STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 11, Special Issue 4, 2023
DOI (Journal): 10.37591/JoPC

http://engineeringjournals.stmjournals.in/index.php/JoPC/index

Research JoPC

Nano-enhanced Bio-based Phase Change Materials: A Brief Review

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Abstract

The high latent temperatures and variable melting points of bio-based phase change materials make them ideal for thermal control. This covers heat regulation for medical and pharmaceutical items, building comfort, and high-end electronics and automobiles. In recent years, research and application of energy-saving materials and technologies in buildings has increased strength. Modern construction technology aims to keep old and new structures energy efficient. TES employing PCMs is an energy-efficient approach. The use of bio-based PCMs in structures is achieving scientific and technical emphasis. Functional bio-PCMs improve building energy efficiency. Hydrogenated palm kernel fat, bio-phase change material (PCM). This bio-based PCM melted at 27.38°C and had 80.52 J/g LHC. To catch PCM without leaks in a prepared matrix and use the composite-PCM for passive TES in building envelopes. This eco-friendly matrix is inexpensive. Clay and cellulose dominated PCMs. TGA demonstrated that the composite-PCM is thermally reliable. Graphite improved heat conductivity in Hot-Disk tests. FTIR confirmed chemical stability. SEM showed that impregnated matrix microstructure preserved bio-based PCM. Sustainability needs resource and energy efficiency. A Method for manufacturing of bio based PCM with Enhanced Nanoparticles Low heat conductivity means PCM hasn't been widely used. The two-step strategy is the most effective way to get ready for the NEBBPCM. In the first step of the two-step process, chemical or physical processes are used to make nanoparticles, nanofibers, and nanotubes.

Keywords: PCMs, High Latent Temperatures, TES, Bio-Based PCMs, first step of the two-step process, conductivity, sustainability

INTRODUCTION

To create a more sustainable future, it is essential to advance the development of bio-based materials for energy applications. The energy supply chain of the future will incorporate a wide variety of renewable energy sources as well as engineering and material methods to energy storage and conservation. Given that phase change materials (PCM) derive their latent heat from the exchange of thermal energy between phases, it is valuable because it may be used in a variety of applications and can be integrated with other materials and manufacturing approaches. Most PCMs on the market today are derived from non-biodegradable inorganic materials like salt hydrates and eutectics, or from petroleum-derived organic compounds like paraffins. The lack of commercial use of bio-derived organic PCMs like fatty acids and fatty acid methyl esters might have disastrous effects in structural applications where PCMs are commonly used due to their severe corrosiveness (of metals) and solvent-like behaviour for polymers. Low-cost, non-corrosive, hydrolysis- and oxidation-resistant organic PCM materials are needed. Ideally, these would be bio-derived. This postdoctoral research aims to develop new bio-based PCMs from sustainable sources such as oils

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Received Date: December 12, 2022
Accepted Date: May 19, 2023
Published Date: June 15, 2023

Citation: Aman Sharma. Nano-enhanced Bio-based Phase Change Materials: A Brief Review. Journal of Polymer & Composites. 2023; 11(Special Issue 4): S515–S27.

and sugar alcohols for use in a variety of commercial applications (at temperatures ranging from -20 degrees Celsius to 65 degrees Celsius).

For building and construction applications, the use of bio-based materials derived from sources that can be replenished is now required. In the construction business, wood is one of the most often used renewable materials due to its abundance and ease of use. Wood and other materials based on wood have risen in popularity over the past decade as a viable option for building both single- and multi-story structures due to their high strength to density ratio [1–3]. Despite being very dense and having a low specific heat capacity, wood is unable to manage temperature changes or absorb substantial amounts of energy [4]. Incorporating bio-based phase changing materials (BPCMs) into wood cells is one possible solution to this issue with wood and wood-based products in the building and construction industry. As a result, a smart bio material that may be employed for energy management and storage in buildings would be created [5]. All substances, organic or inorganic, that can melt and solidify at different temperatures and store and release energy are considered phase-change materials. Because of this capacity, the statement has a specific meaning (heat). So-called "latent heat storage" (LHS) materials are those that undergo phase transitions. PCMs have been around for at least a few hundred years, and have been used for centuries in various applications for heat accumulation and cooling. A novel approach to building insulation and heat storage is possible given the wide temperature range provided by the variety of PCM now commercially available. PCMs that come from natural sources are known as BPCMs. Because there is no one material that possesses the optimal qualities for thermal storage, an acceptable PCM system design may involve the mixing of multiple substances. These may include eutectic solutions of water and salt, mixtures of two or more fatty acids, or combinations of PCM and metals. Extensive research has been conducted on PCM's classification, as well as its advantages and limitations [6–7].

