A REVIEW ON LIFE SCIENCE APPLICATIONS OF PHASE CHANGING MATERIAL

A DISSERTATION

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in

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Submitted by:

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CANDIDATE'S DECLARATION

I, (SONAM, 2k22/MSCCHE/40) students of M.Sc. (Applied Chemistry), herebydeclare that the project Dissertation titled "A Review on life science application of Phase Changing Materials" which is submitted by me to the Department of Applied Chemistry, Delhi Technological University, Delhi in partial fulfilment of the requirement for the awardof the degree of Master of Science, is original and not copied from any source withoutproper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "A Review on Life science application of Phase Changing Materials" which is submitted by [Sonam, 2k22/MSCCHE/40] student of M.Sc. (Applied Chemistry) Delhi Technological University, Delhi in partial fulfilmentof the requirement for the award of the degree of Master of Science, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diplomato this University or elsewhere.

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ABSTRACT

Phase Changing Material based thermal energy storage (TES) systems in life science has become a topic of conversation among the researchers in recent years. Phase change materials (PCMs) have emerged as promising solutions in various life science applications, offering efficient thermal energy storage and release capabilities. This review paper explores recent developments in PCM utilization across diverse areas within life sciences while addressing associated challenges and potential solutions. We delve into the applications of PCMs in thermal management for medical devices, drug delivery systems, food science, tissue engineering, and personalized medicine. However, despite their potential, recent research highlights several obstacles impeding PCM adoption in life science domains. Challenges include issues surrounding stability, biocompatibility, controlled release, scalability, system integration, and regulatory compliance. To surmount these obstacles, we propose strategies such as advancing encapsulation materials, optimizing manufacturing processes, conducting comprehensive biocompatibility assessments, employing responsive polymers for controlled release, and engaging proactively with regulatory bodies. Overcoming these hurdles could establish PCMs as indispensable tools, enhancing thermal management, drug delivery precision, and biomedical innovations, thereby advancing healthcare and biotechnology sectors.

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CHAPTER 1

INTRODUCTION

Thermal energy storage (TES) is a pivotal technological in modern energy system, addressing the need for efficient energy management and supporting the transition to renewable energy sources. By storing thermal energy for later use, TES helps bridge the gap between energy supply and demand, enhancing the stability and reliability of energy systems.

TES systems operate by capturing heat or cold and storing it for periods ranging from hours to months. This capability is essential for optimizing the use of intermittent renewable energy sources, such as solar and wind power, which do not always align with consumption patterns. TES can store excess energy generated during periods of low demand and release it during peak demand, thereby improving energy efficiency and reducing reliance on fossil fuels.

Sensible heat storage, latent heat storage , and thermochemical storage are the three main categories of thermal energy storage technologies. Each kind offers a range of advantages and applications by storing thermal energy using distinct materials and techniques. Latent heat storage stores energy during phase transitions using phase change materials (PCMs) , thermochemical storage stores and releases energy through reversible chemical processes , and sensible heat storage depends on increasing the temperature of a solid or liquid.

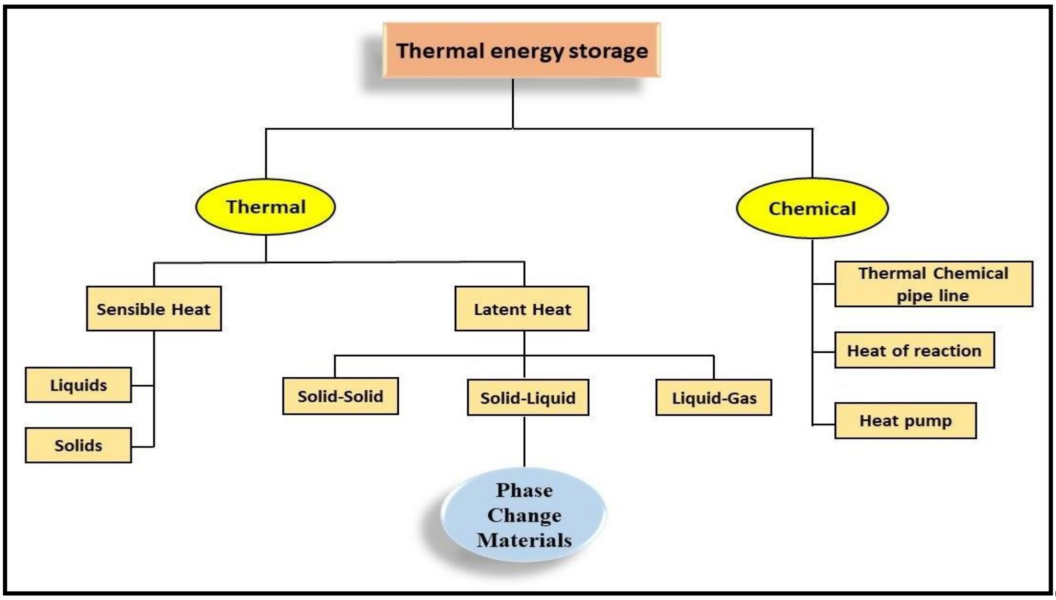
TES is utilized across multiple sectors, including residential and commercial buildings, industrial processes, and renewable energy systems. In buildings, TES can enhance heating, ventilation, and air conditioning (HVAC) efficiency, while in industrial settings, it captures and reuses waste heat. In renewable energy systems, TES plays an important role in stabilizing energy supply by storing excess energy for use during periods of low generation.

The development and deployment of TES technology face challenges such as material limitations, system integration complexities, and economic factors. However, ongoing research and innovation aim to address these issues, improving the efficiency, cost-effectiveness, and integration of TES systems.

In conclusion, thermal energy storage is a vital component of a sustainable energy future. By enabling more efficient energy use and supporting renewable energy integration, TES contributes to reducing greenhouse gas emissions and enhancing energy security. Continued advancements in TES technology will be essential for meeting the growing global energy demand in an environmentally sustainable manner.

1.1 CONCEPT OF THERMAL HEAT STORAGE

Thermal energy storage system, as the name suggests is used for storing/stocking energy. Under such system, energy is stored and it is used for later for heating and cooling purpose. TES systems are used for various purposes but their major role is seen in phase changing materials (PCMs) for energy storage and temperature regulation in buildings, industries and construction. Various advantages of TES include its highly reliable and efficient methods for energy storage. It is economic innature i.e., it reduces the cost of energy consumption for e.g., using PCMs, causes lesser pollution to the environment i.e., it does fewer greenhouse gas emission. Hence, TES not only decreases the difference between the demand and supply of energy/electricity thanks to its energy storage property but also improves the quality and performance of the system wherever inducted. The various types of thermal energy storage are shown below in Figure shown below.[1]



(1,2)

Figure 1: Classification of Thermal Energy storage.

As shown in the figure above, broadly TES can be classified into two types: First, where energy storage happens by thermal mechanism and second where energy storage happens by chemical mechanism. Thermochemical heat storage (TCM-TES) due to its costly nature and lesser lifespan are not considered widely**.** [3]Thermal is further sub divided into Sensible and Latent Heat. [2]

Sensible heat storage (SHS) is the easiest method of storing heat. It is done by heatingor cooling any liquid or solid storage medium e.g., water, rock, salt etc. It is the cheapest method of heat storage. Latent Heat Storage (LHS) are also known as Phase change material due to their change in state while absorbing and releasing heat. The heat is stored and released accompanying phase transition. The use of LHTES using PCM is an effective method of storing and re-distributing energy. The main advantage of Latent heat over Sensible heat is that LHS is capable of storing heat at a similar temperature range. In the initial phase LHS acts as SHS and its temperature increases linearly with time as shown in Figure 2 below later on heat is absorbed or released at a constant temperature. This temperature range is known as effective working range. LHTES are further sub-divided on the basis of their heat transfer mechanism in the later sections of the review.

