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Thermo Physical Properties Based Parametric Analysis To Help PCM Selection

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Abstract - The most significant threat that mankind faces in the 21th century is global warming. Buildings, which account for 40% of global energy consumption and greenhouse gas emissions, play a pivotal role in global warming. Estimates show that their destructive impact will grow by 1.8% per year through 2050, which indicates that future consumption and emissions will be worse than today.

Phase Change Materials (PCMs) have emerged as a promising solution for thermal energy storage due to their ability to store and release energy during phase transitions. This research paper provides a comprehensive review and analysis of the selection criteria for PCMs, with a focus on their applications in various industries and technologies. The paper presents an overview of PCMs, their classification, and highlights the importance of accurate PCM selection to ensure efficient and sustainable thermal energy storage systems. Through this analysis, the paper aims to guide researchers, engineers, and decision-makers in selecting the most suitable PCMs for specific applications.

1. Introduction

PCM has the potential to reduce indoor air temperature and to increase building energy efficiency and thermal comfort. The actual magnitude of reduced temperature, enhanced thermal comfort and energy savings largely depends on local climatic conditions and the thermo-physical properties of PCM.

Thermal energy storage has become increasingly vital in the modern world due to the growing demand for efficient and sustainable energy utilization. Energy storage systems play a crucial role in bridging the gap between energy supply and demand, enhancing energy grid stability, and reducing greenhouse gas emissions. Phase Change Materials (PCMs) have emerged as a promising solution for thermal energy storage, offering high energy storage density and efficient heat transfer capabilities.

1.1 Background:

Phase Change Materials (PCMs) are substances capable of absorbing and releasing significant amounts of energy during their phase transitions, such as melting and solidification, at constant temperatures. The principle of latent heat storage governs their energy storage mechanism, allowing them to store or release large amounts of thermal energy while maintaining a nearly constant temperature. This characteristic makes PCMs highly advantageous for various applications, ranging from buildings and electronics cooling to solar energy systems and cold chain management.

The history of PCMs dates back to the early 18th century when researchers first observed the heat-absorbing properties of substances during phase transitions. However, it was not until recent decades that PCMs gained substantial attention and found practical applications in various industries. Ongoing advancements in material science and engineering have led to the discovery and development of a wide range of PCMs with tailored properties for specific applications.

1.2 Objectives:

The primary objectives of this research paper are as follows:

- To provide a comprehensive review of Phase Change Materials and their significance in thermal energy storage systems.
- To identify and analyze the critical selection criteria for Phase Change Materials based on their thermophysical, chemical, and mechanical properties.

- To investigate the different types of PCMs, including organic, inorganic, eutectic mixtures, composite and compare their performance in various applications.

The successful achievement of these objectives will contribute to a better understanding of the role of Phase Change Materials in thermal energy storage and aid researchers, engineers, and decision-makers in selecting the most suitable PCMs for their specific applications.

2. Overview Of Phase Change Materials:

Phase Change Materials (PCMs) are substances that undergo a physical transformation, changing their state from solid to liquid or vice versa, while absorbing or releasing a significant amount of energy as latent heat. This latent heat storage mechanism allows PCMs to store thermal energy during phase transitions at nearly constant temperatures, making them ideal candidates for thermal energy storage applications.

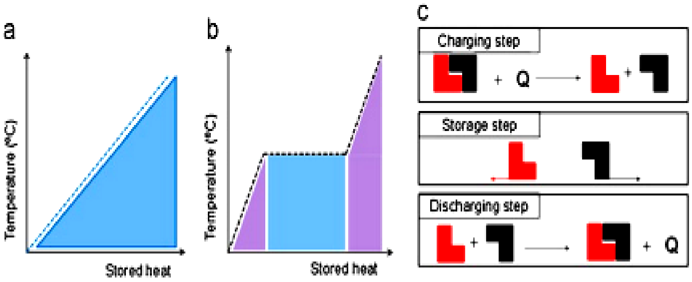

Fig 1: Charging and Discharging, (Source, De Garcia, Energy Build)

2.1 Definition and Classification:

PCMs can be classified into different categories based on their chemical composition, phase change temperatures, and applications. They are broadly categorized as follows:
Abhat et al. [7] classified the substances used for thermal energy storage (TES)

