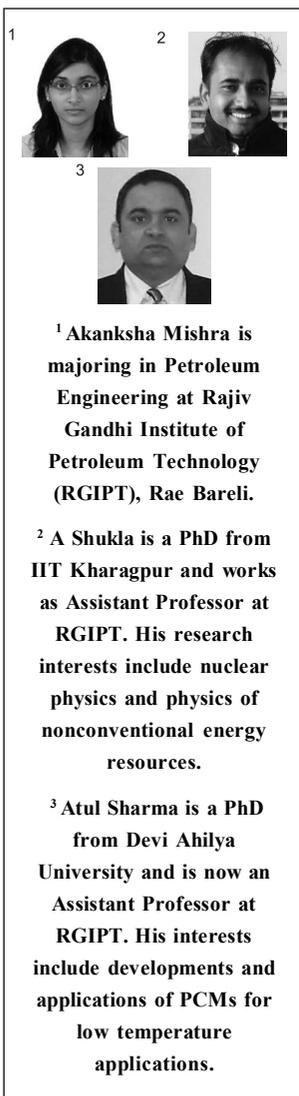


Latent Heat Storage Through Phase Change Materials

Akanksha Mishra, A Shukla and Atul Sharma



¹ Akanksha Mishra is majoring in Petroleum Engineering at Rajiv Gandhi Institute of Petroleum Technology (RGIPT), Rae Bareilly.

² A Shukla is a PhD from IIT Kharagpur and works as Assistant Professor at RGIPT. His research interests include nuclear physics and physics of nonconventional energy resources.

³ Atul Sharma is a PhD from Devi Ahilya University and is now an Assistant Professor at RGIPT. His interests include developments and applications of PCMs for low temperature applications.

Energy requirement is increasing day-by-day for all of us. Though the major demand comes in the form of electrical energy for domestic as well as the industrial sector, some of this demand can be reduced by appropriately utilizing thermal energy available via solar radiation. Phase change material (commonly known as PCM), which has become an attractive means to store thermal energy, has a wide range of applications in today's world. This article explains the PCM-based technology, its principle and its numerous applications in everyday life.

1. Introduction

Many efforts have been made to increase storage capacity while reducing storage volume for different materials. The examples are numerous: computer memory, electronic gadgets, power industry and so on. With a credit/debit card, one can easily carry large amounts of money in one's wallet as 'plastic money'. On similar lines, can one think of carrying an energy wallet too? To make it simple, can we store some thermal energy and use it as and when required? The answer is yes, we can!

A class of materials, called phase change materials (PCMs) are the key to this thermal energy storage technology. As the name suggests, these materials change their phase with a change in temperature. We know that materials can have three¹ phases, i.e., solid, liquid and gas, and materials change phases as pressure and temperature vary. One such example is water (liquid), which becomes ice (solid) when cooled and takes the form of steam (gas) when heated.

The temperature at which it boils (boiling point) or freezes (freezing point), varies with pressure, but is a constant at a given

Keywords

Phase change material, latent heat, latent heat storage system.



pressure. Indeed, water as a PCM and its virtue – to store heat – have long been used by humans for cooling/heating. Similarly, there are other materials available too, which can be used as PCM. This quality of storing heat is basically the latent heat of the material and is different for different materials.

¹ There is also a fourth phase called plasma.

1.1 Latent Heat

Latent heat is the heat released or absorbed by a body or a thermodynamic system during a constant-temperature process. A typical example is a change of state of matter, i.e., the phase transition process during which the temperature of the system remains constant even though heat is absorbed (or released) by the system. The latent heat that is associated with melting a solid or freezing a liquid is called the heat of fusion. The latent heat that is associated with vaporizing a liquid or a solid or condensing a vapor is called the heat of vaporization.