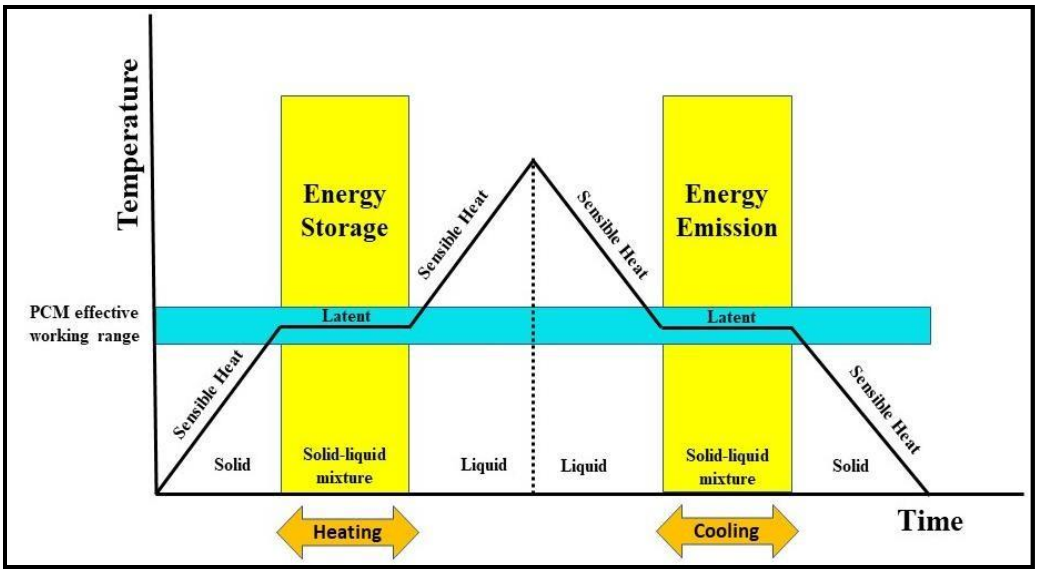


Figure 2: PCM phase transition.

1.2 OPERATING PRINCIPLE:

We know that all the materials interact with the environment but major portion of thematerials do not interact with the environment hence are not able to change their property according to the environment. But unlike these materials, PCM change theirproperties according to the environment temperature. The credit for first work in nano-PCM was done by Elgafy and Lafdi in 2005 Now the use of PCM and LHTES has become one of the most widely accepted techniques for thermal energy storage. Thanks to its various advantages like sustainability and lowering the energy consumption demand.

Phase change materials are that class of materials that have very high heat of fusion. Their melting and solidification happen at a particular temperature. They are even capable of storing and releasing energy. When the material changes its phase, heat energy is released or absorbed. A schematic showing the basic working principle of PCM is shown below in Fig 3.

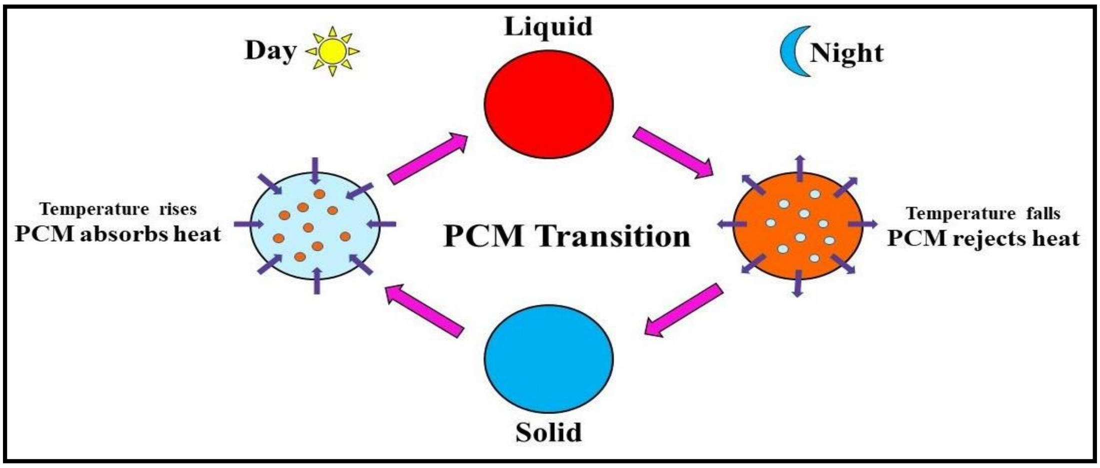


Figure 3: Working Principle of PCM.

When the temperature increases (generally during daytime) the PCM absorb and storethe energy due to which there is a change in the state from solid to liquid. Whereas, when the temperature decreases (generally during night) they release the previously absorbed energy causing change in sate from liquid to solid state. During the change in phase of the material i.e., during phase transition of solid to liquid, PCMs store theenergy in the form of latent heat that dissolves the chemical bonds. This process is endothermic in nature and therefore the phase change happens. Whereas, when coolingtakes place, exothermic reaction happens and solid state is recovered.

There are various types of phase transitions, including solid to liquid, solid to solid, and solid to gas. The phase transition from solid to gas involves a high enthalpy change and is associated with significant variations in volume and pressure. While the solid-to-solid phase transition is similar to the solid-to-liquid transition, it generally has a lower energy storage capacity. The solid-liquid phase transition is preferred for thermal energy storage due to its moderate volume change and relatively high energy storage capacity.

1.3 CLASSIFICATION OF PHASE CHANGING MATERIALS:

On the basis of chemical composition, phase change materials are classified into threemain categories: (1) Organic PCMs, (2) Inorganic PCMs and (3) Eutectics. The group of organics is paraffins and non-paraffins. Each group has its typical range of enthalpy and its range of melting temperature. Inorganic PCMs are also divided into salt hydrates, salts and metallics. Solid-liquid PCMs are used and are available with a wide range of phase change temperatures on the market.

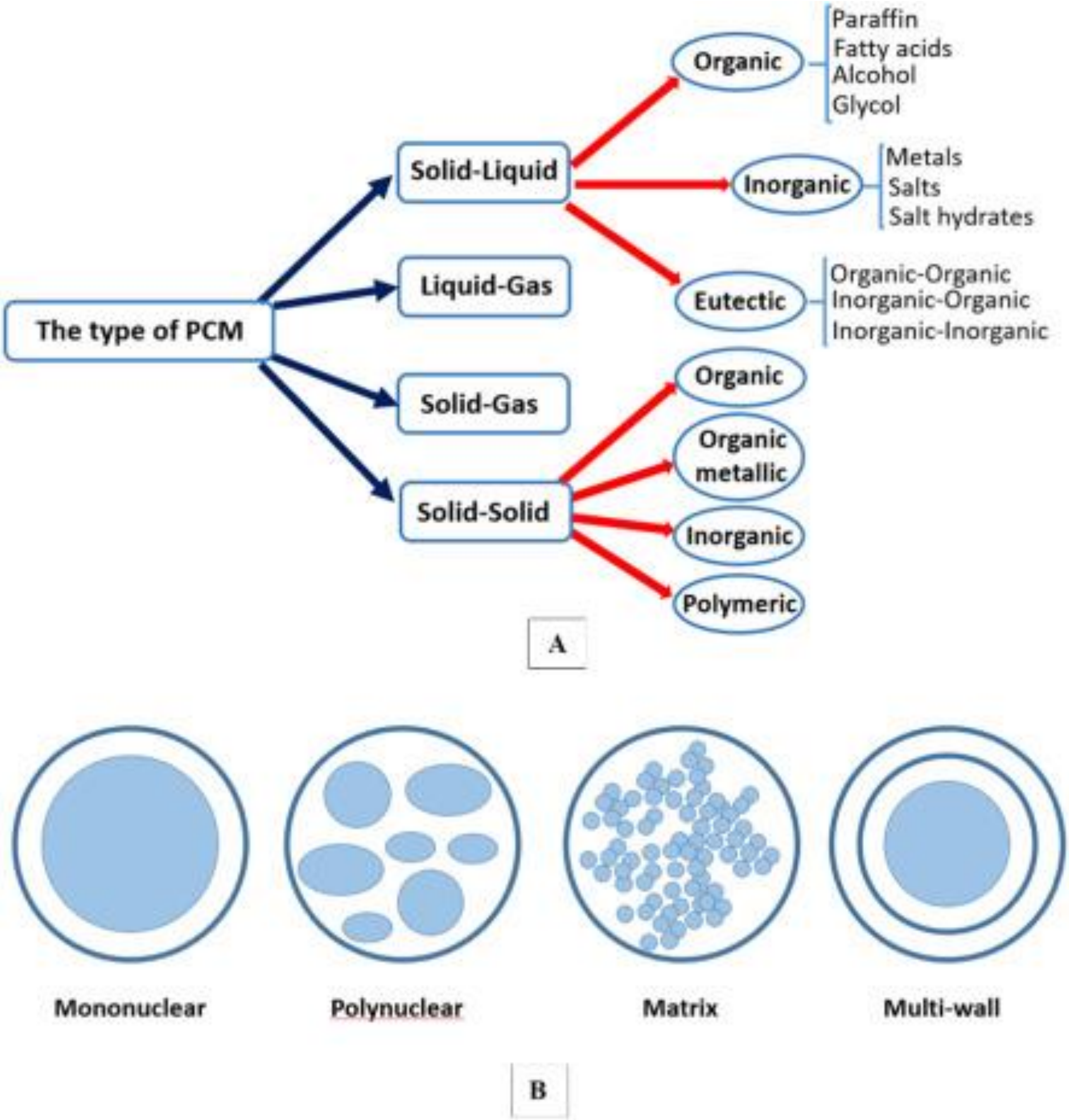


Figure 4: The classification of PCMs (A) and structure of a capsule (B).