In order to effectively combat global warming, we must increasingly rely on renewable energy sources like solar and wind. However, renewable sources of energy are inconsistent. It's not always breezy, and the moon doesn't always shine. Natural variations can affect renewable energy sources, which adds to the mismatch between supply and demand. Energy storage that is both affordable and large-scale, able to store excess energy during off-peak times and provide it at peak times, is needed for renewable energy. PCMs store renewable thermal energy effectively [8–9]. During phase changes, PCMs can both store and release heat. PCMs are used for thermal management of batteries, microelectronics, greenhouses, Uses for photovoltaics/thermal energy, thermal energy storage (in space and on Earth), thermionic fibres, and intelligent textiles. There are three types of PCMs (organic, inorganic, and eutectic) that can be used to store energy. Several factors, including melting point, latent heat, thermal conductivity, toxicity, flammability, cost, and availability, are considered. How quickly a PCM absorbs and releases thermal energy, and hence its efficiency, depends on the predicted thermal conductivity [10–11]. A primary design consideration for PCM storage is thermal conductivity. Increased heat transmission can be achieved through the use of fins, high thermal conductivity materials, or micro or macro encapsulation.

LITERATURE REVIEW

Kylili et. al [12] and A. Pasupathy et. al [13] and K. El Omari [14] Over the past few years, PCMs have risen in popularity as a means of storing latent heat thermal energy in buildings. The purpose of these programmes is to increase the thermal inertia of construction materials and so make people's homes more habitable by lowering temp changes. The use of PCMs in passive LHTES systems for walls, ceilings, and floors is an efficient method of lowering the peak demand for energy in buildings.

J. Kosny et al and E. Kossecka, et al. [15] and P. Shafigh, et al. [16] There are also some PCMs that are used to improve construction materials that can be used for further structural purposes in structures, such as PCM-impregnated concrete or PCM-gypsum Heat and air conditioning systems can limit their usage due to their great capacity to store heat and isothermal behavior during phase transitions.

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

L.F. Cabeza, et. al. [17], C. Liu, Y et al. [18]. Because of this, building owners, architects, and engineers have shown a great deal of interest in these materials. S.M. Hasnain [19]. Eutectics (PCM) are a subcategory that includes both organic and inorganic PCMs.

S.E. Kalnaes [20], A. Sharma, [21], Y. Sang, [22] When it comes to PCMs with desired qualities for LHTES, fatty acids are among the most popular organic PCMs in use. From animal fat, the raw materials for fatty acids can be extracted. Y. Yuan, N [23] Soybean, coconut, and palm oils, are examples of vegetable fats.

N. Zhang [24], D. Rozanna [25] as well as palm kernel oils Fatty acids and their derivatives have the extra benefit of being abundant and environmentally benign materials that can be reused indefinitely [26]. Because fatty acids are superior PCMs, they're a plus.' Their matrices' surface tension of 2-3 × 10^{-4} N/cm is sufficient for the liquid surface tension to maintain them in place [27]. In addition to this, these PCMs are capable of storing thirty times as much usable energy than other conventional building materials, such as rocks, even when compared to the same mass [28–29]. Despite the fact that paraffin and salt are the conventional PCMs utilized for LHTES applications in buildings, these characteristics make them a desirable alternative.

Organic, inorganic, and hybrid micro/nano PCMs are the most prevalent for solar thermal applications, as shown in Figure 1. However, inorganic PCMs are also commonly used in a variety of industries due to their low volume change and cost. Researchers are now investigating organic-inorganic composite PCMs due to the inherent limitations of both organic and inorganic PCMs.

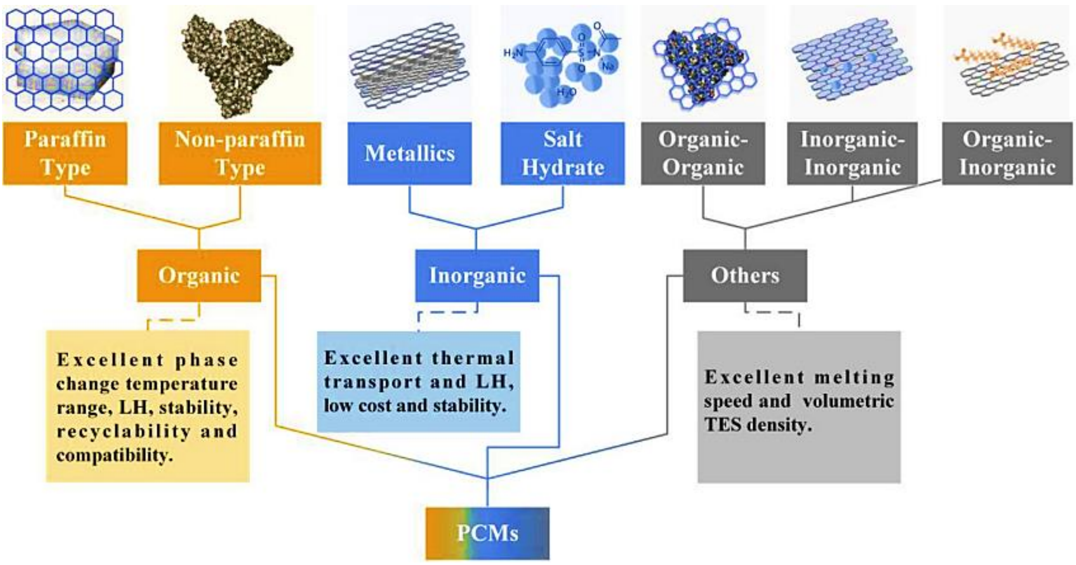

Figure 1. In solar thermal applications, typical micro- and nano-scale phase change materials [30].