1.2 Latent Heat Storage System

Latent heat storage can be achieved through solid–solid, solid–liquid, solid–gas and liquid–gas phase changes. Solid–solid phase changes (see *Box 1*) are typically very slow making them an impractical form of storage. Also, even though the liquid–gas phase transition involves a higher heat of transformation than solid–liquid transitions, its application is not realistic as the thermal storage of the materials in gas phase requires large volumes or high pressures which make the system complex and impractical. Therefore, the only phase change used for thermal storage is the solid–liquid change.

Box 1. Solid–Solid Phase Changes

There are some materials which change their crystalline structure from one lattice configuration to another, when heated, i.e., they undergo solid to solid transformation. This transformation can involve latent heat comparable to the most effective solid/liquid PCMs and these materials can be utilized for those PCM applications where their slower speeds are not inconvenient. Since such materials undergo solid–solid phase change, there is no visible change in the appearance of the PCM (other than a slight expansion/contraction). Some examples of solid–solid PCMs are: micro-encapsulated paraffin (thermosorb), paraffin (eicosane, docosane, etc.), non-paraffin organics (beeswax), salt hydrates ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$), metallics (eutectic Bi–Cd–In).



Phase Change Material is a substance having a high heat of fusion which, on melting and solidifying at a certain temperature is capable of storing and releasing large amounts of energy.

Latent heat is an attractive way to store solar heat as it provides high energy storage density, i.e., a lot of energy can be stored in a very small volume. Also, it stores the energy at a constant temperature which widens the scope for the application of a latent heat storage system.

1.3 Phase Change Material

A PCM is the heart of any latent heat storage system. Having a high latent heat is not the only requirement to use a material as a thermal energy storage material. The desired PCM properties are:

- Melting point should be in the desired temperature range. For example, if we want to incorporate PCM in building materials, then the melting point of the PCM should be around the required room temperature.
- High latent heat of fusion per unit volume to store more energy in a given volume.
- High thermal conductivity to assist charging and discharging of energy.
- Low changes in volume during phase change and low vapor pressure to avoid containment problems.
- Non-flammable & non-toxic.
- Chemically stable.
- Low cost and low containment cost.

The main components of any latent heat thermal energy storage system are

- PCM: A suitable material having all the desired properties of a phase change material and having its melting point in the required temperature range.
- Heat Exchanger: A suitable heat exchange surface or a suitable heat carrying fluid for transferring the heat effectively from the heat source to the heat storage. Also, a lot of PCMs have poor thermal conductivity and thus require large heat exchange area.
- Container: A container for storage which is compatible with



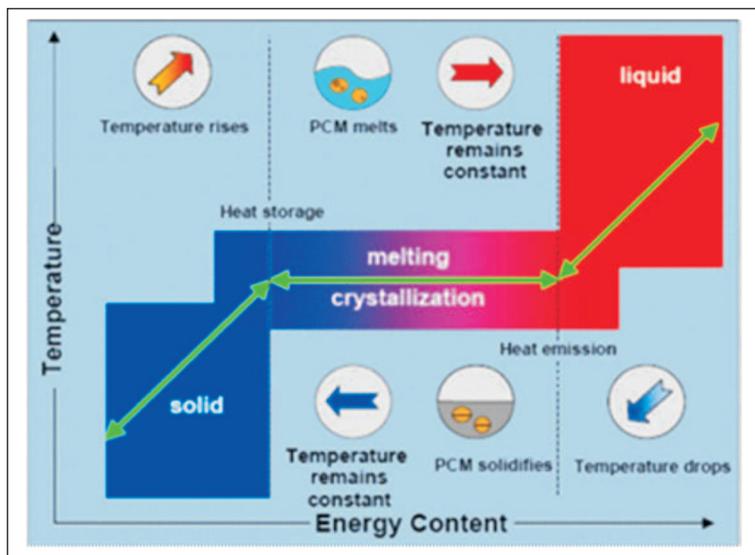


Figure 1. Variation of temperature with energy provided to a PCM.

the PCM as sometimes the PCMs are corrosive and thus require special containers.

PCMs are classified into three categories depending on their composition – organic PCMs, inorganic PCMs and eutectic PCMs (mixture of both).

