A short review on the Industrial applications of phase change materials

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Abstract. Latent heat storage is the best possible ways of storing thermal energy. This provides higher storage density with very small temperature difference between storing and releasing heat energy. This review paper provides a detailed classification of Phase change materials (PCMs) along with their varied applications. To the best of author's knowledge till now, nearly all the applications of PCMs are listed in this short review. The gap between demand and supply of energy can be bridged by using PCMs and thereby it has become a very attractive technology. The use of a PCMs in thermal insulation, thermal comfort and energy storage have been tested in many applications.

Keywords: Phase change materials (PCMs), applications, latent heat storage.

1.0 Introduction

The most efficient procedure for storing thermal energy is by latent heat storage which in turn uses Phase Change Materials (PCMs). Different systems are applied with PCMs for increasing the thermal energy storage capacity [1, 2]. The usage of PCMs provides isothermal behavior and high heat storage capacity [3] in the process of charging and discharging as compared to sensible heat storage. For the betterment in operational performance of industrial systems thermal energy storage (TES) systems are necessary. The two basic requirements of TES are high power capacity and high energy storage density.

The phase change from solid to liquid is required for storage of huge quantity of energy. The PCMs can be inorganic like aqueous salt solutions and organic like fatty acid and paraffin waxes. They show a range of melting temperature when they are used as mixtures and single melting temperature in pure form. The literature review suggests many applications of PCMs like domestic hot water tanks, space cooling and heating in case of buildings, peak load shifting and solar energy applications [4].

Many researchers have stated applications and classification of PCMs but this paper deals with nearly all the applications of PCMs in all sorts of temperature ranges. Many new applications like PCMs in battery thermal management, PCMs in textiles and PCMs in automotive applications are dealt in this paper.
2.0 Classification of Phase change materials

The PCMs can be classified into three types namely organic, inorganic and eutectic PCMs. The detailed differentiations are shown in figure 1.

![Figure 1 Classification of PCMs][5]

2.1 Organic PCMs

They are of basically two types non paraffin and paraffin based PCMs, the later involves glycol, esters, fatty acids and alcohol. They are safe, stable having latent heat of fusion more than 180 kJ/Kg. These PCMs are accessible in large temperature range (15-45°C). The paraffin based PCMs are toxic, flammable and can have very low thermal conductivity (0.1 to 0.35 W/mK). Figure 2 shows the paraffin wax based PCM.

![Figure 2 Picture of an organic PCM][6]

2.1.1 Paraffin

Paraffin wax is a mixture of lengthy alkane chain. It's chemical formula is \( \text{CH}_3(\text{CH}_2)_n\text{CH}_3 \) where \( n \) is the number of chains and iso-paraffin and cyclo-paraffin are also part of mixture [1]. The chain length also determines the actual melting temperature as shorter the chain higher the melting temperature therefore a high number of melting points are available. However, it's low thermal conductivity limits its applications but still it can be improved by adding materials like graphene to paraffin wax.

2.1.2 Fatty acids
Their chemical formula is \( CH_3(CH_2)_nCOOH \) with 'n' being the number of chains. They have got more cycling stabilization than paraffin wax and characteristics common to paraffin.

2.2 Inorganic PCMs

The composition of inorganic PCMs is of inorganic molecules. The typical examples of it are metallic PCMs and hydrated salts. These PCMs are thermally safe, have a wide range of melting temperatures (5-130\(^\circ\) C) and also the latent heat is much higher in the range of 220-250 kJ/kg. It's disadvantage is insufficient long term stability which limits its use as a latent heat storage systems [5]. This poor property is due to poor stability of material properties due to thermal cycling and corrosion between container and PCM. The inorganic PCM is shown in figure 3.