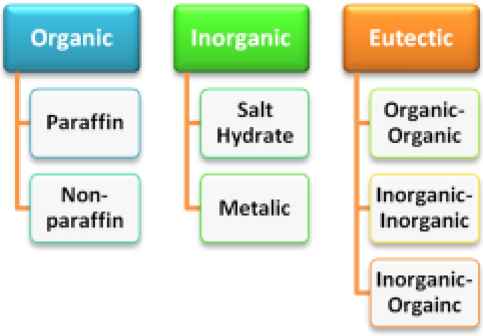

Fig 2: Different types of PCMs Zhou D, Zhao CY, Tian Y. Review on thermal energy storage with phase change materials (PCMs) in building applications. Appl Energy 2012;92:593– 605

2.1.1 Organic PCMs:

Organic PCMs are composed of carbon, hydrogen, and oxygen atoms, and they are derived from natural or synthetic sources. Examples of organic PCMs include paraffins, fatty acids, and polyethylene glycols (PEGs). it displays many suitable properties, such as high latent heat, low super cooling, no phase segregation and different melting temperature, it may be suitable for different climates and conditions [58]. Furthermore, this type exhibits reproducible freezing and melting properties with no super cooling during freezing [52]. However, compared to paraffin, they are more expensive. In addition, they can be corrosive.

2.1.2 Inorganic PCMs:

Inorganic PCMs are typically composed of metals, salts, or minerals. Some common examples include hydrated salts (e.g., sodium sulfate decahydrate), metal alloys (e.g., Indium), and clathrates (e.g., hydrates of natural gases). Comparing to organic PCMs, inorganic PCMs have higher heat of fusion per unit mass with lower cost and flammability(usually).

However, they do suffer from super cooling phase segregation, lack of thermal stability, corrosion and decomposition, which overshadows their advantages [59–61]. This category includes salt hydrates, salt solutions and metals [62]

2.1.3 Eutectic Mixtures and Composite PCMs:

Eutectics are available as alloys of organics and/or inorganics and mostly (inorganic salt-hydrates) that feature congruent melting/freezing with no phase segregation [47].

Eutectic mixtures are blends of two or more substances that have a lower melting point than the individual components. Composite PCMs are a combination of a PCM and other materials, such as polymers or nanoparticles, to enhance their thermal properties.

2.2 Types of Phase Change (Melting and Solidification):

The two primary types of phase change in PCMs are melting (solid-to-liquid) and solidification (liquid-to-solid).

2.2.1 Melting:

During the melting phase change, a solid PCM absorbs energy from its surroundings, causing its temperature to rise until it reaches its melting point. At this point, the PCM undergoes a phase transition and transforms into a liquid state while storing the absorbed energy as latent heat. The PCM remains at a nearly constant temperature until complete melting occurs.

2.2.2 Solidification:

During the solidification phase change, a liquid PCM releases energy to its surroundings, causing its temperature to decrease until it reaches its solidification point (the same as the melting point). At this point, the PCM solidifies and transitions back to its solid state while releasing the stored latent heat.

2.3 Advantages and Limitations of PCMs:

2.3.1 Advantages:

1. High energy storage density: PCMs can store and release a large amount of thermal energy in a relatively small volume.
2. Thermal regulation: PCMs can help maintain a nearly constant temperature during phase transitions, providing efficient temperature control in various applications.
3. Reduced energy consumption: By storing excess thermal energy during low-demand periods and releasing it during peak demand, PCMs contribute to energy savings and grid stability.
4. Longevity: PCMs can undergo numerous phase change cycles without significant degradation, making them durable and reliable.
5. Environmentally friendly: Some bio-based PCMs and eco-friendly additives in composite PCMs align with sustainable practices and contribute to a reduced carbon footprint.

2.3.2 Limitations:

Limited operating temperature range: PCMs have specific melting and solidification temperatures, limiting their applications in extreme temperature conditions.

1. Heat transfer limitations: The rate of heat transfer during phase change can be relatively slow, affecting the overall performance in certain applications.
2. Phase segregation: In composite PCMs, phase segregation may occur over time, affecting their overall thermal performance and stability.
3. Cost considerations: Some high-performance PCMs can be expensive, impacting the economic feasibility of certain applications.