1.3.1 Organic Phase Change Materials:

Most of the Organic PCMs in general are non-corrosive in nature, chemically stable, nontoxic, recyclable and having typically appropriate thermal properties like no or lesssubcooling and absence of phase segregation. Moreover, they are flammable and havelow thermal conductivity. Also, their phase change enthalpy is lower than the other type of PCMs and undergo large changes during the phase transitions. Organic PCMsare subdivided into paraffins and non-paraffins.

1.3.1.1 Paraffin:

Petroleum refinery byproduct paraffin is made up of carbon and hydrogen atoms connected by a single bond, with the general formula CnH2n+2, where n is the number of carbon atoms present (C). The substance is gaseous if the value of n is between 1 and 4 carbon atoms, liquid if it is between 5 and 17 carbon atoms, and solid if it is greater than 17 carbon atoms. Since paraffins have straight chains of n-alkanes, are readily accessible, less costly, and do not corrode, they are frequently utilised for thermal energy storage. The melting temperature and phase transition enthalpy of paraffin both rise with chain length. Commercial paraffin waxes range from 120kJ/kg to 210kJ/kg, which is a respectable heat storage density.

They are inert chemically, having a low vapor pressure in the melt, no phase segregation and available in a wide range of melting temperatures from approximately 20˚C up to about 70˚C.

Some disadvantages of paraffins are its flammability and reduced thermal conductivity approximately 0.2W/(mK) which limits its applications. Paraffins undergo huge changes in their volume during the phase transitions. In order to increase thermalconductivity of paraffins metallic fillers and matrix structures are used, other than thatplastic containers or containers with different geometries are used to decrease volumechange during freezing or cooling. Apart from this paraffin as phase change emulsionhas allowed for a potential application in cold storage and in high energy density applications.[4]

1.3.1.2Non-Paraffin:

Non-Paraffin includes some organic compounds like fatty acids and their derivatives,esters, glycols and alcohols. Non-paraffins are stable both chemically and thermally, less corrosive, non-toxic and shows excellent cooling and melting properties. Theyare much expensive than paraffins. Fatty acids based PCMs can be both saturated andunsaturated having one or more double bonds. Fatty acids are long chain of hydrocarbons having carboxyl group (COOH) at the end whose general formula can be given as $CH_3(CH_2)_{2n}COOH$. Different fatty acids can be incorporated with PCMs with different melting temperatures. Most commonly use fatty acids are divided into six categories: caprylic, capric, lauric, myristic, palmitic and stearic having 8 to 18 carbons per molecule respectively. 16 to 65℃ is the range for their melting points, 17 to 64℃ for freezing points and the heat of fusion lies between 155 to 180KJ/Kg.

1.3.1 Inorganic Phase Change Materials

Inorganic PCMs are further categorized into salt hydrates, salts and metals. They are inexpensive, non-burnable, have higher phase changing enthalpy, good heat of fusionand good thermal conductivity. But it was found that most of them were corrosive in nature, undergo subcooling, phase segregation, phase decomposition and lack of thermal conductivity. These are some important cons that restricts their use and makesthe organic PCMs much better. Hydrated salts are the most common type of inorganicPCMs.

1.3.2.1Hydrated salts:

Salt hydrates are created when water molecules mix with inorganic salts in a certain ratio to form a crystal. The are expressed as AnBm.zH2O, where z is the number of water molecules and A and B stand for cation and anion, respectively. Since hydrated salts have certain special qualities, they are frequently employed to store thermal energy: 1) 240 kJ/kg of high storage density; 2) 0.5 W/mK of high heat conductivity; and 3) less costly than paraffin waxes. When the melting point is reached, the hydrated salt begins to dissolve in its own water crystals, but at normal temperature, they are solid.

Glauber's salt ($Na_2SO_4 \cdot H_2O$) with melting temperature between 32 and 35°C and high latent heat of 254 kJ/kg is one of the inexpensive materials that is used for thermal energy storage, but because of supercooling and phase segregation, it is restricted in its applications. During the process of cycling, as the formation of lower salts takes place, hydrated salts will startsmelting which reduces the energy storing capacity and makes the process irreversible. Phase change materials may be used in direct contact heat exchange with the ceramic-based composite thermal storage medium, and it has been noted that this material has the potential to become more affordable. Solid-solid PCMs are potential candidates for space heating and heat process implementations because they can have huge latent heats if one of the states is much more disorganized than the above. Pentaerythritol C(CH2OH)4, pentaglycerine CH3C(CH2OH3)2, polyethylene glycol, neopentyl glycol (CH3)2C(CH2OH)2, and their eutectic mixes are examples of solid-solid PCMs. Additionally, a lot of them are employed as storage methods, and only a limited number of solid-solid transitions that take place at more extreme temperatures—that is, between 30 and 600 degrees Celsius—are studied.

1.3.2.2Salts:

The inorganic salts which are represented as A_xB_y, where A and B is cation and anionrespectively are used at high temperatures. However, they have reduced enthalpy as compared to hydrated salts. For instance, a Concentrated Solar Power (CSP) plant thatmakes the use of salt to stock energy so that it can be used later on.

1.3.2.3 Metallics:

The low melting metals and their eutectic mixtures are included in the subgroup of inorganic phase change materials. From the literature study it was observed that they are considered superior candidates for rising the temperature during the phase changeas far as the volume in the system is concerned in the view of the fact that their high heat of fusion per unit volume. However, this subgroup of inorganic PCM has elevatedthermal conductivity but specific heat and vapour pressure is low.[5–7]

1.3.3 Eutectics:

This subcategory of inorganic PCMs is a mixture of many solids in a specific proportion that their melting point is minimal, have in common high melting points and density of volumetric storage must be a little higher as compared to organic compounds. It is a combination of chemical elements or compounds having only one chemical composition and hardens at reduced temperature than any other composition achieved from the same components. These mixtures are further divided into three categories: organic–organic, inorganic–inorganic or inorganic–organic. These combinations are worthy to be used as phase change material specifically in various cooling applications but they are widely used in building applications only disadvantage is that finite test data is accessible on their thermo-physical properties. The isolation of these constituents is highly unexpected as it is observed thatthe phase is changed without separation. The process of freezing leads to the formationof blend crystal. All the constituents throughout the time of melting undergoes a change in their physical state i.e., liquid.[2,3,8]

CHAPTER 2

PROBLEMS ASSOCIATED WITH PCM IN LIFE SCIENCE APPLICATION

Recent research on the application of phase change materials (PCMs) in life sciences faces several significant challenges, primarily centered around ensuring efficacy, stability, and scalability. A major concern is the stability and longevity of PCMs. Encapsulation materials can degrade over time, leading to leakage and reduced effectiveness. Additionally, repeated thermal cycling can cause mechanical and chemical degradation, impacting the thermal storage capacity and reliability of PCMs, which is particularly problematic in medical applications that require consistent performance.

Biocompatibility and safety present another critical challenge. Both the PCMs and their encapsulating materials must be non-toxic and biocompatible to prevent health risks, especially for applications involving direct contact with biological tissues or fluids. Potential immune responses triggered by these materials can lead to adverse effects such as inflammation. Researchers are thus tasked with designing PCMs that minimize immunogenic reactions while maintaining biocompatibility.

Achieving precise control over the release of thermal energy or encapsulated drugs remains difficult. Variability in phase transition temperatures and performance inconsistency can undermine the effectiveness of PCM-based applications. Developing reliable trigger mechanisms for the controlled release of stored energy or substances at specific times and locations is also complex.

Scalability and manufacturing issues further complicate the use of PCMs. The production methods for nanoscale PCMs are often costly and complex, which hampers their commercial viability. Scaling up these processes from laboratory to industrial production without compromising quality is a significant hurdle. Ensuring consistent high-quality output with uniform particle sizes, encapsulation efficiency, and thermal properties is crucial for reliable performance.

Integrating PCMs into existing systems poses additional challenges. Ensuring compatibility with current technologies and materials is essential for leveraging PCMs' benefits effectively. Moreover, navigating the regulatory landscape for new PCM-based technologies can be time-consuming and expensive, delaying the deployment of innovative solutions.