Analysis of fatty acids and their binary combinations' thermal characteristics has been conducted. According to the study, they're promising for storing latent heat for space heating. Fatty acids have a wide range of melting points (40 to 80°C) and latent heats of transition (40 to 80°C). The proper functioning of a latent heat thermal energy storage system depends on these qualities. The temperature range, solid-liquid interface propagation, and heat flow rate of the used circular tube storage system were among the factors studied parametrically during the phase shift transition. Cold storage mixtures of capric and lauric fatty acids have been tested. The mixture has a melting point of 14°C and a latent heat of melting of 113–133 kJ/kg, depending on the exact constituents. They were only used for testing, and they won't likely be applied in the actual world. The additional water principle has been proposed as a means of preventing anhydrous salt production. This limits storage density and demands a wide temperature range for effective functioning. Glauber salt solutions can be made less prone to phase segregation by adding a thickening agent, such as Bentonite clay. The slower crystallization rates and less heat transmission to the salt are the results of the mixture's lower thermal conductivity. However, this necessitated the use of a thickening agent to keep the borax from settling. The same issues apply to most other hydrated salts. Table 1 shows Various Literature Review for Bio-Based Phase Change Materials.

Table 1. Various Literature Review for Bio-Based Phase Change Materials

Author	Description of work	Discussion
Nazari, Meysam, et.al, (2020) [31]	Review of Eco-friendly buildings can benefit from an increase in thermal mass by using bio-based polymer composite materials (BPCMs) made from wood and wood-based goods. The challenges associated with using BPCMs, bio-based matrices, phase change processes, and combinations thereof are outlined and analyzed in the paper.	Both BPCMs and wood-based matrices are renewable and sustainable, therefore combining them can result in entirely bio-based materials for energy management.
Saffari et al. (2019) [32]	study numerically examined the potential for cooling energy savings by combining PCM with passive natural ventilation technology in a moderate-climate workplace.	The results showed that cooling energy savings might be anywhere from 8% to 15%. In addition, PCM's efficiency was boosted by 8% thanks to natural ventilation's positive effect on the system's performance.
Djamai et al. (2021) [33]	As a hybrid latent system for heat storage, a PCM-infused water tank was studied for its potential to improve the energy density of a standard sensible water tank.	The results showed that a water storage tank's heat-retaining capacity was increased by 70% when PCM was added at a rate of merely 15%.
Al-Yasiri et al. (2021) [34]	Buildings' cooling and heating systems, as well as the costs associated with them, can be greatly enhanced by research into the effects of passive and active PCM approaches.	Based on the findings, it was determined that implementing any kind of PCM into the buildings might increase energy savings by up to 44.16 percent. Finally, it was determined that PCMs improve building efficiency by reducing heating and cooling demands and advocating for renewable energy sources.
Stritih, U et al., (2018) [35]	The effect of phase change materials (PCMs) on the thermal and mechanical performances of textile-reinforced concrete is investigated in this work (TRCs). In order to determine how effective the novel PCM-TRC model is, it was subjected to thermal and mechanical analysis.	The results reveal that a PCM-TRC slab with a thickness of 4.5 cm can reduce peak temperatures by 4 C while saving 37% of energy compared to TRC.
Sheikh, Yahya, et al. (2022) [36]	A variety of additives and surfactants are examined for their potential to alter the thermal parameters of phase transition materials, leading to improved cooling qualities and chemical stability. Here, graphene nanoplatelets of varying concentrations are used as a heat sink for an electric heating source by being integrated with surfactant-induced Pure Temp phase change material.	To measure cooling qualities, scientists have relied on indices such thermal conductivity, thermal energy capacity over a wide temperature range, phase change enthalpy, and time to reach the reference temperature.
Li, Dehong, et al (2022) [37]	draws some key findings from the existing literature, and raises certain difficulties that need future research by reviewing the incorporation technology of BPCMs in detail.	More warming and less energy can be expected as a result. To address this issue, scientists have created phase change materials (PCMs). Superior PCMs can close the gap between supply and demand by storing energy until it is needed.

METHODOLOGY

Types of Phase Change Materials

Many different phase transition materials exist, but generally speaking, they fall into one of three categories: eutectic, salt hydrates, and metallic alloys are inorganic, inorganic, and organic, respectivelyLatent heat can be stored in phase changes.**,** solid→gas solid→liquid, liquid→gas, liquid→solid.

Thermal Characteristics' Stability Over Continuous Cycling

With repeated storage cycles, PCMs may deteriorate. A PCM's thermo-physical characteristics should not degrade over time. ц After numerous thermal cycles, it retains its latent heat and melting point. If a PCM's melting point and latent heat of fusion remain constant after being subjected to multiple thermal cycles, then it is thermally stable for latent heat storage. Commercial-grade PCMs are favoured for latent heat storage systems because of their low price and wide availability. However, commercial-grade materials' thermo-physical characteristics and behaviour deviate significantly from those described in the literature for laboratory-grade materials (greater than 99% purity). Since their covalent bonds break down at higher temperatures, organic PCMs are typically unstable. Organic PCM typically has a density of less than 103 kg/m^3 [10]. The latent heat of fusion per unit volume of organic materials is thus lower than that of inorganic materials.