Overall, PCMs offer significant advantages for thermal energy storage applications, but their successful implementation requires careful consideration of their specific properties and limitations for each intended use case. Advances in materials science and engineering continue to expand the range of available PCMs, enabling more efficient and sustainable thermal energy storage solutions.

3. Applications Of Phase Change Materials

3.1 Building and Construction
3.2 Solar Energy Systems
3.3 Electronics Cooling
3.4 Thermal Comfort in Textiles
3.5 Cold Chain Management
3.6 Other Emerging Applications

Applications of Phase Change Materials:

Phase Change Materials (PCMs) have found diverse applications in various industries and technologies due to their unique thermal energy storage capabilities. Some of the key applications of PCMs are as follows:

3.1 Building and Construction:

In the building and construction sector, PCMs are utilized to enhance the thermal performance of buildings, contributing to energy efficiency and occupant comfort. PCM-enhanced building materials, such as gypsum boards or concrete, are integrated into walls, ceilings, and floors. During high-temperature periods, the PCMs absorb excess heat from the indoor environment, reducing the need for air conditioning and lowering cooling costs. Conversely, during cooler periods, PCMs release the stored heat, providing passive heating benefits and maintaining a comfortable indoor temperature. PCM-based building envelopes play a crucial role in creating energy-efficient and sustainable buildings, contributing to reduced energy consumption and greenhouse gas emissions.

3.2 Solar Energy Systems:

PCMs are employed in solar energy systems to store and release thermal energy generated from solar collectors. During periods of high solar radiation, the PCM absorbs excess heat, which can be used later when solar energy is not available, such as during the night or cloudy days. This thermal energy storage capability enables continuous energy supply and enhances the efficiency of solar thermal systems. PCM-based solar energy storage solutions are particularly valuable in off-grid or remote areas, where access to a stable power grid is limited.

3.3 Electronics Cooling:

Electronics cooling is essential for maintaining the optimal operating temperature of electronic components and devices to ensure their reliability and longevity. PCMs with high thermal conductivity and specific heat capacity are used as thermal interface materials or heat sinks in electronic devices. They efficiently absorb and dissipate heat generated during device operation, preventing overheating and ensuring optimal performance. PCM-based cooling solutions have gained popularity in electronic devices, computers, and mobile devices, where efficient thermal management is critical.

3.4 Thermal Comfort in Textiles:

PCM-infused textiles offer enhanced thermal comfort to users in clothing and bedding. These textiles contain microencapsulated PCMs, which can absorb or release heat based on ambient conditions and body temperature. During warm conditions, the PCMs absorb body heat, providing a cooling effect, while in cooler conditions, they release stored heat, offering warmth. PCM-enhanced textiles promote more comfortable and energy-efficient solutions for thermal regulation, especially in extreme weather conditions.

3.5 Cold Chain Management:

In cold chain management, maintaining the desired temperature range during the storage and transportation of temperature-sensitive goods, such as pharmaceuticals and perishable food items, is crucial. PCMs are integrated into packaging materials and insulated containers to provide passive temperature control. During refrigeration, PCMs absorb excess cold and prevent temperature fluctuations. Subsequently, during transportation or power outages, PCMs release stored cold to maintain the required temperature, minimizing spoilage and wastage of sensitive products.

3.6 Other Emerging Applications:

The versatility of PCMs has led to ongoing research and exploration of new applications. Some emerging areas of interest include thermal energy storage for electric vehicles, waste heat recovery systems, and temperature regulation in advanced medical devices. As technology and materials science continue to evolve, new and innovative applications for PCMs are likely to emerge.

Phase Change Materials have a wide range of applications across various industries and technologies. Their ability to efficiently store and release thermal energy during phase transitions makes them valuable in enhancing energy efficiency, reducing environmental impact, and improving overall system performance in numerous applications. As research and development in PCM technology continue to progress, their adoption is expected to grow, driving advancements in sustainable and efficient thermal energy storage solutions.