To address these issues, research is focused on developing advanced materials that offer improved stability and biocompatibility, utilizing nanotechnology to enhance precision and control, and innovating cost-effective manufacturing techniques. Comprehensive biocompatibility and toxicity testing are essential to ensure safety, while close collaboration with regulatory bodies can streamline the approval process for new PCM-based technologies. Overcoming these challenges will help unlock the full potential of PCMs in life sciences, leading to more effective thermal management solutions and advanced drug delivery systems.

WAYS OF OVERCOME THE PROBLEMS IN PCM:

To overcome the challenges associated with phase change materials (PCMs) in life science applications, a multifaceted approach is necessary. Enhancing stability and longevity involves the development of robust encapsulation materials such as advanced polymers and hybrid nanocomposites. Optimizing encapsulation techniques and applying protective coatings can further improve durability. Biocompatibility and safety concerns can be addressed by selecting non-toxic materials and conducting comprehensive in vitro and in vivo testing. Responsive polymers and microfluidic encapsulation systems enable precise control over release mechanisms, ensuring consistent performance. Scalability and manufacturing challenges can be tackled with innovative, cost-effective production methods and modular systems. Compatibility testing and collaboration with industry partners aid in integrating PCMs into existing systems, while proactive engagement with regulatory agencies ensures smooth approval processes. By employing these strategies, the full potential of PCMs in life science applications can be realized, driving advancements in thermal management, drug delivery, and biotechnology.

2.1 Encapsulation:

2.1.1 Micro- encapsulation

Micro-encapsulation is defined as the process of containing droplets of liquid, solid orgas in any inorganic shell. This is done to prevent any leakage when the phase changetakes place. It gives a protective effect to the PCM. The products of this process are known as microparticle, microsphere and microcapsule. These particles are different on the basis of their morphology and internal structure. This technique also improves the conductivity of the PCM and hence increases its efficiency. Broadly, there are 3 methods of PCM microencapsulation viz., Physical, physical chemical and chemical methods. Presently**,** several microcapsules for PCM are made for use in building construction industry. Most of such capsules are cementitiouscomposites.

Generally, it is observed that PCM microcapsules, in constructions are useddirectly by mixing it with concrete in place of sand. Incorporating using micro encapsulation not only increases the thermal conductivity of the material but also increases the mechanical properties by changing the specific heat capacity of the material. Table 1 gives the summary of the popular PCM Microcapsules that are used. It is clearly visible from the table that mostly cementitious made PCM microcapsules are used.

There are about 50 different polymers known that can be used for wall in microencapsulation techniques. They are various natural as well as synthetic polymer used according to the different conditions. The material that is coated on the shell must have some particular requirements. They are: The polymer must have the capability toform thin film i.e., it must have the property of cohesion with respect to the core material. It must be stable as well as pliable. It should not react with the core of the shell i.e.; it must be non-reactive. It must be soluble in some aqueous solvent. Ultimately it must give the desired properties viz., strength, impermeability, stability and low cost etc. The thickness of the film thus obtained can be changed accordingto the surface area of the coating material and other properties of the system.

Methods of microencapsulation:

The core and shell are two very important facets of microcapsule fabrication becausefunction of the shell is to protect the core and avoid leakage and the function of the core is to keep the active material or the PCM. Different microencapsulated phase change materials (MPCMs) have different morphology and internal structure. Figure 6 below shows the different morphologies.

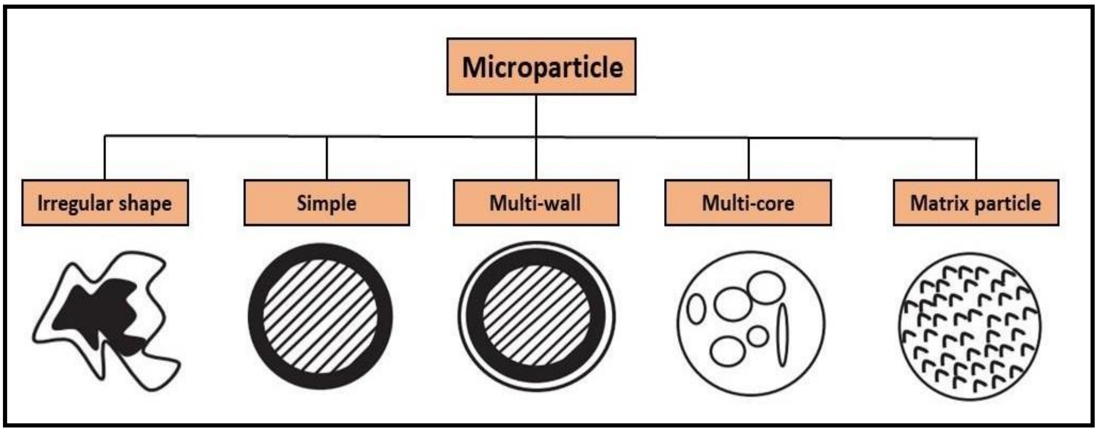


Figure5: Morphology of different MPCMs.

Broadly, on the basis of microparticle formation there are three different methods to microencapsulate PCM. They are physical, physical and chemical and chemicalmethod.

2.1.2 Macro-encapsulation:

Micro-encapsulation is a technique in which PCMs are encapsulated into capsules. Likewise, in macro-encapsulation PCMs are enclosed in a container. Size of these containers (tubes, spheres and panels etc) is generally larger than 1cm and this was reported by Cabeza et al. A major drawback of this technique is that some PCMs have reduced thermal conductivity so it leads to solidification at the corners. Due to this slower energy release and uptake can occur. This helps in preventing the system from discharging completely during the night time. The macro-capsule obtained from this technique needs to be protected against destruction otherwise their integration into the building materials will become very difficult. This is the only reason which makes this technique expensive. [7,9]

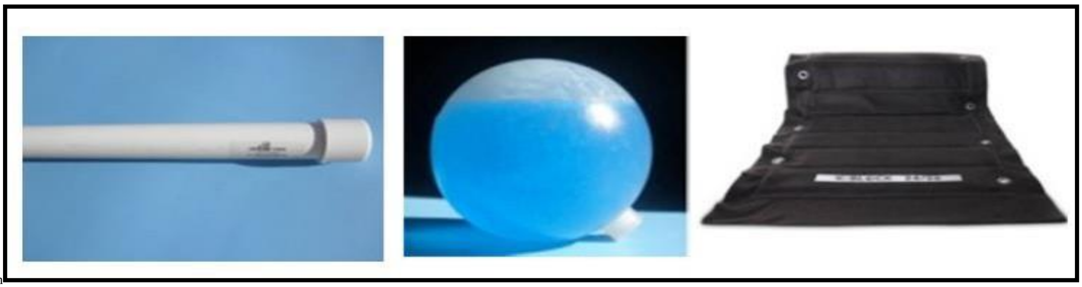


Figure6: Examples macro-encapsulation of PCMs.

Many commercially used PCMs can be encapsulated using this technique. This also helps in preventing the problem of leakage and the structure of construction remains unaffected.

2.1.3 NANO – ENCAPSULATION:

Nanoencapsulation of phase change materials (PCMs) involves encasing these materials within nanometer-scale capsules, enhancing their thermal storage and release properties. This technique offers significant benefits, including improved thermal stability, better control over the phase change process, and enhanced compatibility with various substrates. By encapsulating PCMs at the nanoscale, it is possible to prevent leakage during the phase transition, which is a common issue with bulk PCMs. Additionally, nanoencapsulation facilitates the integration of PCMs into composite materials, enhancing their applicability in thermal management systems for electronics, textiles, and building materials. However, despite these advantages, nanoencapsulation of PCMs presents several drawbacks. The process can be complex and costly, requiring precise control over the encapsulation conditions to ensure uniformity and efficiency. There are also challenges related to the long-term stability of the encapsulated PCMs, as the encapsulating shell can degrade over time, potentially leading to a loss of material and reduced performance. Furthermore, scalability remains an issue, as the techniques suitable for lab-scale production may not easily translate to industrial-scale manufacturing. These limitations must be addressed to fully leverage the potential of nano encapsulated PCMs in practical applications. [7]

There are several techniques to produce nano capsulated PCMs:

1. Emulsion Polymerization
2. Mini emulsion polymerization
3. In – situ polymerization
4. Interfacial polymerization
5. Sol- gel polymerization

6. Suspension Polymerization
7. Electrohydrodynamic encapsulation

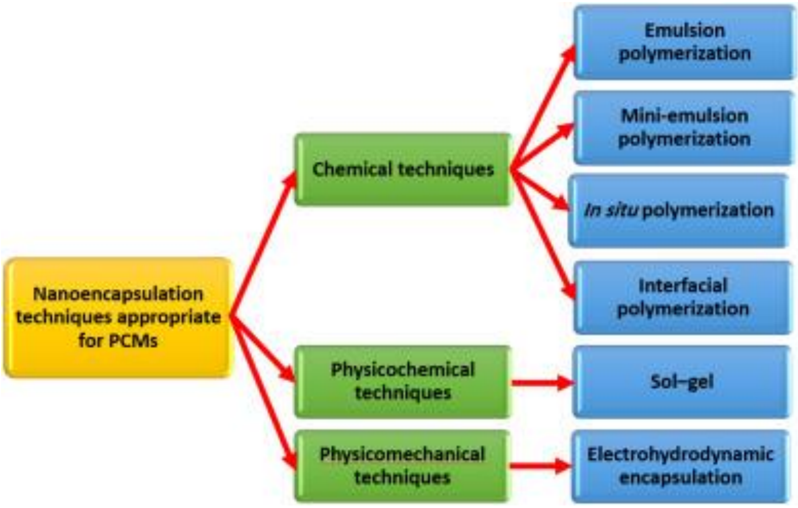


Figure7: Nanoencapsulation techniques appropriate for PCMs.