1.4 Working of a PCM system

Figure 1 shows a typical solid–liquid PCM system. Initially, the PCM is in solid state. As the environmental temperature rises, it absorbs energy in the form of sensible heat². When ambient temperature reaches the melting point of the PCM, it absorbs large amounts of heat at an almost constant temperature. This continues until all the material is transformed to the liquid phase. In this way, heat is stored in a PCM and the temperature is maintained at an optimum level. When the environmental temperature around the liquid PCM falls, it solidifies again, releasing its stored latent heat. Thus, the managed temperature again remains consistent.

2. Applications of Phase Change Materials

A large numbers of PCMs have been found that melt and solidify

² In contrast to latent heat, sensible energy is the heat released or absorbed by a body or a thermodynamic system during processes that result in a change of the temperature of the system.

at a wide range of temperatures, which allows them to have diverse applications. With widespread development of PCM technology, its applications are also reaching an awing number with both, domestic and industrial utilization. Some of these include conditioning of buildings, cooling of electrical and heat engines, cooling food, beverages, milk, greenhouses, medical applications like – transportation of blood and hot-cold therapies, waste heat recovery, heating and cooling water, incorporation into textiles for human comfort, solar power plants, spacecraft thermal systems, etc. Some of the popular applications of PCM are discussed in the following sections.

2.1 Buildings

It's a well-known fact that houses with thicker walls take longer time to heat or cool during the day as the high-mass materials slow down the flow of heat. PCMs are an answer to this problem. PCMs can be incorporated into buildings in various ways but the three basic ways are:

- (i) In building walls, i.e., in wallboard, plaster, gypsum products and paints.
- (ii) In other building components like glass windows, shades, etc.
- (iii) In heat and cold storage units.

The application of PCMs in a building can have two different goals; first, using natural heat, i.e., solar energy for heating or night air for cooling, and second, using man-made heat or cold sources [1].

In summers, during the daytime, hot air from outside will melt the PCM as it passes through the building. The heat from the air will be stored as latent heat and the temperature of the air will decrease thus maintaining an optimum room temperature. During night-time, the air from the airconditioning system will refreeze the PCM (*Figure 2*). In winters, the same thing will happen except that a heater would be used. This has helped in reducing the size of the air conditioning plant and has also solved the problem of

The property of PCMs to store heat energy can be utilised for number of applications to increase human comfort.



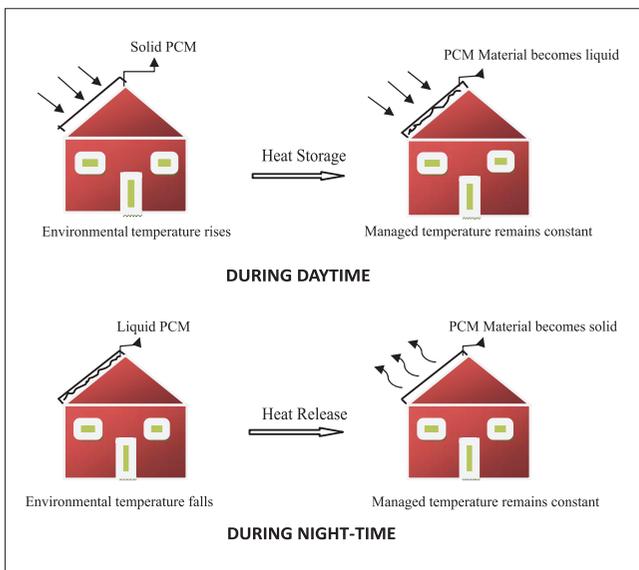


Figure 2. PCM application in a building.

overheating/cooling.

2.2 Solar Water Heating System

Solar water heaters are gaining tremendous popularity nowadays as they are relatively inexpensive and easy to maintain. A built-in storage-type water heater contains a layer of PCM filled at the bottom. During the sunshine hours, the water gets heated up which in turn transfers heat to the PCM below it. The PCM collects energy in the form of latent heat and melts. During off-sunshine hours, the hot water is withdrawn and is substituted by cold water, which gains energy from the PCM. The energy is released by the PCM as it changes its phases from liquid to solid.