Heat Transfer Enhancement Methods

Improving the efficiency of heat exchangers is what's meant by "heat transfer enhancement." Either increasing the device's heat transfer power or decreasing the pressure losses it generates will accomplish this. Active and passive strategies are used to improve heat transmission in a single phase. Enhancement by active techniques like electrohydrodynamic (EHD), magnetohydrodynamic (MHD), or mechanical motion necessitates the use of an additional power source.

Encapsulation of Phase Change Materials

Protection of phase-change components through encapsulation. The PCM (which is the central component of the encapsulated PCM) is covered with a coating or shell material during the encapsulation process. According to [30], this method was developed by Barrett K. Green in the 1940s and 1950s.

Selection Criteria for PCM

As shown in Figure 2, the physical properties, chemical properties, thermal properties, and economic considerations of PCMs all play a role in the selection of PCMs for certain applications and Figure 3 shows the ideal characteristics of bio based phase change material [38].

OBJECTIVES

- Bio-based PCMs are manufactured from vegetable oils and animal fats. Organic PCMs are less flammable than paraffin. The room-temperature operation, inherent safety, and switchable thermal conductivities are all made possible by bio-based PCMs. This enables for a unique system architecture that dehydrates the PCM at ambient temperature and hydrates it at evaporator temperature. Thus, the PCM's thermal conductivity switching ratio and energy storage density can be increased because it can be stored at room temperature, in contrast to traditional PCMs, which must be kept below their freezing point.
- Bio-based PCMs must be manufactured on a megagram scale and at a price point that makes the construction of heat exchangers viable. Bio-based PCMs are made in laboratory-scale batches for academic study. To enhance scale, we're improving the PCM architecture, microbial production strain, feedstock, growing conditions, and purification parameters to boost volumetric yield and reduce production costs while retaining purity. This effort will produce PCM for later prototype construction and a manufacturing roadmap for pilot and commercial scale-up.
- PCM's revolutionary operation will result in unique thermodynamic and techno-economic analysis outcomes. During study and experimentation, we'll use thermodynamic analyses to rate system concepts. Thermodynamics relate material and system attributes (such as specific heat, glass transition temperatures, conductivity, and heat exchanger). New hydration-bio PCM improves heat storage. The PCM would require less insulation and could be easily integrated into a building's evaporator air handler, reducing expenses.