![Figure 3 Picture of an inorganic PCM in a container [5]](image)

2.2.1 Hydrated salt

Hydrated salts have over the years shown great ability as PCMs due to its wide melting range as mentioned above in inorganic PCMs. Some examples are sodium sulfate decahydrate and disodium hydrogen phosphate decahydrate [7]. They are shown in figure 4[5].
2.2.2 Metallic PCMs
They have got high thermal conductivity in the range of 15 W/mK [8] and high specific heat (185 kJ/kg) than organic PCMs but they 2.5 times more costly than organic PCMs like paraffin too. The different examples of these PCMs are paraffin copper foam composite and composites formed by mixing gallium in bimetallic alloys like GaIn and GaSn.

2.3 Eutectic PCMs
The inorganic and organic compounds when combined in a specific atomic ratio are called eutectic mixtures. They have a higher latent heat and precise melting point.

3.0 Potential Applications in Various fields
This review tries to combine the applications of PCMs in variety of fields. The novelty of this work is that all the general applications related to almost all the PCMs can be found in this review.

3.1 PCMs related cold storage applications
Due to its high thermal inertia PCMs offer thermal protection. The thermal protection offered can be used in many heat and cold storage applications like storage and transport of beverages, Protection of solid food, blood derivatives, pharmaceutical products, electronic circuits, biomedical products and cooked food etc. Some of the varied applications of cold storage as found in the literature are medical applications like transport of blood, organs and cold therapies, Thermal protection of food and ice creams etc, regasification terminals in industrial cooling systems, cooling systems for reduction of installed power and air
conditioning applications[4]. The concept of catering application is schematically shown in figure 5 [4].

![Figure 5 Concept of catering applications](image)

The containers for transport of blood is as shown in figure 6 [4].

![Figure 6 Containers to transport blood and organs containing PCM](image)

PCMs can also be used for performance enhancement of refrigerators another important phase change applications[9].

3.2 PCM used in buildings applications
The PCM enhanced Wallboards are less costly and are used in the buildings for thermal comfort. The PCMs enhanced clay tiles and PCMs enhanced concrete[10] or thermocrete are technologies for enhancing thermal comfort in buildings .The PCMs improved insulation materials for buildings is yet another applications of PCMs in buildings[11, 12].The PCM enhanced building Insulation materials are of polyurethane foam and cellulose . These mixed with PCMs are kept in residential wall cavities .Floor warming by under floor heating system
is another application of PCM used in buildings[13, 14]. Other PCMs application in buildings are pipe insulations, hot water heat storage and cool thermal energy storage. PCM shutters placed outside of the window area in buildings [7] are useful for thermal comfort as it stores and dissipates heat when required. PCMs can be used also in building[15] air conditioning applications [16] for cooling and heating application in different seasons. PCMs are also used in asphalt pavements[17] for regulating the temperature and is a wonderful candidate for reducing rutting and thermal cracking[18].

3.3 PCMs used in solar energy based applications

Simple reheat rankine cycle and Direct steam generation is used by PCMs solar thermal power plants to store thermal energy. The systems are highly cost effective as stored energy is released at the time of need. Another application is PCM based solar energy water heating systems where warm water is supplied in the night time in areas having cold climate. Similarly PCM based solar cooker can supply energy in off sunshine hours. PCM based solar dryer and PCM based solar green house for drying purposes as well as production of plants is also the application of PCMs[19]. The schematic for solar heating system and solar cooker is described in figure 7 and 8 [19].

![Figure 7 Schematic of solar water heating system[19]](image-url)
3.4 PCM used in automotive and spacecraft applications
Battery thermal management systems use PCMs. Electric vehicles (EVs) and Hybrid vehicles (HEV) utilize PCMs for proper thermal operation of battery packs. To avoid expensive, battery overheating and premature batteries failure PCMs are used for automotive applications[5, 20]. Due to fluctuation of temperature in space craft PCMs can be used as materials for thermal control in spacecrafts[21]. They are used as thermal capacitors with internal zones filled by PCMs (paraffin wax) [22]. The battery system and battery module by adding PCM/graphite is shown in figure 9.

3.5 PCMs used in textile operation
The cooling and heating applications in industries like textile, construction and transportation are fulfilled by PCMs. The prime aim of textiles is to defend us against different climatic conditions. Next to our skin[23] the perfect condition is being kept by layers of PCMs embedded in the cloths or textiles. So, clothing are designed to keep ourselves warm during winter season and cold during summer season by charging and discharging of PCM layers.
inside the garments [24]. The schematic diagram for electro spinning of fibres used in textile industries and the hydrocarbon based PCM are as shown in figure 10.