4. Selection Criteria For Phase Change Materials:

PCMs can reduce the energy needs of cooling systems and indoor temperature fluctuations, however, for PCMs to be effectively implemented for passive cooling in the building envelope, several selection criteria must be considered. From a physical point of view, the melting point of the PCM should be in the range of 10 °C to 30 °C to provide thermal comfort for occupants. This temperature should be selected with respect to average day and night temperatures and other climatic conditions of the building site [65,66]. Thermodynamically, the PCM should have high latent heat per volume unit, which is an important factor in building applications because it means that with lower volume, the PCM can absorb/release higher amounts of energy leading to a lighter building envelope [67]. Moreover, it should also have a large specific heat capacity (Cp) [68]

The selection of Phase Change Materials (PCMs) is critical to ensure their optimal performance and efficiency in specific applications. Various criteria must be considered to match the PCM properties with the requirements of the intended use. The following are key selection criteria for PCMs:

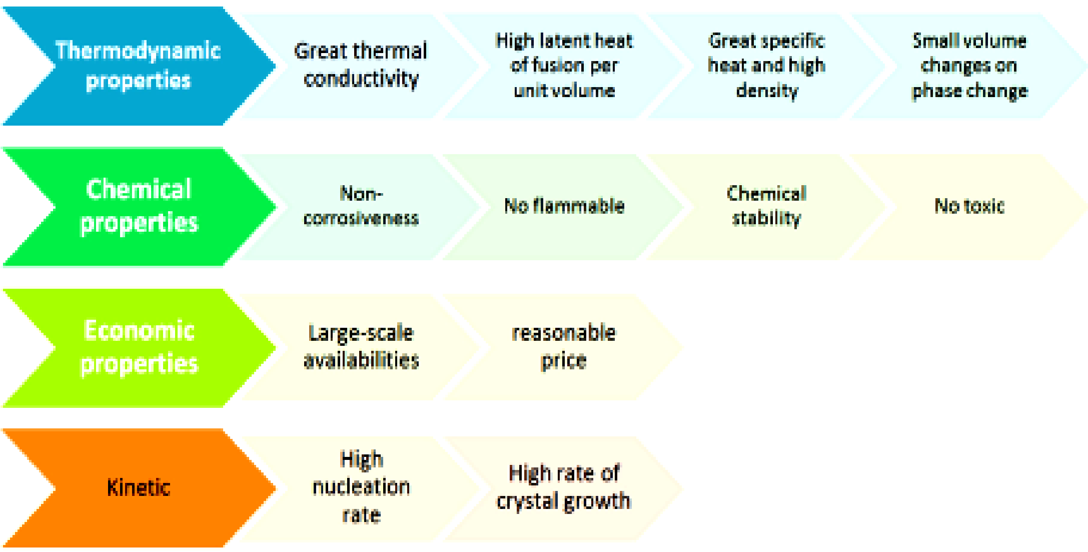

Fig. 3: Selection criteria based on PCM characteristics Renew Sustain Energy Rev 2013;26:425–36

4.1 Thermal Properties:

4.1.1 Melting and Solidification Temperatures:

The melting and solidification temperatures of PCMs should align with the desired operating temperature range of the application. Selecting a PCM with a suitable phase change temperature ensures efficient energy storage and release during the desired time frame.

4.1.2 Latent Heat:

The latent heat of fusion is a crucial parameter that determines the amount of thermal energy absorbed or released during the phase transition. Higher latent heat values indicate higher energy storage capacity, making the PCM more effective in storing energy.

4.1.3 Thermal Conductivity:

Thermal conductivity influences the rate at which heat is transferred into or out of the PCM. PCMs with high thermal conductivity ensure efficient heat transfer during phase change, enhancing overall system performance.

4.1.4 Specific Heat Capacity:

The specific heat capacity of a PCM determines its ability to store heat even without undergoing phase change. PCMs with high specific heat capacity can absorb and release additional heat beyond the phase transition, contributing to improved thermal regulation.

4.2 Chemical Stability:

Chemical stability is crucial to ensure the long-term performance and reliability of PCMs. PCMs should be chemically inert and stable to prevent degradation, decomposition, or reactions with other materials in the system, which could lead to reduced effectiveness and potential hazards.

4.3 Physical and Mechanical Properties:

4.3.1 Density:

The density of the PCM affects its volumetric energy storage capacity. PCMs with higher density can store more energy per unit volume, making them suitable for applications with space constraints.

4.3.2 Volume Change during Phase Transition:

Some PCMs undergo volume changes during phase transitions, which can lead to mechanical stresses and potential damage to encapsulation materials. Minimizing volume changes is essential to ensure long-term stability and reliability.