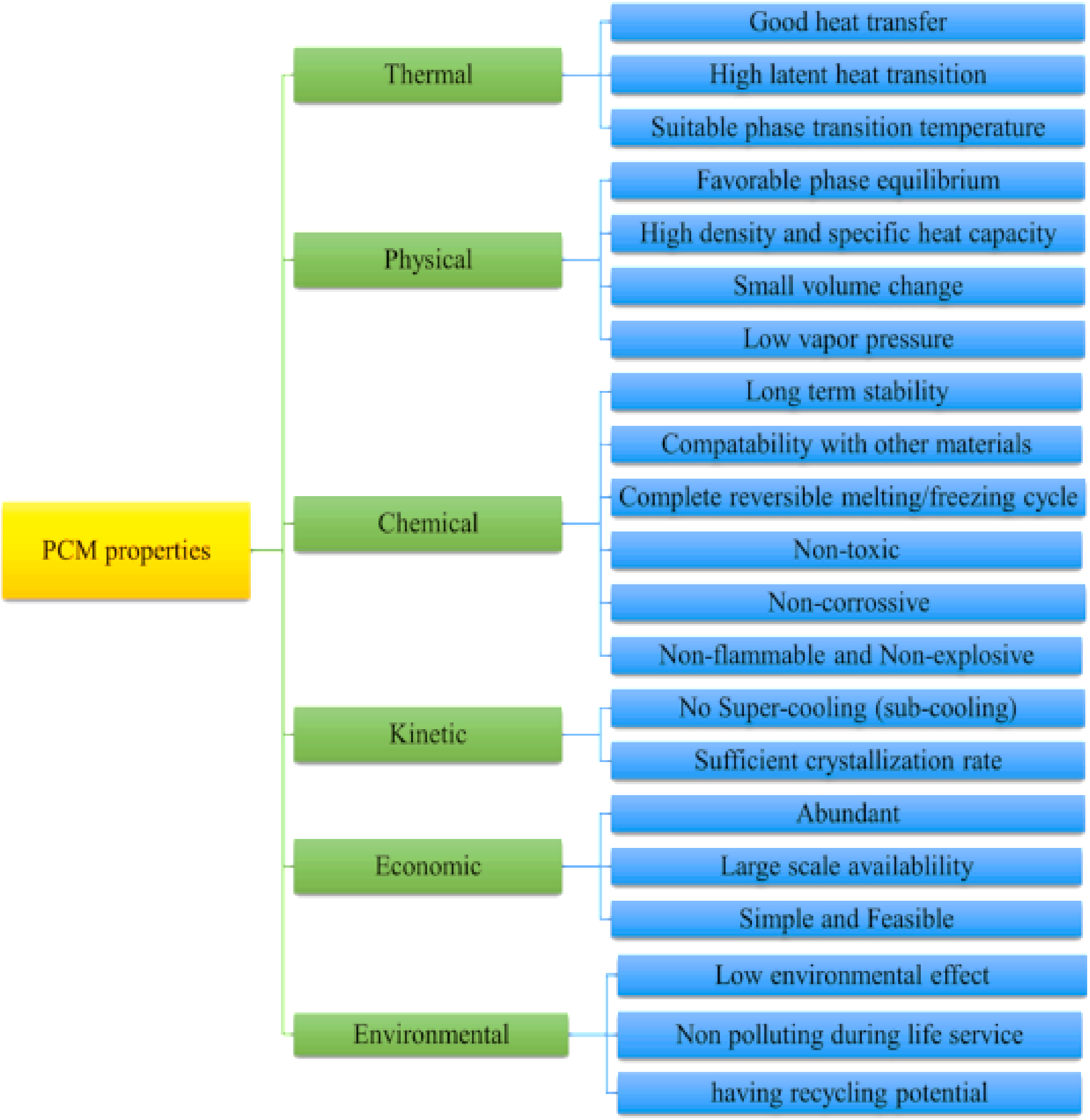

Figure 2. Selection criteria for PCM, and PCM Properties.

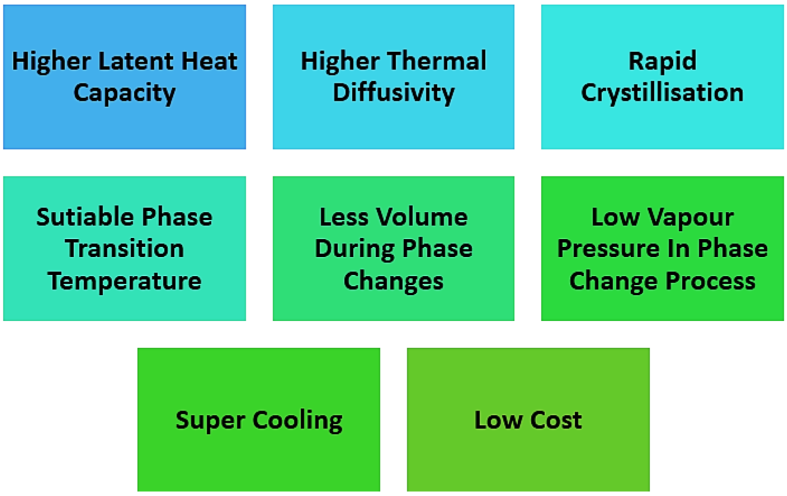

Figure 3. Ideal Characteristics of Bio-based PCM.

Journal of Polymer & Composites
Volume 11, Special Issue 4
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

MANUFACTURING A BIO-BASED PHASE-CHANGE MATERIAL WITH NANOMATERIALS

A Method for manufacturing of bio-based PCM with Enhanced Nanoparticles Low heat conductivity means PCM hasn't been widely used. So, the answer to enhancing performance is to incorporate higher conductivity elements into the PCM's dispersion. Studies have shown that increasing the PCM's nanoparticle dispersion leads to improved heat transfer and conductivity. Nanoparticle-enhanced PCM describes the process of incorporating nanoparticles into the PCM (NEBBPCM). Various approaches to NEBBPCM cooking are explored here. Figure 4 (a, b) illustrates some of the techniques used to develop the NEBBPCM. Traditionally, NEBBPCM was made using either a one-step or a two-step process. In a single-step process, both the creation and distribution of nanoparticles take place at the same time. The most common approach to making NEBBPCM is heat evaporation.