Figure 10 The schema of the melt coaxial electrospinning setup [24]

3.6 PCMs used in photonics applications
In optoelectronic systems capable of display and multi level storage PCMs are used as metamaterials. On transmission from amorphous stage to crystalline phase short electric pulses can be utilized for switching between these states making it attractive for photonic applications [25].

3.7 PCMs used in heat exchanger and applications
For the increment of heat storage and heat transfer rate PCMs are used in heat exchangers. The PCMs also reduce heat exchanger size and pipe line size [22]. The cylindrical heat exchanger is as shown in figure 11 for the thermal energy storage system where fatty acid and paraffin wax are used as PCMs and PCMs surrounds the heat exchanger.
Figure 11 Cylindrical heat exchanger of thermal energy storage system (TES) at solar energy research centre (SERC)

The thermal energy can be stored by PCM based various types of heat exchanger[26] as shown in figure 12.

![Figure 12 PCM-based shell and tube heat exchangers: a) cylinder model, b) pipe model, and c) multi-tube model[26]](image)

3.8 PCMs used in microelectronic applications

The PCMs having chalcogenide glasses are used as non volatile memory devices [16]. They are called non volatile because it can retain information even when electric power is not applied. They are also applied for cooling and thermal management of micro sized circuits.

3.9 Batteries thermal management system (BTMS)

BTMS maintains the temperature within the battery to an optimal range and maintains temperature evenness throughout the battery module. Thermal safety as well as lifespan of batteries can be incremented by BTMS[27]. By the help of BTMS batteries can be used at various locations having different temperatures. The basic flow diagram for thermal management using batteries are shown in figure 13. Apart from this PCMs are used in photo voltaic thermal systems for thermal energy storage applications [28]
Figure 13 Thermal management in battery system[27]

Table 1 Different PCM with their applications

| Reference Number | Name of the PCM | Applications |
|------------------|----------------|--------------|
| [29]             | Organic PCM and Inorganic PCM like salt and metal hydrates | Building and Residential applications. Air-conditioning with solar hot water yielding applications |
| [30]             | Tetradecane | Thermal energy storage applications in Space shuttles |
| [31]             | Salt hydrates, paraffin wax, bio-PCM and fatty acid | Building applications |
| [32]             | Form stable PCM. Multiwalled carbon nanotube with graphene nano platelets cross linked with polyethylene glycol-600 | Thermal management applications |
| [33]             | Caprylic acid based PCM. | Packaging and Thermal buffering applications |
| [34]             | PCM-RT25HC | Energy performance in different weather and building applications |
| [35]             | Polyethylene glycol, stearic acid paraffin a, 1-tetradeconal and n octadecane | Medical applications for tumour and cancer eradication, building application, electronics and solar applications |
| [36]             | Biochar PCM | Solar thermal energy applications for storage |
| [37]             | Paraffins RT 31 and RT 37 | In photovoltaic system for providing thermal and electric energy |
| [38]             | Paraffin based microencapsulated PCM | Building envelope applications |
| [39]             | Liquid PCM PARAFOR 18–97, Sasol) a commercial PCM | Building applications |
| [40]             | PCM eutectic solution | Refrigerator based cold storage application |
4.0 Conclusions
This review paper is based on diverse classification and versatile applications of PCMs. Excess energy is stored at higher temperatures and given back at a certain temperature of phase change. The energy savings reported are also high. Organic and inorganic PCMs are two major classes of PCMs. PCMs are chemically stable, non-corrosive and shows very little subcooling. These properties lead to its application in variety of fields like cold storage, buildings, solar energy, automotive and spacecraft, textile, photonics, heat exchanger and microelectronics. The table mentioned at the bottom before concluding remarks list the various applications of the PCM in various researches around the world. The research is ongoing and many more applications are yet to be discovered.

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