2.3 Solar Cookers

One of the major domestic uses of solar energy is cooking using solar cookers. Due to the irregularity of solar radiation, the use of these solar cookers is limited. But if storage of solar energy is provided in a solar cooker, then the utility and reliability of these solar cookers would increase. A few studies have been conducted on latent heat storage materials in a box-type solar cooker to cook the food after sundown. Even though the solar cookers with a latent heat storage system are more expensive than the normal



solar cookers, they have good potential for mass rural and semi-rural applications. At present, further research is in progress on new PCMs which could be used effectively in solar cooking applications and make it more economical.

2.4 Cooling Helmets

The PCM helmet cooling system is simple and has the potential to be implemented as a practical solution to provide a comfortable experience to motorcycle riders and sportspersons. In 2006, Tan and Fok designed a helmet cooling system using PCM to absorb and store the users' body heat to achieve comfort cooling [2]. The PCM is packed into a pouch and placed such that it is in contact with the users. The heat from the users' bodies is conducted to the PCM so that the PCM temperature is maintained just below that of the users' body temperature. This keeps the user cool and alert. The cooling unit is able to provide comfort cooling up to 2 hours till the PCM is completely melted. The heat stored in the PCM pouch is discharged by immersing in water for about 15 minutes which solidifies the PCM before re-use.

2.5 Textiles

For industry workers, many-a-times specialised clothing is required that protects the workers from acute cold, intensive heat, high voltage, toxic chemicals, nuclear radiations, biological toxins, etc. Clothing is more comfortable if it can adjust to all types of environments. PCM can be used for fulfilling this requirement. PCMs that have their melting point within a temperature range that is around the human skin temperature can be incorporated within fibers or foams, or may be coated onto fabrics, in the form of microcapsules, to store and release body heat, as needed.

Studies have shown that skin temperature and sweat loss reduce significantly when vests made of PCM-treated fabric are used. Maintenance of the PCM treated fabric is easy. The melted PCM can be reused after dipping in ice water for about 15 minutes. User acceptance of this cooling vest is excellent. After series of successful tests, the vest is comfortably worn by the environmen-



tal control unit at the Cape Canaveral Air Station, USA and many other places for significant heat stress relief and has space applications as well. PCMs found in today's consumer products were originally developed for use in space suits and gloves to protect astronauts from extreme temperature fluctuations while performing extra-vehicular activities in space. Applications of phase-change textiles now include apparel, blankets, medical field, insulation, shoes, protective clothing and many others.

Applications of phase-change textiles now include apparel, blankets, medical field, insulation, shoes, protective clothing and many others.

2.6 Medical Applications

PCMs have a wide-range of medical applications, also, such as transportation of blood, vaccines, hot-cold therapies, etc.

Vaccines are effective only if they remain within a narrow temperature range, generally between 2–8°C. But the temperature inside the vaccine container changes when it is opened. In a hot climate with unreliable electricity, often ice packs are used to prevent overheating in the vaccine supply chain. But since ice cools the vaccines to less-than-recommended temperatures, they can freeze, becoming ineffective. Presently, a number of PCMs are under-trial which when integrated into vaccine-carrying boxes can increase the lifetime of vaccines upto a decade. PCM is slowly replacing water-based gel as a refrigerant by providing a customized phase change that the payload requires. It is being used for transportation of blood and various other temperature-sensitive products.

Junghanss *et al* at Heidelberg University have experimented with sodium acetate trihydrate³ as PCM and used it as heat application system for thermotherapy treatment of Buruli ulcers [3] *Table 1*. The reusable PCM-based heat application device was observed to be perfectly suited to treat Buruli ulcers in low resource countries.