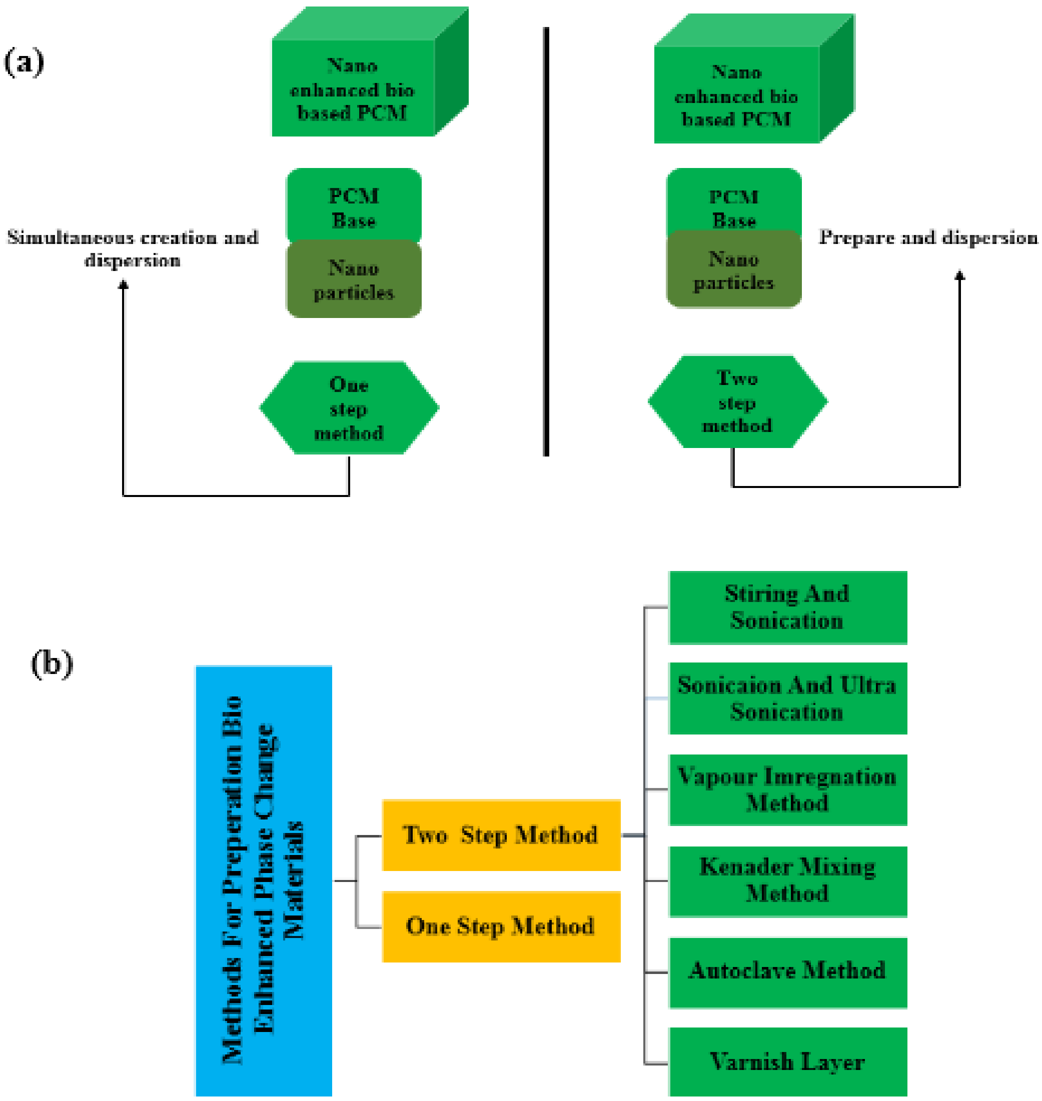

Figure 4. Methods for Preparation Bio Enhanced Phase Change Materials.

The two-step process is the recommended approach for NEBBPCM preparation. Nanoparticles, nanofibers, and nanotubes are created through chemical or physical processes in the first step of the two-step approach. Next, high-shear mixing and homogenizing are used to combine the liquid PCM and nanoparticles. It's cheaper and easier to make a lot of nanoparticles using this method [39]. The vast majority of scientists have used the two-step strategy to design effective NEBBPCM.

Stirring and Sonication Method

A magnetic stirrer is used to vigorously mix the liquid PCM for roughly 1 hour after a specific number of nanoparticles have been added. Once everything has been mixed together, it is sonicated continuously at a frequency of 45–65 Hz for around 30 minutes before being cooled. The temperature obtained during sonication is lower than the PCM melting point. The stirring and sonification process (shown in Figure 5) is illustrated in detail in [40–41].

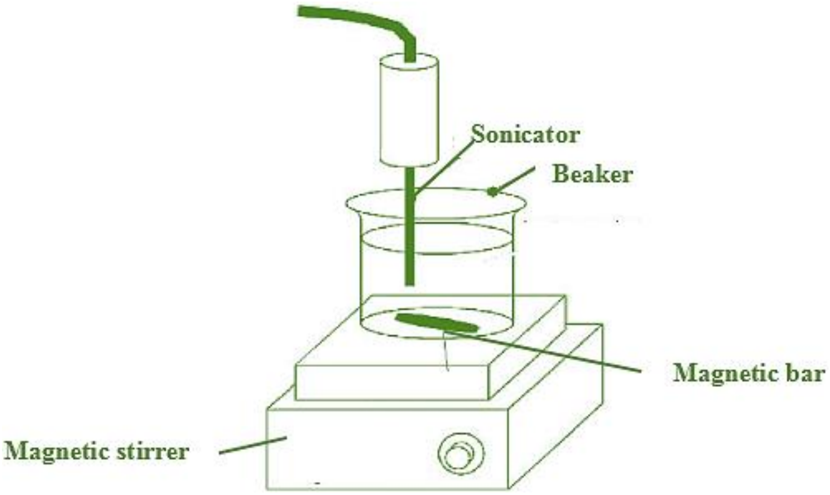

Figure 5. Stirring and Sonification Process.

