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An overview on types and working principle of phase change materials (PCMs)

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Abstract
PCMs are the substance which absorb and release huge amount of latent heat when they undergo changes in their physical state. Phase Change materials are gaining an enormous attention in almost all the fields and it became an important key player in textile industry these days. Thus, due to its popularity, the comparative reviews regarding different PCM and the working principle of PCMs is presented in this paper. Its helps the researchers in understanding the actual working principle and aids in selecting appropriate PCM with suitable properties.

Keywords: Phase change material, working principle, paraffin, non-paraffin, properties

1. Introduction

The major requisite of any textile is to afford utmost protection to the person who is wearing it from the extremities of weather, fire, heat, chemicals, radiation, high voltage, propelled bullets, biological toxins etc,. These days smart clothing is the key player of the textile industry. Smart clothing signifies the innovative class of wearable technology, which are engineered to be comfortable, aesthetic and "fit for purpose" to the consumers [1]. The textiles which are capable to sense and react to environmental condition and external stimuli are called smart textiles [2]. One of the trending intelligent materials in the current market is Phase Change Materials. PCM's are thermal storage substances which controls the temperature fluctuations of the products [3]. Phase Change Materials absorb and stores or releases heat according to the change in temperature during Phase Change Process. It is a process of transformation from one type of physical state to another physical state i.e. from solid to liquid and liquid to solid [4].

2. Working principle of PCMs

Phase change material is not a new subject and it exists in the universe in various forms [5], [6]. Phase change materials use chemical bonds for the storage and release of heat. Every material absorbs heat during heating process with its constant rise in temperature until it reaches its melting point. If the material is intended to change from solid to liquid, the energy captivated by the material is utilized for breaking down the bond responsible for solid structure and phase change occurs. The temperature stability is maintained until the PCM change entirely from solid to liquid state [3]. Releasing the stored heat energy in a reverse cooling/crystallization process to the surrounding environment PCMs can store great amount of latent heat energy and releasing the stored heat energy in a reverse cooling/crystallization process to the surrounding environment.

These materials are capable to store huge quantity of latent heat energy and releases into the surrounding environment through crystallization process or inverse cooling method [7]. The storage of thermal energy is crucial for the utilization of thermal energy. The general alternatives for thermal energy storage are latent heat utilization, utilization of heat of dilution, sensible heat utilization and reversible chemical heat utilization. Usually materials exists in 4 states such as liquid, solid, gas & plasma. The process of material adapting from one state to another state is called as phase change process. There are 4 types of phase change processes based on the state of substances like, solid to solid, solid to liquid, solid to gas and liquid to gas. Heat energy is either absorbed or released during the phase change process and that heat content is called as latent heat. This latent heat is an energy which is usually utilized for the conversion of substances from solid to liquid or from liquid to solid. In this way, the latent heat energy is utilized to produce heat-storage or thermo-regulated clothing and textiles [8].

PCMs could take a benefit of latent heat energy that released or stored in a material over a slight temperature range. They absorb energy in to the material during the heating process and releases the energy into environment through reverse cooling process. Thus, the insulation effect captivated by the PCMs entirely depend upon the time and temperature [9]. The mode of heat transfer strongly depends upon the phase of substance involved in the heat transfer process. If the material is solid, conduction is the prevailed mode of heat transfer, for liquid, convection heat transfer, and for vapor radiation and convection is the chief mode of heat transfer.

The phase change materials from liquid to solid and solid to liquid are only considered for textiles and clothing applications. The phase change from solid state to liquid occurs, when the melting temperature of the PCM reaches its exhaust level. Differential scanning calorimetry heating thermogram for phase change material melting is shown in Fig. 1. During this phase change, the PCM absorb huge quantity of latent heat from the surrounding environment. PCM might frequently converts between solid and liquid phases to consume their latent heat of fusion to absorb, release and store the heat or cold during the conversions [10].

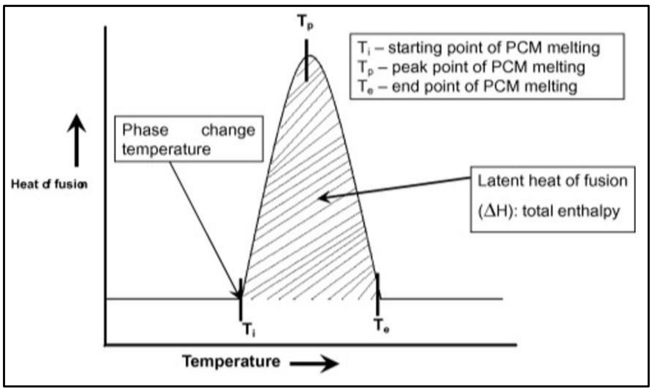

Fig 1: DSC heating thermogram of PCMs [9]

The 0 °C water is the best example of phase change material that crystallizes from liquid to solid state (ice). The phase change will also occur when water gets heated upto 100 °C, which becomes water into steam. Water is best example to find out the comparison for the quantity of heat absorbed by PCM throughout the actual phase with the quantity of heat absorbed in ordinary heating procedure. Usually 335 KJ/Kg of latent heat is absorbed while the ice turns into the water, but when water is further heated, only 4 KJ/Kg sensible heat is absorbed and the temperature gets raises 1 °C. Thus, the absorption of latent heat during the solid to liquid phase change is approximately 100 times higher than sensible heat absorption [11].