4.3.3 Compatibility with Encapsulation Materials:

PCMs are often encapsulated to facilitate their integration into various systems. The compatibility between the PCM and the encapsulation materials is crucial to prevent leakage, chemical interactions, or degradation, ensuring the PCM's proper functioning and safety.

4.4 Cost and Availability:

The cost-effectiveness and availability of PCMs are essential considerations for practical implementation. PCMs that are readily available at reasonable costs are more attractive for large-scale applications.

4.5 Environmental Impact:

4.5.1 Life Cycle Assessment:

A life cycle assessment of PCMs considers their environmental impact throughout their entire lifecycle, from raw material extraction to production, use, and disposal. Choosing environmentally friendly PCMs contributes to sustainable energy storage solutions.

4.5.2 Biodegradability:

Biodegradable PCMs are desirable, especially for applications where disposal is challenging. Biodegradable PCMs reduce environmental concerns and provide a more sustainable option.

4.6 Reliability and Durability:

PCMs must exhibit long-term reliability and durability, particularly in applications with numerous phase change cycles. PCMs that maintain their thermal properties over extended periods without degradation are preferred.

4.7 Scalability and Practicality:

PCMs should be scalable to meet the requirements of the intended application. Practical considerations, such as ease of integration, handling, and maintenance, are crucial for successful implementation selecting the appropriate Phase Change Materials involves a thorough evaluation of their thermal properties, chemical stability, physical and mechanical properties, cost, environmental impact, reliability, and practicality. The optimization of these criteria ensures the efficient and sustainable use of PCMs in various thermal energy storage applications.

5. Selection Process And Tools For Phase Change Materials:

The selection of Phase Change Materials (PCMs) requires a systematic and data-driven approach to match the specific requirements of the intended application. Several tools and methodologies are available to aid in the PCM selection process, including material databases, numerical simulations, and experimental characterization.

When choosing a phase change material (PCM), it's important to consider various factors. An optimal PCM should exhibit a substantial heat of fusion, excellent thermal conductivity, high specific heat, and density. Additionally, it should demonstrate long-term reliability through repeated cycles and consistent and reliable freezing behavior.

Table 1: Thermal properties of common organic PCMs

Name	Type	Tm (°C)	Latent heat (kJ/kg)	ρ (kg/m3)(sol)	ρ (kg/m3)(liq)	Cp (J/kg) (sol)	Cp (J/kg)(liq)	k (W/m K)(sol)	k (W/m K) (liq)	thermal expansion(k-1)
Octadecane	Paraffin	29	244	814	724	2150	2180	0.358	0.152	0.00091
Heneicosane	Paraffin	41	294.9	791	773	2100	2386	0.14	0.145	-
Tricosane	Paraffin	48.4	302.5	770	777.6	2210	2181	0.15	0.124	-
Tetracosane	Paraffin	51.5	207.7	799	773.6	2200	2924	0.16	0.137	-
IGI 1230A(isodecyl acrylate)	Blended paraffin	54.2	278.2	880	770	2800	2800	0.25	0.135	-
Oleic acid	Fatty acid	13	75.5	870	871	2300	1744	0.168	0.103	-
Capric acid	Fatty acid	32	153	1004	878	1950	1720	0.21	0.153	-

Table 2: Thermal properties of common inorganic PCMs

Chemical formula	Name	Peak melt point (°C)	Latent heat (kJ/kg)	Density (kg/m3)(solid)	Density (kg/m3) (liq)	Cp (J/kg)(solid)	Cp (J/kg)(liq)	Thermal conductivity (W/m K)(solid)	Thermal conductivity (W/m K) (liq)	thermal expansion(k-1)
MgCl2 · 6H2O	**Magnesium chloride hexahydrate**	**117**	**168.6**	**1569**	**1450**	**2250**	**2610**	**0.694**	**0.579**	**-**
CaCl2 · 6H2O	**Calcium chloride hexahydrate**	**29**	**170 – 192**	**1802**	**1562**	**2060**	**2230**	**0.58**	**0.561**	**0.0005k-1**
NaSO4 · 10H2O	**Glauber's salts**	**32**	**251**	**1485**	**1330**	**1760**	**3300**	**0.61 .**	**0.544**	**-**
NaNO3	**Sodium nitrate**	**307**	**172**	**2260**	**1910**	**1655**	**1655**	**0.57**	**0.5**	**-**
KNO3	**Potassium nitrate**	**333**	**266**	**2110**		**1439**	**1480**	**0.62**	**0.5**	**-**