Ultrasonication and Sonication

After a predetermined quantity of nanoparticles has been introduced to the PCM in liquid form, it is sonicated continuously at a frequency of 45–60 Hz for approximately 30 minutes. For 2 hours, the NEPCM is placed in an ultrasonic bath to ensure that all of the nanoparticles have been incorporated into the PCM Figure 6. The ultrasonication process necessitates a bath temperature over PCM's melting point [42–43].

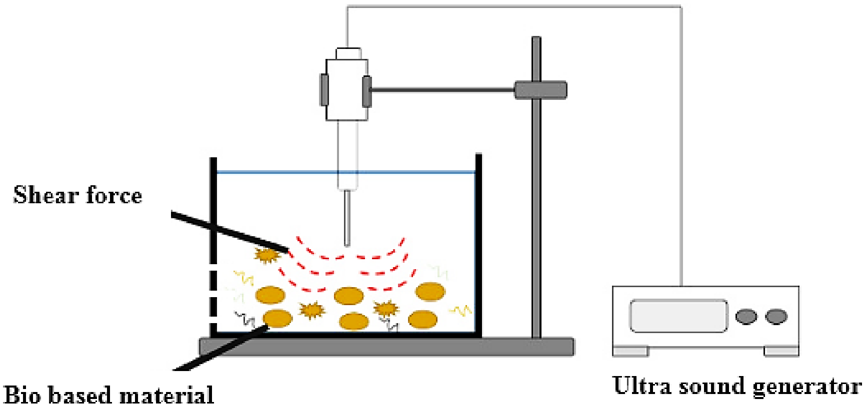

Figure 6. Sonication and ultrasonication method.

Thermal Conductivity

A material's thermal conductivity is its capacity to conduct heat. The material is better for storing heat if it conducts it quickly. Organic and inorganic PCMs are used in TES. Due to their poor thermal conductivity, however, PCMs have been fortified with high-conductivity nanoparticles. Manufacturing microscopic particles has become possible thanks to the development of nanotechnology. Metals, metal oxides, CNTs (multi-walled and single-walled carbon nanotubes), graphene, graphite, etc. are just some examples of the nanoparticles that are utilised regularly Figure 7 displays the numerous factors influencing the NEPCM's thermal conductivity.

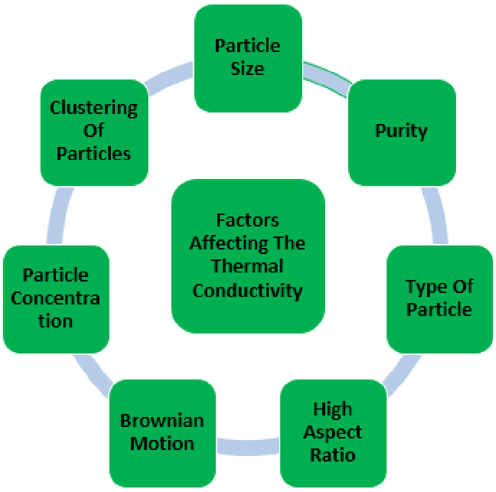

Figure 7. Factors Affecting the Thermal Conductivity

Numerical Simulation Process for Nano-enhanced Bio-based Phase Change Material

Nano-enhanced PCM becomes a nanofluid once melted. When it comes to buoyancy-driven laminar flow, liquid nano PCM is distinct from nanofluid, which can experience both [44]. As its temperature fluctuates, NEPCM exhibits various rheological and thermal behaviours, making it useful in both solid and mushy states. In the single- and two-phase physical model of liquid NEPCM, nanoparticle size in the base PCM is considered. Single-phase models come in two varieties: those that account for thermal dispersion. When nanoparticles are evenly distributed throughout a fluid, this is called homogeneous dispersion. The nanoparticles fluidized by preventing sliding between the base fluid and nanoparticles while preserving thermal equilibrium [38]. In contrast to dynamic techniques, the homogeneous method is a "static" model that is straightforward to grasp and computationally efficient. Effective thermophysical features of nanofluids are critical to simulation findings. Various thermal dispersion strategies have been developed to improve heat transfer in nanofluids. Thermal dispersion causes temperature and speed changes [45]. As a result of nanoparticle migration, thermal dispersion creates fully formed flow. Slip velocity of nanoparticles and fluid may not be zero with high particle concentration. Due to nanoparticle migration, concentrations and thermal properties won't be uniformly distributed across the flow zone. Using two phases, each with its own temperature and velocity, replicates the interaction between nanoparticles and the base fluid. The most prevalent models for two-phase mixtures are Eulerian and Eulerian-Lagrangian. Nanoparticle diffusion in PCM must be monitored and maintained using specialized methods. In NEPCM with a solid phase, Brownian motion is to be avoided, whereas in NEPCM with a mushy or liquid phase, the phases must be handled independently. It is also not shown that experimentally verified procedures are correct. Most of these models and the assumptions upon which they are based are single-phase techniques that make use of canonical phase change equations [27].