³ This PCM is widely used in commercial pocket heat pads. It is easy to apply, rechargeable in hot water, non-toxic and non-hazardous to the environment.

Currently, there are gel pads with PCM available, for treatment of injured joints or limbs, for improving the thermal energy storage capacity of the gel pad. The PCM integrated pad may be encapsulated, formed into pellets, soluble, insoluble, or in any desirable form. The gel pad may be removed from the orthopaedic device



Material	Melting Point (°C)	Heat of Fusion (KJ. kg ⁻¹)	Specific Heat Cp (solid) (KJ. kg ⁻¹ . K ⁻¹)	Conductivity K (W. m ⁻¹ . K ⁻¹)	Application
Water	0	333.6	2.05	1.6–2.2	–
CaCl ₂ .6H ₂ O	26–29	190.8	1.088	–	Greenhouse
Acetamide	82	263	1.94	0.5	Solar cooker
N-octadecane	27	243.5	1.934	0.148–0.358	Building
Sodium acetate trihydrate	56,7	199	3.18	0.41–0.65	Thermotherapy
N-eicosane	36.5	247	2.46	0.1505	Cooling mobile phones, Textiles, Building
Stearic-myristic acid (80%–20%)	61-65	190.9	–	–	Solar water heating system
Climsel C28 (Salt Hydrate)	28	126	–	0.5–0.7	Cooling helmet
0.9 CH ₃ CONH ₂ + 0.1 Ca(NO ₃) ₂ .4 H ₂ O	27.7	141	2.51	–	Agricultural greenhouse

Table 1. Some commercially used PCMs and their properties.

and heated or cooled. Two different phase change materials may be included in the gel pad, one of which may be used for cold temperature therapy while the other is used for hot temperature therapy. Medical therapy products like cushions, rolls, belts, etc., have been developed based on a bound PCM in extremely fine form. These are very comfortable and the PCM material is non-toxic. Reheating these products is easy and release of absorbed heat takes place over 1–2 hours depending on the ambient temperature.

2.7 Agricultural Greenhouse

The use of solar agricultural greenhouses to increase plant quality and productivity has increased noticeably in the past few years. An effective greenhouse controls the internal temperature, hu-



midity, light intensity and internal gas composition with a judicious usage of energy. Because of this reason, a large number of passive solar greenhouses use latent heat storage materials. In a recent study, it has been found that metal complexes dissolved in a suitable PCM and its latent heat of fusion can be used for simultaneous control of temperature and light intensity in agricultural greenhouses. This may prove to be very effective and useful for cultivation of some delicate plants in fluctuating climate conditions.

It is clear that PCMs have a wide range of applications in every walk of life. Some of the PCMs that are being used commercially, for the above mentioned applications are given in *Table 1*.

3. Conclusion

With the declining supply of conventional sources of energy, the need and demand for the utilization of renewable sources has increased; Proper exploitation and storage of solar energy being one of them. Since the early 1980s, PCM technology has come a long way. With developments in this technology on almost a day-to-day basis, this technology is sure to become a prominent thermal storage technique in the near future.

Suggested Reading

- [1] Atul Sharma, V V Tyagi, C R Chen and D Buddhi, Review on thermal energy storage with phase change materials and applications, *Renewable and Sustainable Energy Reviews*, Vol.13, pp.318–345, 2009.
- [2] F L Tan and S C Fok, Cooling of helmet with phase change material, *Applied Thermal Engineering*, Vol.26, pp.2067–2072, 2006.
- [3] S Braxmeier, M Hellmann, A Beck, A Umboock, G Pluschke, T Junghanss, H Weinlaeder, Phase change material for thermotherapy of Buruli ulcer: modelling as an aid to implementation, *Journal of Medical Engineering & Technology*, Vol.33, No.7, pp.559–566, 2009.

Address for Correspondence

A Shukla

Rajiv Gandhi Institute of
Petroleum Technology
(RGIPT)

Rae Bareilly 229316, India.

Email:

amritanshu.shukla@gmail.com