2.2 Shape Stabilization:

This is a technique in which shape-stabilized PCMs are obtained using PCM and a supporting material. The most widely used supporting materials found in literature arehigh density polyethylene (HDPE) and styrene-butadiene-styrene (SBS). This reactionoccurs at high temperature. Usually, a PCM and supporting material both are melted and blended together which is followed by cooling of the supporting material. It is observed that this supports in leakage prevention which is one of the major problems with other incorporation techniques. However, the applications of shape-stabilized PCMs are restricted as the PCMs obtained through this method have reduced thermalconductivity and that why they are not used widely in latent heat storage systems. Some well-known characteristics of shape-stabilized PCMs are mentioned below

1) Huge apparent specific heat.
2) Suitable thermal conductivity.
3) The shape remains stabilized throughout the phase change transitions.
4) It is thermally dependable specifically melt or freeze cycle over a prolonged period.
5) The mass percentage of PCM is likely up to 80%.

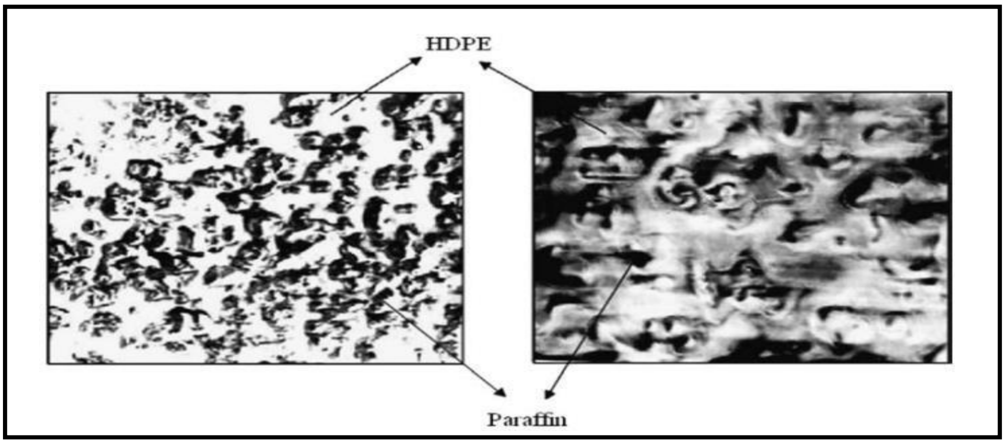


Figure8: SEM image of High-density polyethylene.

Table 1 Various studies on Shape-Stabilized PCMs

PCM	Supporting materials	Ratio of PCM and Support material
Paraffin	High density polyethylene	75:25
Paraffin	High density polyethylene	75:25
Paraffin	High density polyethylene	80:20
Paraffin	High density polyethylene	70:30
Paraffin	High density polyethylene	77:33
Paraffin	High density polyethylene	74:26
Paraffin	Styrene-butadiene-styrene (SBS)	70:30
Fatty acids	graphite	92:8

2.3 EXPERIMENTAL STUDIES ON CAPRYLIC ACID :

2.3.1 MATERIALS AND METHOD:

Caprylic acid (Merck, Germany, melting point; 15–17 °C) was used as the core material. Styrene (499%, Sigma Aldrich company USA) was used as the monomer for the shell material. DDT is used as the chain transfer agent. Sodium lauryl sulphate was used as the emulsifier. Emulsion polymerization method was used to synthesis nano encapsulate PCMs of caprylic acid.

Figure 9: Washing of styrene.

Figure10.: Solution of caprylic and styrene.

DSC RESULTS :

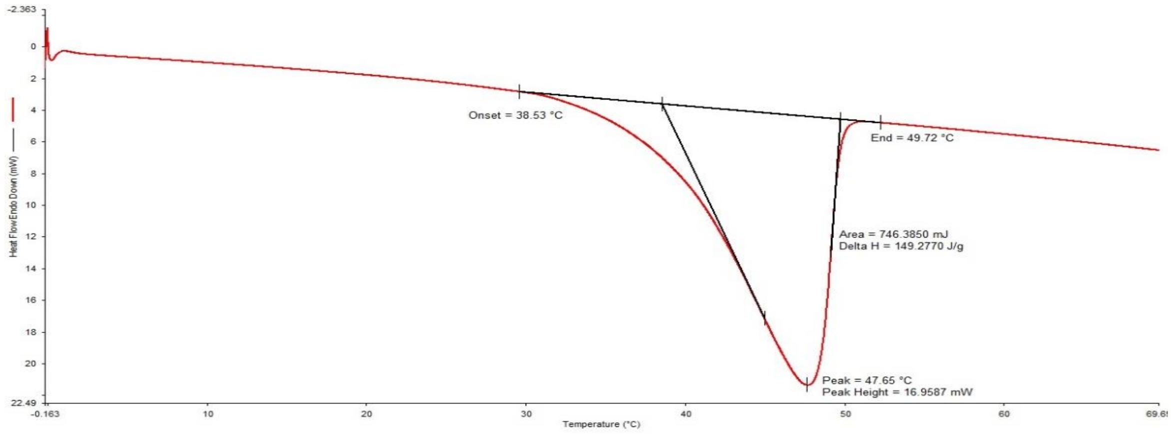
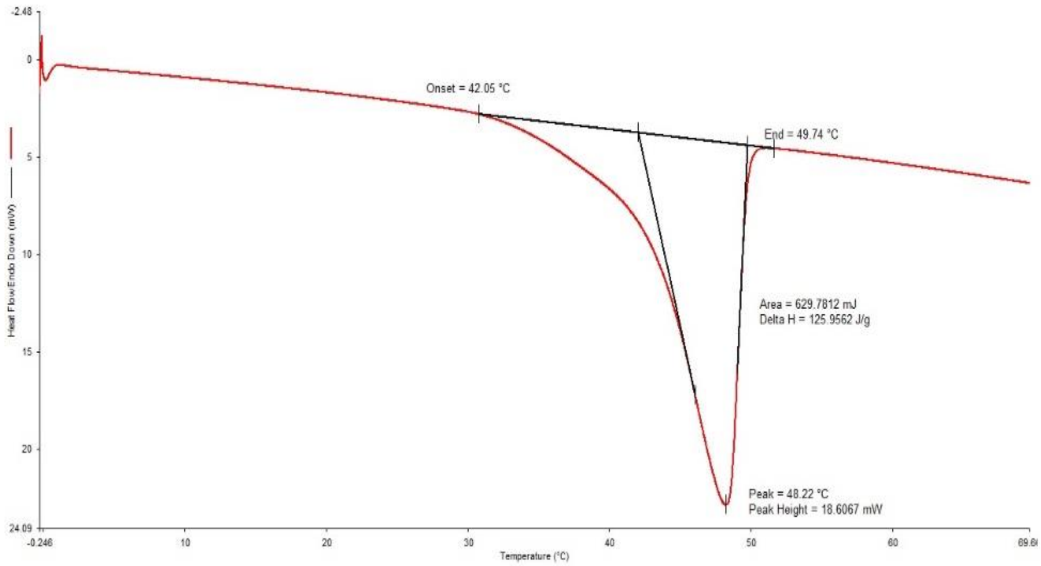


Figure11: DSC curve for caprylic acid (sample A).