This phase-change material with nano-enhanced characteristics offers consistent, isotropic properties across the board. The nano-enhanced phase transition material is a Newtonian fluid that cannot be compressed. Having a low viscosity and a laminar flow, this nano-enhanced phase transition liquid is convenient to work with. Unlike many other thermophysical properties, NEPCM's buoyant density and thermal conductivity remain constant with temperature. Numerical simulation process for nano enhanced bio-based phase change material in Figure 8

SUSTAINABILITY OF BBPCM CONSIDERING ON VARIOUS ASPECTS

Performance

Safe to deal with, BBPCMs have great thermal and chemical stability, are non-corrosive, and have a high latent heat of fusion and melting temperature. Most PCMs are encapsulated and form stabilized. Recently, porous materials and fibers have been used to stabilize shape.

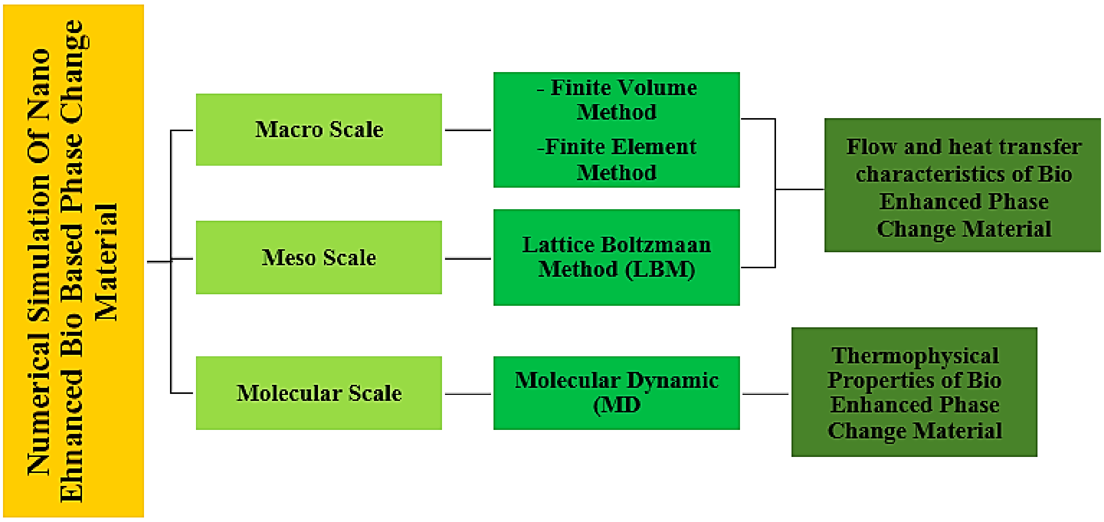

Figure 8. Numerical simulation process for nano-enhanced bio-based phase change material

Environmental

They dissolve and sub-cool, which affects their phase transition qualities and produces corrosion. Crystallizing and thickening chemicals prevent phase separation and subcooling in inorganic PCMs. These agents are still wanted by businesses. Buildings, spacecraft, and PPE can use PCM heat and cool storage.

Economic

This is cheaper than encapsulation, which reduces PCM thermal efficiency. BPCMs can have higher heat conductivity by employing carbon nanoparticles in a carbon and graphite scaffold.

Social Aspect

Wood and wood-based materials are renewable and sustainable construction materials, and by incorporating BPCMs into these materials, thermal mass in green buildings can be increased. Metal ores utilised in PCMs, such as manganese nitrate hexahydrate, are produced by the mining and quarrying industry. The PCMs that utilise hydrocarbons are made with the help of crude oil. Biobased PCM production can be understood by considering the social effects of current agriculture practices.

CONCLUSION

- Both organic and inorganic PCMs are widely used; inorganic PCMs offer the advantages of being non-corrosive, chemically inert, and exhibiting low or no subcooling, while organic PCMs are compatible with the vast majority of commonly used building materials. Organic per chlorofluoro alkyl substances (PCMs) have a low vapour pressure and a high latent heat per unit mass. Their drawbacks include poor heat conductivity, volatility in volume, and flammability.
- Inorganic materials are low-cost, non-combustible, and have a high thermal conductivity per unit volume. Nonetheless, they disintegrate and sub-cool, which impacts their phase transition properties and causes corrosion of most metals.
- Crystallizing and thickening agents are necessary for inorganic PCMs to avoid phase separation and subcooling. These agents are still being sought after by commercial organizations. Buildings, satellites, and personal protective equipment (PPE) can all benefit from PCM heat and cool storage. For passive solar applications, melting point is the most important consideration.
- The most promising OPCMs for use as PCMs include fatty acids, fatty acid derivatives, and eutectic blends. In terms of solar energy, they've been researched, but not for inside temperature control.

- BPCMs are safe to work with and have excellent thermal and chemical stability; they are also non-corrosive and have a high latent heat of fusion and adequate melting temperature.
- PCMs are most often incorporated by encapsulation and form stabilization. Shape stabilization utilizing porous materials and fibers has received recent interest. This approach is cheaper than encapsulation, which reduces PCM thermal performance.
- The low heat conductivity of BPCMs can be increased by using carbon nanoparticles enclosed in a carbon and graphite scaffold.

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