Table 3: Thermal properties of common metallic PCMs

Name	Tm (°C)	Latent heat (kJ/kg)	ρ (kg/m3)	Cp (kJ/kg)	k (W/m K)	thermal expansion(k-1)
Cesium	28.65	16.4	1796	0.236	17.4	0.0000974
Gallium	29.8	80.1	5907	0.237	29.4	0.0000187
Indium	156.8	28.59	7030	0.23	36.4	0.0000321
Tin	232	60.5	730	0.221	15.08	0.000022
Bismuth	271.4	53.3	979	0.122	8.1	0.0000134
Zinc	419	112	7140	0.39	116	0.0000302
Al59-35Mg-6Zn	443	310	2380	1.63	170	0.000024
Al54-22Cu-18Mg-6Zn	520	305	3140	1.51	188	0.00002
Al65-30Cu-5Si	571	422	2730	1.3	210	0.000024
Al88-Si12	576	560	2700	1.038	160	-
Mg	648	365	1740	1.27	156	-
Al	661	388	2700	0.9	237	-

5.1 Material Databases and Repositories:

Material databases and repositories are valuable resources that provide a vast collection of data on various PCMs. These databases contain information on the thermophysical properties, chemical composition, phase change temperatures, latent heat, specific heat capacity, thermal conductivity, and other relevant characteristics of different PCMs. Researchers and engineers can access these databases to compare and analyze the properties of various PCMs, allowing them to shortlist candidates suitable for their specific application.

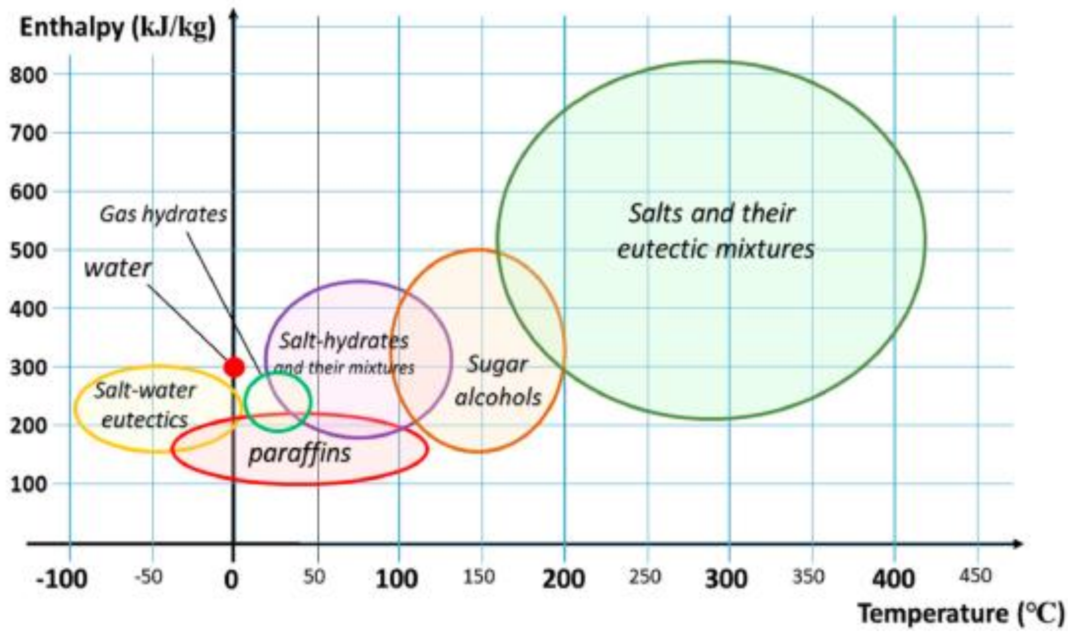

Fig. 4: Melting range and melting enthalpy for different PCM types (Baetens R, Petter B, Gustavsen A.2010)

Some examples of material databases and repositories for PCMs include: National Institute of Standards and Technology (NIST) ,Materials Data Repository, European Thermodynamics Database (ETH Zurich), Thermophysical Properties of Materials for Nuclear Engineering Database (IAEA)

5.2 Numerical Simulation and Modeling:

Numerical simulation and modeling techniques play a crucial role in predicting the behavior and performance of PCMs under different conditions. These tools offer a cost-effective and time-efficient means to explore a wide range of PCM candidates and assess their feasibility in specific applications.

Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) simulations are commonly employed to model heat transfer and phase change processes in PCM systems. Through numerical simulations, researchers can analyze temperature distributions, heat transfer rates, and phase change behavior of various PCMs in different geometries and configurations. This enables them to optimize the PCM selection and system design before conducting physical experiments.

5.3 Experimental Characterization:

Experimental characterization is a fundamental aspect of the PCM selection process, as it provides essential data to validate simulation results and understand the actual behaviour of PCMs under real-world conditions. Experimental techniques are used to measure various thermo physical properties of PCMs, including: Differential Scanning Calorimetry (DSC) to determine melting and solidification temperatures and latent heat. Heat flow measurements to assess specific heat capacity. Thermal conductivity measurements using methods like the transient hot-wire technique or guarded hot plate method. Density measurements.
Volume change during phase transition using dilatometry.

Experimental characterization also involves assessing other factors like chemical stability, compatibility with encapsulation materials, and long-term reliability. Real-world testing is essential to evaluate the practical performance of PCMs and identify any challenges or limitations that may arise in the intended application.

Combining Material Databases, Numerical Simulation, and Experimental Characterization:

An effective PCM selection process often involves combining data from material databases, numerical simulations, and experimental characterization. The material databases help researchers identify potential PCM candidates with suitable thermophysical properties. Numerical simulations assist in evaluating the PCM behavior and performance under different conditions, guiding the shortlisting of candidates. Experimental characterization validates the simulation results and ensures that the selected PCM meets the application requirements in terms of reliability, durability, and practicality.

By utilizing a combination of these tools, researchers and engineers can make informed decisions when selecting the most appropriate Phase Change Materials for specific thermal energy storage applications. This approach helps optimize system performance, enhance energy efficiency, and promote the adoption of sustainable and effective thermal energy storage solutions.

6. Challenges And Future Perspectives For Selection Of Phase Change Materials

Phase Change Materials (PCMs) offer immense potential for thermal energy storage applications, but their successful selection and implementation are not without challenges. Addressing these challenges and exploring future research and development opportunities are crucial to advancing the use of PCMs and unlocking their full potential. The following sections discuss the main challenges and future perspectives for PCM selection:

6.1 Technological Challenges:

6.1.1 Limited Operating Temperature Range:

One of the significant technological challenges in PCM selection is finding PCMs with suitable melting and solidification temperatures for specific applications. The range of available PCMs covers only a portion of the temperature spectrum, limiting their use in extreme temperature conditions.

6.1.2 Heat Transfer Limitations:

During the phase change process, the rate of heat transfer can be relatively slow, particularly in large-scale applications. This limitation affects the overall efficiency and performance of PCM-based systems.

6.1.3 Thermal Cycling Stability:

Repeated phase change cycles can lead to degradation or phase segregation in some PCMs, impacting their long-term stability and performance.

6.1.4 Volume Change and Mechanical Stress:

Certain PCMs undergo volume changes during phase transitions, leading to mechanical stresses that can affect the integrity of encapsulation materials and reduce the PCM's reliability.

6.2 Economic and Market Barriers:

6.2.1 Cost and Availability:

Some high-performance PCMs can be expensive, making them less economically feasible for certain applications. The availability of specific PCMs can also be limited, hindering their widespread adoption.

6.2.2 Infrastructure and Integration Costs:

PCM-based systems may require specific infrastructure and integration, leading to additional costs and challenges during implementation.

6.2.3 Market Acceptance and Awareness:

The relatively novel nature of PCM technology may lead to resistance or hesitation from industries and consumers to adopt PCM-based solutions. Increasing market acceptance and awareness is essential for broader market penetration.