(sample b)

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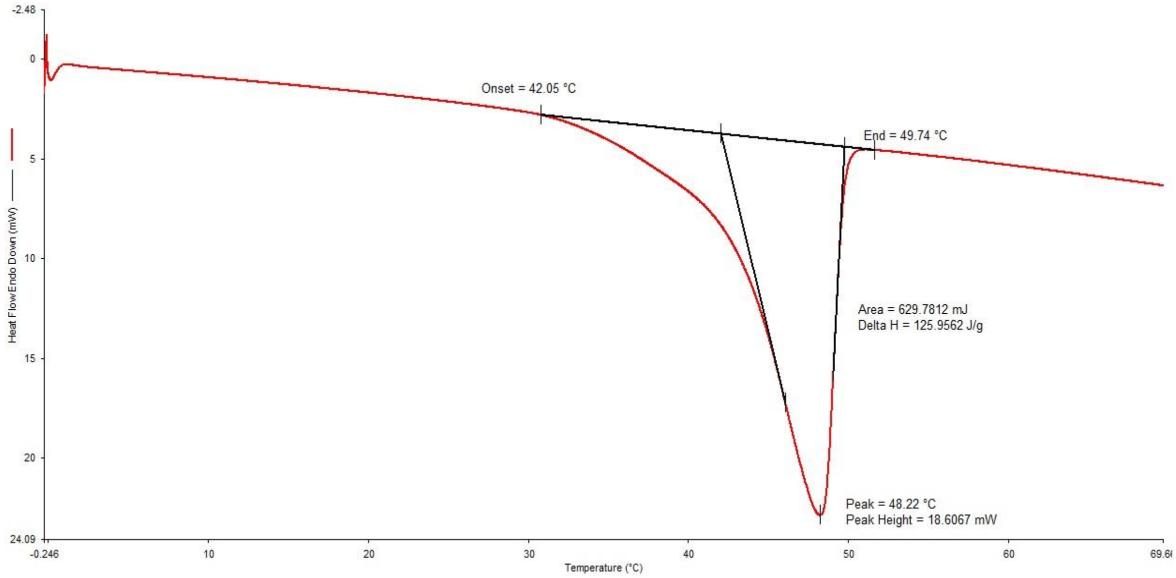

(sample c)

The DSC data in above graphs show the thermal analysis of caprylic acid. The DSC (Differential Scanning Calorimetry) results showed anomalies that the received data was not expected the unexpected peaks and irregular baselines in the graph did not match the anticipated thermal transitions of the sample. Additionally, the enthalpy values were insignificant here. That's why other analysis like SEM, TEM, FTIR didn't get measured.

CHAPTER 3:

LIFE SCIENCE APPLICATIONS OF PCM AND THEIR THERMAL PERFORMANCE

3.1 : - CHOICE OF PCM FOR LIFE SCIENCE APPLICATIONS

For life science applications, PCM possessing certain desirable properties such as thermal-physical, kinetic, chemical, economic and environmental properties can be used. But it is hard to find such a material possessing all the properties. Therefore, the criteria for best choice of PCM are listed below

- Appropriate phase transition temperature for life science applications.
- Thermally reliable high latent heat of fusion and stable phase transition.
- The material must be having heat capacity and latent heat as high as possible.
- The change in volume during phase transition must be small.
- No subcooling of PCM in liquid phase.
- Non-flammable, non-explosive and chemical compatibility with encapsulated materials must be high.
- Bio compatibility and safety
- Non-toxic and non-polluting so that it is safe for environment and humans.
- Recyclable
- Low cost
- Commercially available
- Do not degrade after large number of thermal cycles.

3.2 : - CURRENT LIFE SCIENCE APPLICATIONS OF PCM :

Applications of PCMs are many but in this section, we will be focusing on the applications listed below:

- PCM in Biological and Biomedical field.
- PCM in Food Science.
- PCM in Wearable Health Devices.
- PCM in Barcoding.
- PCM in Additive Manufacturing.

3.2.1 PCM in Biological and Biomedical field:

Phase change materials (PCMs) have emerged as promising solutions in various life science applications, offering efficient thermal energy storage and release capabilities. This review paper explores recent developments in PCM utilization across diverse areas within life sciences while addressing associated challenges and potential solutions. We delve into the applications of PCMs in thermal management for medical devices, drug delivery systems, cryopreservation, tissue engineering, and personalized medicine. However, despite their potential, recent research highlights several obstacles impeding PCM adoption in life science domains. Challenges include issues surrounding stability, biocompatibility, controlled release, scalability, system integration, and regulatory compliance. To surmount these obstacles, we propose strategies such as advancing encapsulation materials, optimizing manufacturing processes, conducting comprehensive biocompatibility assessments, employing responsive polymers for controlled release, and engaging proactively with regulatory bodies. Overcoming these hurdles could establish PCMs as indispensable tools, enhancing thermal management, drug delivery precision, and biomedical innovations, thereby advancing healthcare and biotechnology sectors.[3,10,11]

Phase Change Materials (PCMs) have become versatile tools in many biomedical applications as well addressing various challenges in the field. They're used in therapies like thermotherapy, cold compress therapy, drug delivery, and wound healing due to their effective temperature modulation abilities. In cancer treatment, PCMs are employed in photothermal therapy, photodynamic therapy, chemodynamic therapy, and sonodynamic therapy, showcasing their diverse applications. One key benefit of PCMs is their precise temperature control, crucial for therapies like thermotherapy, and their ability to release drugs when melting, making them adaptable for specific medical need. Fatty acids and fatty alcohols are commonly used as PCMs in biomedicine because they're biodegradable, non-toxic, abundant, and have antibacterial properties. Exploring the characteristics of PCMs has led to innovative advancements in creating various PCM-based structures, offering new opportunities for technological innovation and enhancing therapeutic benefits. By strategically designing and constructing PCMs and integrating stabilization methods, they have the potential to revolutionize healthcare technologies by improving energy efficiency, thermal comfort, and treatment outcomes.

In biomedical applications, PCMs are used both on the human body and in logistics involving transportation and storage. Examples include reusable cooling packs for sports injuries, heat pillows for rheumatism, and incubators for babies. PCMs can also be used to improve comfort in orthoses and prostheses by reducing sweat. For example, the Outlast PCM in the Alpha Smart Temperature Liner helps regulate skin temperature for amputees. Polyethylene glycol (PEG) treated textiles with liquid transport and antimicrobial properties find uses in medical products like surgical gauzes and diapers. Fabrics with PCM can regulate temperature, making them suitable for clothing and heat-cool treatments. Molecular alloys with high latent heat of fusion are used for thermal energy storage in medical applications, such as blood thermal protection. Controlling heat during phase transitions is crucial, for instance, in bone cement polymerization to prevent tissue damage. Glauber salt solution serves as a suitable PCM for cooling newborns suffering from oxygen deprivation during birth. Fatty acids like acetamide, stearic acid, and lauric acid are promising PCM materials due to their melting point and latent heat of fusion.

3.2.2 PCMs in FOOD SCIENCE:

Phase change materials (PCMs) have consumer attention in food research due to their widespread use in food processing, storage, and transportation. One of the biggest challenges in food storage is keeping food at the correct temperature to maintain its quality and safety. PCM has emerged as a promising solution to this challenge, especially in situations related to food storage and transportation. In the food industry, where the heating and cooling process requires a lot of energy, PCM is a suitable option to increase energy efficiency. The use of various materials in food science, including the use of small pre-cooled milk, fresh pre-cooled products, and new dryers, are changes that demonstrate their many applications in business.

Moreover, PCMs are instrumental in beverage cooling applications, providing alternatives to conventional methods such as ice cubes or standard refrigeration techniques. For instance, they offer efficient means for storing beverages like cold beer. The integration of PCMs in food transformation processes has shown significant promise in reducing energy consumption compared to traditional methods such as diesel-powered refrigeration systems. Studies indicate notable reductions in energy usage, illustrating the potential for PCMs to contribute to sustainable food processing practices.

Furthermore, employing PCMs in food refrigeration systems brings additional benefits, including minimized temperature fluctuations, reduced compressor power during peak periods, and overall decreased energy consumption. These advantages make PCMs particularly suitable for applications requiring frequent access or rapid cooling of food products. Overall, the incorporation of PCMs into various faces of food science holds promise for enhancing energy efficiency, improving food quality, and advancing sustainable practices in the food industry. [12] In order to uphold food quality and ensure microbial safety, certain food items require refrigeration or freezing throughout their distribution and marketing processes. Preventing food spoilage, extending the shelf life of products, and preserving the cold chain during storage, transportation, delivery, and retail are essential aspects of food handling. Traditionally, Phase Change Materials (PCMs) have found application in the food industry primarily for heat storage and transit systems, including heat processing units, refrigerated storage, and packaging solutions. [13,14] PCM-based packaging represents an innovative approach to safeguarding temperature-sensitive foods. Additionally, the encapsulation of PCMs at micro or nano scales serves as an effective strategy to enhance their performance in maintaining optimal temperatures for food items. This technology not only ensures the integrity of perishable goods but also contributes to enhancing efficiency and sustainability in the food supply chain.

