid and back again as the load varies and as the grid deviates.

According to (Alvi et al., 2021) [5] As the working fluid's critical temperature rises or falls, the system's efficiency goes up or down, respectively. The maximum system efficiencies for Benzene have been obtained at the evaporation temperature 10 °C higher and lower than a "melting point temperature" of the "phase change material", during charging & discharging, respectively. Heptane achieves the highest values for the increase and decrease in the phase change material temperature, working fluid temperature, and the amount of energy stored & released during the charging and the discharging mode ("5.35 °C and 7.34 °C, 0.48 °C and 0.44 °C, and 13.81 MJ and 23.04 MJ", respectively). In the "phase change material storage based direct" vapour production solar ORC system, heptane was shown to have the greatest general performance among the chosen working fluids.

(BABA et al., 2021) [6] Evaluate VO_2's temperature-leveling ability when linked to a heat source to see whether or not it might be used as a passive heat sink. The paraffin also undergoes same test so that we may compare the two.

The testing findings reveal that VO2 outperforms paraffin in terms of maintaining a constant temperature. Numerical simulations are also used to assess the impact of the PCM's various thermophysical properties on its temperature-balancing abilities. Results from the simulation show that VO2 is an effective PCM for the passive heat sink.

(Das et al., 2021) [7] This research synthesises several methods and examines the selection procedures from multiple perspectives. Using Ashby's method, characteristics (or qualities of the PCMs) are evaluated objectively using MODM. In addition to entropy-based weights, we also use "Analytic Hierarchy Process" (AHP) and Technique for Ordering Preference by "Similarity to Ideal Solution"(TOPSIS). Gallium and some of the other PCMs are proposed as good options by selection algorithms. In cases where test set of the PCMs might be restricted in the first step to save time and money in the second stage of analysis, this research could serve as a prelude to experimental and "computational fluid dynamics" (CFD)-based studies.

(Forner-Escrig et al., 2021) [8] explores the maximum Rankine's equivalent stress and energy density capability of tin and aluminium nanoPCMs using a probabilistic numerical tool that combines the "Monte Carlo techniques" and the "finite element thermomechanical model" with the phase change. The maximum Rankine's stress is then determined by performing uncertainty and sensitivity calculations, which reveal that "melting temperature and thermal expansion" of core are the most influential physical characteristics. Finally, the impact of the deterministic and the probabilistic failure criteria on the anticipated failure rate is analysed, with a focus on cases when there is also dispersion in tensile strength data. Tin nanoPCMs have a low probability of mechanical failure (1.87%), but aluminium nanoPCMs are very unlikely to survive.

According to (Karimi et al., 2021) [9] It is suggested to employ a hybrid TMS (HTMS) consisting of the "phase change materials" (PCM) and 6 flat heat pipes to keep the temperature profile below 40 °C while operating at the high current rate of 150 A for 1400 s profile without any break. The temperature changes in the tests are tracked by means of "two K-type thermocouples" (T1 and T2). The temperature profile is also analysed mathematically and compared with experimental data. Since the HTMS lowers the "T1 temperature" by 35% compared to "natural convection case study", the findings show that it is an unusually powerful cooling system. The heat pipe TMS may reduce T1 temperature by 15% compared to a same case study.

According to (Lau et al., 2021) [10] To maintain a temperature profile below 40 °C while running at the "high current rate of 150 A for 1400 s profile" without any interruption, it is recommended to use a "hybrid TMS" (HTMS) composed of the "phase change materials" (PCM) and six flat heat pipes. "Two K-type thermocouples" (T1 and T2) are used to monitor the temperatures during the testing. Mathematical analysis and comparison with experimental data are also performed on temperature profile. Since the "T1 temperature" is reduced by 35% with the HTMS compared to the "natural convection case study," it can be concluded that this is an exceptionally efficient cooling system. T1 may be kept 15% cooler using "heat pipe TMS" compared to the identical case study.

(Madruga & Mendoza, 2021) [11] found that larger metallic nanoparticles facilitate more vigorous convective flows because their Prandtl numbers and Marangoni numbers decline more slowly at greater concentrations. In addition to improving the heat transmission efficiency of most nanoparticle arrangements relative to the basic PCM, the lengthy free surfaces of the "high aspect ratio" geometries significantly lower thermal energy needed to completely melt the PCM. We also discover that the rate of progress of the melting front at the free surface is described by a power-law to whose exponent increases as Prandtl's number does.

III. CONCLUSION

In order to improve the heat transmission in phase change material during melting and solidification, this paper has undertaken a thorough literature analysis on different heat transfer enhancement approaches employed in latent heat storage phase change material. This research provided an in-depth analysis of how using nano-enhanced phase transition materials might greatly improve the efficiency of thermal systems.

Since the incorporation of nano-enhanced PCMs leads in quicker melting/solidification rates, the phase transition may occur in much less time than in systems with pure PCM, these materials are seen as attractive candidates for thermal systems.

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