6.3 Research and Development Opportunities:

6.3.1 Advanced PCM Formulations:

Continued research in material science and chemistry presents opportunities for developing novel PCM formulations with enhanced thermal properties, improved thermal stability, and expanded operating temperature ranges.

6.3.2 Nano-enhanced PCMs:

Integrating nanoparticles or nanomaterials into PCMs can significantly enhance their thermal conductivity and mechanical properties, addressing heat transfer limitations and improving overall performance.

6.3.3 PCM Composites and Encapsulation Techniques:

Developing innovative encapsulation techniques and composite PCMs can mitigate volume change issues and enhance compatibility with encapsulation materials, leading to more reliable and durable PCM systems.

6.3.4 Hybrid Energy Storage Systems:

Combining PCMs with other energy storage technologies, such as sensible heat storage or latent heat storage with other materials (e.g., thermochemical materials), presents opportunities for designing hybrid energy storage systems that offer improved overall performance and flexibility.

6.3.5 Sustainable PCMs:

Efforts to explore and develop biodegradable and bio-based PCMs align with sustainability goals and can address environmental concerns associated with PCM disposal.

6.3.6 Material Informatics and Machine Learning:

Advancements in material informatics and machine learning techniques can accelerate PCM discovery and optimization by predicting material properties and behavior, reducing the need for extensive experimental screening.

6.3.7 PCM Standardization and Regulations:

Standardization of PCM testing procedures and regulations for PCM use in specific applications can promote market adoption, ensure product quality, and facilitate compliance with industry standards.

While Phase Change Materials hold great promise for thermal energy storage applications, there are several challenges that need to be addressed to fully exploit their potential. Future research and development efforts should focus on overcoming technological limitations, addressing economic barriers, and exploring novel PCM formulations and integration techniques. By proactively addressing these challenges and pursuing research opportunities, PCM technology can continue to evolve and make significant contributions to sustainable energy storage solutions and efficient thermal management in diverse industries and applications.

7. Conclusion

It was found that the organic type (particularly paraffin) drew the most attention from scholars owing to its appropriate characteristics, such as reasonable price, stability, non-corrosivity and high heat of fusion. However, paraffin suffers from low thermal conductivity. Even though other types of PCM, such as salt hydrates, demonstrated suitable properties, their application was found to be limited.

In this study is presented a new database to help during the selection process of PCM depending on the requirements of the application. PCM are classified by working temperature of the application and nature/family of the PCM as well.

Advantage and disadvantage of selecting a PCM will depend on the nature of the PCM. Because of this reason, this database is innovative and interesting

A brief comparison between the different types of PCM

Type	Organic material		Inorganic material		Eutectics
	Paraffin	Non-paraffin (fatty acids)	Salt hydrates	Metallic	
Melting point	-12 to 71 °C	7.8-187 °C	11-120 °C	30-96 °C	4-93 °C
Latent heat	190-260 kJ/kg	130-250 kJ/kg	100-200 kJ/kg	25-90 kJ/kg	100-230 kJ/kg
Characteristics	1.Latent heat & melting point rise with the number of carbon 2.Most applied PCM	1.Vast melting point range 2.A wide range in latent heat of fusion	1.Wide interests for study 2. It is a solution of water and inorganic salts	Not broadly studied because of high density, cost, and other technical limitations.	Includes two or more of PCMs
Cost	Fairly expensive	2-3 times more expensive than paraffin	Reasonable price	Costly	Costly
Merits	1.No segregation & supercooling 2.Chemically stable 3.High latent heat 4.High compatibility with all metal containers 5.Safe and non-reactive	1.Sharper phase transformation	1.High availability 2.Shape melting point 3.Appropriate thermal conductivity 4.Small volume variation 5.Suitable density	1.High heat of fusion per unit volume. 2.High conductivity	1.Great latent heat per unit volume 2.Numerous conductivity
Defects	1.Poor conductivity 2.Do not have sharp melting point 3.High flammability 4.Considerable volume charge	1.Partly corrosive 2.Flammable, should not exposed to excessively high temperature, flames or oxidizing agents	1.Supercooling 2.Corrosive 3.Due to higher density, salts settle down at bottom and reduce active volume	Low heat of fusion per unit weight and low specific heat	Low heat of fusion per unit weight

SOURCE: May 2021AIP Conference Proceedings 2339(1):020131

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