3.2.3 PCMs IN WEARABLE HEALTH DEVICES:

Phase change materials (PCMs) significantly enhance the functionality and comfort of wearable health devices by managing temperature. PCMs absorb or release large amount of during their phase transitions between solid and liquid states, making them ideal for maintaining optimal temperature ranges in wearable devices and improving user comfort.

In wearable health devices like fitness trackers, smartwatches, and biosensors, PCMs help manage the heat generated during operation, keeping the device's temperature within a comfortable range for the wearer. This is especially important during continuous wear or physical activities, where excessive heat can cause discomfort or skin irritation. By integrating PCMs, these devices can provide a cooling effect during high activity levels or in hot environments, absorbing excess heat and stabilizing skin temperature for enhanced comfort.

Additionally, PCMs contribute to extended battery life by managing the heat produced by batteries and electronic components. They absorb heat, preventing overheating and improving device efficiency. This thermal regulation reduces the need for active cooling mechanisms, conserving battery life and ensuring the longevity of the device and its components. Furthermore, by stabilizing the temperature, PCMs ensure consistent and reliable sensor readings for health metrics such as heart rate, temperature, and glucose levels, which are crucial for accurate health monitoring.[15–17]

The types of PCMs used in wearable health devices include organic PCMs like paraffin waxes and fatty acids, which are known for their high latent heat and non-corrosive nature. Inorganic PCMs, such as salt hydrates, offer high thermal storage capacity but may require encapsulation due to their corrosive properties. Bio-based

PCMs, derived from natural sources, provide biocompatibility and sustainability, making them suitable for applications involving close contact with the skin, such as medical textiles in wearable devices.

To prevent leakage and enhance stability, PCMs are often encapsulated using materials like polymers or silica. Techniques like microencapsulation and nanoencapsulation allow PCMs to be integrated into wearable fabrics and devices without compromising functionality. Ensuring material compatibility is also crucial, and ongoing research focuses on creating composite materials that incorporate PCMs while maintaining flexibility, durability, and comfort. Although the cost of integrating PCMs into wearables can be a barrier, advances in manufacturing processes and materials science aim to reduce costs and improve scalability for mass production. [18–20]

The use of PCMs in wearable health devices include the development of new PCMs with enhanced properties, such as higher thermal conductivity and specific phase change temperatures tailored to wearable applications. Embedding PCMs in smart textiles can create garments that actively regulate body temperature, which has applications in medical wearables for therapeutic processes. By enabling more accurate and reliable wearable devices, PCMs contribute to personalized health monitoring and tailored healthcare solutions.

In summary, phase change materials play a crucial role in improving the functionality, comfort, and performance of wearable health devices. By effectively managing heat and maintaining optimal operating conditions, PCMs ensure accurate data collection, user comfort, and longer device lifespans. Ongoing research and development in this field promise further advancements in wearable health technology, enhancing its potential impact on personal health management and medical diagnostics.[19,21–23]

3.2.4 PCMs IN BARCODING:

Phase change materials (PCMs) significantly enhance the functionality and efficiency of barcoding technologies in life sciences by providing reliable thermal management. Barcoding involves using unique identifiers to track and manage biological samples, which require precise temperature control to maintain sample integrity and ensure accurate data collection. PCMs help achieve this by absorbing or releasing heat as needed, thus maintaining a stable temperature environment for samples during storage and transportation. This stability prevents temperature-induced degradation of sensitive biological materials such as blood, DNA, RNA, and other cellular materials, which is crucial for accurate barcoding results.

In laboratories and biobanks, PCMs are integrated into storage systems to ensure that samples remain within optimal temperature ranges, thereby reducing the risk of thermal damage and preserving sample quality for accurate barcoding and subsequent analysis. During transportation, PCMs in packaging materials create thermally insulated environments that protect samples from external temperature fluctuations. This is particularly useful for transporting samples between laboratories, research facilities, and clinical settings. Furthermore, in field research and point-of-care diagnostics where sophisticated temperature control equipment might not be available, portable barcoding devices equipped with PCM technology can maintain required temperatures, facilitating accurate data collection and analysis in remote or resource-limited settings.[24–27]

The advantages of using PCMs in barcoding include enhanced stability and reliability, which are essential for maintaining the quality of biological samples and ensuring reproducible results. PCMs can be seamlessly integrated into existing barcoding and storage systems without significant modifications, making them a cost-effective enhancement. Additionally, PCMs contribute to energy efficiency by reducing the need for constant active cooling or heating, thus lowering energy consumption and operational costs.

However, challenges such as ensuring material compatibility, preventing leakage through advanced encapsulation techniques, and addressing the cost and scalability of PCM integration need to be addressed. Research focuses on developing composite materials that incorporate PCMs while maintaining compatibility and performance, as well as advanced encapsulation methods like microencapsulation and nanoencapsulation to improve PCM longevity and effectiveness.

PCMs in barcoding technology include the development of new PCM materials with enhanced thermal properties tailored for biological applications, smart packaging solutions that can monitor and regulate temperature in real-time, and personalized barcoding systems designed for precision diagnostics and personalized medicine. These advancements promise to further enhance the efficiency and effectiveness of barcoding in life sciences, ensuring the integrity of biological samples and supporting accurate data collection across various research and diagnostic applications.

3.2.5 PCMs IN ADDITIVE MANUFACTURING:

Phase change materials (PCMs) are increasingly being used in additive manufacturing (AM) to improve life science applications. Additive manufacturing, commonly known as 3D printing, allows for the precise creation of complex structures and devices, making it particularly valuable in the life sciences. The integration of PCMs into these structures enhances thermal management, crucial for maintaining the integrity and functionality of medical and biological devices. PCMs can regulate temperature by absorbing and releasing latent heat during phase transitions, which is especially beneficial for tissue engineering and drug delivery systems where maintaining specific temperature ranges is essential.

In drug delivery systems, PCMs can be incorporated into 3D-printed devices to ensure the controlled release of therapeutics. They help maintain the integrity of temperature-sensitive drugs during storage and transportation and can be designed to melt at specific temperatures to trigger the release of encapsulated drugs, providing a targeted delivery mechanism. For tissue engineering, 3D-printed scaffolds with embedded PCMs help maintain optimal temperatures for cell viability and proliferation by buffering against external temperature fluctuations, crucial for bioprinting where temperature control is critical for cell survival.

Additionally, in cryopreservation, 3D-printed devices with PCMs offer precise thermal control during cooling and thawing processes, minimizing thermal shock and improving the survival rates of preserved cells and tissues. Wearable health devices such as smart patches and sensors also benefit from the thermal regulation provided by PCMs. These materials help manage the heat generated by electronic components in wearable devices, enhancing user comfort and device performance without causing discomfort or irritation.

However, there are challenges to the integration of PCMs in additive manufacturing. Ensuring material compatibility is crucial, and research is focused on developing composite materials that effectively combine PCMs with 3D printing resins and polymers. Advanced encapsulation techniques like microencapsulation and nanoencapsulation are necessary to prevent PCM leakage and ensure durability, allowing for stable incorporation into 3D-printed structures. Cost and scalability are also significant concerns, and innovations in material science and manufacturing processes aim to make PCM-enhanced 3D printing more economically viable. Additionally, developing PCMs with customized thermal properties tailored for different life science applications is an ongoing research area, providing more precise thermal management solutions.[28,29]

In summary, integrating phase change materials in additive manufacturing holds great potential for advancing life science applications. By offering effective thermal management, PCMs enhance the functionality, reliability, and performance of 3D-printed drug delivery systems, tissue engineering scaffolds, cryopreservation devices, and wearable health technologies. Continued research and development promise to unlock new possibilities and improve outcomes in medical and biological research and applications.[30,31]

CONCLUSION

This paper is all about PCM and their Life science applications. PCMs are now used more frequently because of their advantages in various fields but here we are only concerned about their usage in life science applications. PCMs are considered to be the most influential substitute to conventional materials when it comes to heating and cooling techniques. The idea behind the working of PCMs is latent heat storage and they are of three types: organic, inorganic and eutectic mixtures. Depending upon the requirements selection of PCM for a particular application is done. Phase change materials (PCMs) hold significant potential to revolutionize various life science applications due to their efficient thermal energy storage and release capabilities. By leveraging their unique properties, PCMs can greatly enhance thermal management, drug delivery systems, cryopreservation techniques, tissue engineering, and personalized medicine. However, to fully realize the benefits of PCMs in these applications, several challenges need to be addressed.

One of the primary issues is ensuring the stability and longevity of PCMs. This involves developing advanced encapsulation materials, such as robust polymers and hybrid nanocomposites, which can withstand numerous thermal cycles without significant degradation. Improving the thermal and chemical stability of PCMs will help maintain their functionality over extended periods.

Biocompatibility and safety are also critical concerns. Selecting non-toxic and biocompatible materials is essential to prevent adverse reactions in biological systems. Comprehensive in vitro and in vivo testing must be conducted to verify the safety and efficacy of these materials, ensuring they do not provoke immune responses or cause inflammation. Controlled release and performance are vital for applications like drug delivery. Utilizing responsive polymers that react to specific triggers, such as temperature changes or pH levels, can provide precise control over the release mechanisms. This ensures that therapeutic agents are delivered consistently and effectively to the target sites. Scalability and manufacturing present another set of challenges. Developing cost-effective and reproducible production methods is crucial for the widespread adoption of PCMs in life sciences. Innovations in manufacturing techniques, such as direct ink writing and modular production systems, can help scale up production while maintaining quality and performance. Integration with existing systems requires thorough compatibility testing. Ensuring that PCMs can be seamlessly incorporated into current medical devices, packaging, and drug formulations is essential for practical applications. Collaboration with industry partners and stakeholders can facilitate the development of standardized protocols and materials.

Regulatory approval is a critical step for PCMs used in medical and biological applications. Proactively engaging with regulatory bodies early in the development process can help identify potential hurdles and address them promptly. Preparing comprehensive documentation and conducting thorough safety and efficacy studies are essential to support regulatory submissions.

By addressing these challenges through a combination of advanced material science, innovative manufacturing techniques, thorough testing, and strategic regulatory engagement, PCMs can become indispensable tools in life sciences. This will lead to improved thermal management solutions, more precise drug delivery systems, enhanced cryopreservation methods, and significant advancements in tissue engineering and personalized medicine. Continued research and development are essential to fully unlock the potential of PCMs, ultimately driving innovations that improve healthcare outcomes and advance the biotechnology field.

REFRENCES

1. Wei G, Wang G, Xu C, Ju X, Xing L, Du X, et al. Selection principles and thermophysical properties of high temperature phase change materials for thermal energy storage: A review. Vol. 81, Renewable and Sustainable Energy Reviews. 2018.
2. Du K, Calautit J, Wang Z, Wu Y, Liu H. A review of the applications of phase change materials in cooling, heating and power generation in different temperature ranges. Vol. 220, Applied Energy. 2018.
3. Pereira da Cunha J, Eames P. Thermal energy storage for low and medium temperature applications using phase change materials - A review. Vol. 177, Applied Energy. 2016.
4. Mishra DK, Bhowmik C, Bhowmik S, Pandey KM. Property-enhanced paraffin-based composite phase change material for thermal energy storage: a review. Vol. 29, Environmental Science and Pollution Research. 2022.
5. Li C, Li Q, Ge R. A review of heat transfer performance enhancement and applications of inorganic salt based shape-stabilized composite phase change materials for medium and high temperature thermal energy storage. Vol. 8, Energy Reports. 2022.
6. Peng H, Wang J, Zhang X, Ma J, Shen T, Li S, et al. A review on synthesis, characterization and application of nanoencapsulated phase change materials for thermal energy storage systems. Appl Therm Eng. 2021;185.
7. Patil JR, Mahanwar PA, Sundaramoorthy E, Mundhe GS. A review of the thermal storage of phase change material, morphology, synthesis methods, characterization, and applications of microencapsulated phase change material. Vol. 43, Journal of Polymer Engineering. 2023.
8. Nazir H, Batool M, Bolivar Osorio FJ, Isaza-Ruiz M, Xu X, Vignarooban K, et al. Recent developments in phase change materials for energy storage applications: A review. Vol. 129, International Journal of Heat and Mass Transfer. 2019.
9. Alva G, Lin Y, Liu L, Fang G. Synthesis, characterization and applications of microencapsulated phase change materials in thermal energy storage: A review. Vol. 144, Energy and Buildings. 2017.
10. Ma K, Zhang X, Ji J, Han L, Ding X, Xie W. Application and research progress of phase change materials in biomedical field. Vol. 9, Biomaterials Science. 2021.

11. Zare M, Mikkonen KS. Phase Change Materials for Life Science Applications. Vol. 33, Advanced Functional Materials. 2023.

12. Soukoulis C, Bohn T. A comprehensive overview on the micro- and nano-technological encapsulation advances for enhancing the chemical stability and bioavailability of carotenoids. Crit Rev Food Sci Nutr. 2018;58(1).

13. Mehling H. Use of Phase Change Materials for Food Applications—State of the Art in 2022. Vol. 13, Applied Sciences (Switzerland). 2023.

14. Ilangovan A, Hamdane S, Silva PD, Gaspar PD, Pires L. Promising and Potential Applications of Phase Change Materials in the Cold Chain: A Systematic Review. Vol. 15, Energies. 2022.

15. Zhong B, Jiang K, Wang L, Shen G. Wearable Sweat Loss Measuring Devices: From the Role of Sweat Loss to Advanced Mechanisms and Designs. Vol. 9, Advanced Science. 2022.

16. Oh HS, Lee CH, Kim NK, An T, Kim GH. Review: Sensors for biosignal/health monitoring in electronic skin. Vol. 13, Polymers. 2021.

17. Farooq AS, Zhang P. A comprehensive review on the prospects of next-generation wearable electronics for individualized health monitoring, assistive robotics, and communication. Vol. 344, Sensors and Actuators A: Physical. 2022.

18. Sayyad PW, Park SJ, Ha TJ. Bioinspired nanoplatforms for human-machine interfaces: Recent progress in materials and device applications. Vol. 70, Biotechnology Advances. 2024.

19. Miao P, Wang J, Zhang C, Sun M, Cheng S, Liu H. Graphene Nanostructure-Based Tactile Sensors for Electronic Skin Applications. Vol. 11, Nano-Micro Letters. 2019.

20. Jin H, Abu-Raya YS, Haick H. Advanced Materials for Health Monitoring with Skin-Based Wearable Devices. Vol. 6, Advanced Healthcare Materials. 2017.

21. Huynh TP, Haick H. Autonomous Flexible Sensors for Health Monitoring. Vol. 30, Advanced Materials. 2018.

22. Wu W, Haick H. Materials and Wearable Devices for Autonomous Monitoring of Physiological Markers. Vol. 30, Advanced Materials. 2018.

23. Gao C, Kuklane K, Wang F, Holmér I. Personal cooling with phase change materials to improve thermal comfort from a heat wave perspective. Indoor Air. 2012;22(6).

24. Tackels D. Types of Barcodes: Choosing the Right Barcode. ScanditCom. 2015;

25. Zhang H, Deng X, Zhang J, Xue D, Huang Y, Bai F, et al. Phase transformation of Sn-based

nanowires under electron beam irradiation. J Mater Chem C Mater. 2015;3(21).

26. Duong B, Liu H, Ma L, Su M. Covert thermal barcodes based on phase change nanoparticles. Sci Rep. 2014;4.

27. Wang M, Duong B, Su M. Organic phase change nanoparticles for in-product labeling of agrochemicals. Nanomaterials. 2015;5(4).

28. Naftulin JS, Kimchi EY, Cash SS. Streamlined, inexpensive 3D printing of the brain and skull. PLoS One. 2015;10(8).

29. Lacey SD, Cresce A v., Xu K, Lin Y, Hu L. (Battery Division Student Research Award sponsored by Mercedes-Benz Research & Development) Advanced Electrochemical Energy Storage Systems: Material Development, Alternative Electrode Processes & Planar Devices. ECS Meeting Abstracts. 2018;MA2018-02(1).

30. Cui H, Yu S, Cao X, Yang H. Evaluation of Printability and Thermal Properties of 3D Printed Concrete Mixed with Phase Change Materials. Energies (Basel). 2022;15(6).

31. Yang Z, Jia S, Niu Y, Lv X, Fu H, Zhang Y, et al. Bean-Pod-Inspired 3D-Printed Phase Change Microlattices for Solar-Thermal Energy Harvesting and Storage. Small. 2021;17(30).


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