PCM is a matter with high heat of fusion which melts and crytallizes at particular temperature, inturn had the capacity to store and release immense quantity of heat energy. As, the heat is released or absorbed when the substance changes from solid state to liquid and liquid state to solid, the PCMs are classified as (LHS) latent heat storage units [12].

PCMs exists in varied temperature ranges which are from -5 to 190 ºC. Especially within the human comfort ranges i.e,. 20 °C to 30 °C. Some of the PCMs are extremely effective and capable to store latent heat energy upto 200 KJ/Kg against to specific heat capacity of nearly one KJ/(Kg* °C) for masonry. Thus the storage density could be 20 times better than the masonry per Kg, if a temperature sway of 10 °C is permissable [13].

3. Types of PCMS

According to the thermal storage by solid-liquid phase change, more than 150 PCMs are existed, where 45 are commercially available [14].

PCMs are majorly differentiated into 2 groups, such as organic PCMs and inorganic PCMs (Fig.2) [13].

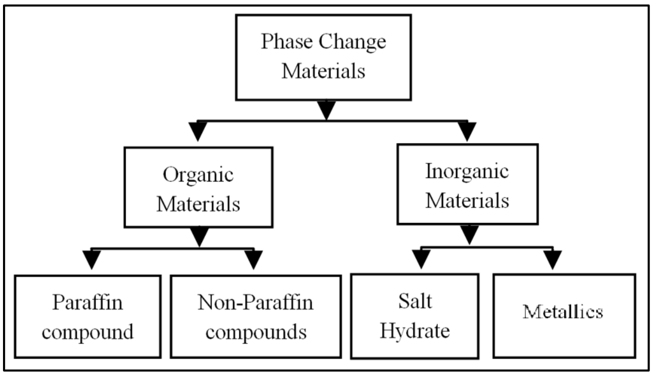

Fig 2: Types of PCMs

Among several classes of PCMs, Paraffin wax is most regularly used for thermal management in electronic devices owing to its large melting point, high heat of fusion per unit weight, repeated cycling, chemical inertness and non-corrosiveness.

The organic PCMs go through phase change over certain range of temperature. The utility of PCM in energy storages and thermal insulations have been tested industrially and scientifically in numerous applications. Using organic PCMs in industrial application is anticipated to grow at 32%/yr [15]. Organic PCM had the capability to undergo constant melting without phase separation and the degradation of their latent heat of transformation. Additionally they self nucleates, that means crystallizes with little or no super cooling and usually noncorrosive [16]. They show no change in performance or structure over numerous cycles [17]. Organic PCMs are costlier compared with the inorganic PCMs as these are available abundantly as a byproduct from oil refineries [18].

Some of the organic PCMs are paraffins, polyethylene glycol and fatty acids [19]. Additionally, there are other organic PCMs also like polyethylenes and polyalcohols which undergo solid to solid transition at rigid temperatures by absorbing and releasing great quantity of latent heat. They also got attention as a potential organic PCMs. Paraffin is a linear chain aliphatic hydrocarbon with formula CnH2n+2. Due to their molecular structure and complex structural & thermodynamic behavior, they are being used since more than half century. These are most commonly available in nature in various forms and can spot in gasoline and other industrial solvents for some carbon atoms (n) between 4 and 10, in fuel and diesel for 10≤n≤28. These are produced by cracking and isomerization or petroleum fractional distillation on an industrial scale [20]. Paraffin wax is a fusion of many straight chain n-alkanes. (CH_3 - (CH2)n-CH3). Numerous investigations were carried out by using precision adiabatic calorimetry for measuring the thermal properties of linear n - alkanes in 1930 - 1950 [21], [22]. Paraffins are considered as the standard PCMs for the thermal management of electronics as well. Because of its diverse temperature ranges and its huge latent heat energy, they are chemically compatible with many of the metals.

Table 1: Typical Paraffin Wax PCMs [23].

Examples of Paraffin	$C_{36}H_{74}$	$C_{32}H_{66}$	$C_{30}H_{62}$
Density solid (Kg/m^3)	857	809	810
Latent Heat (KJ/kg)	223	261	249
T_{melt} (°C)	72 -76	66-70	59-66

Table1 shows few highest pure paraffin waxes potential to use in several electronic applications. The paraffin waxes with 59-66 °C, 66-70 °C72-76 °C temperature variations are safe to go for many of the electronic devices [23].

Furthermore, in many circumstances, the PCMs density is below103 Kg/m^3, which is smaller than the many of the inorganic materials such as salt hydrates, water etc,. The PCMs are said to be organic, when they had the structure of covalent bond of hydrocarbons, carbon compounds and their derivatives. These materials covers the temperature ranges between 0 °C to 200 °C. Many of them are unstable at high temperatures due to the covalent bond in the organic materials. Paraffin waxes as PCM have been used in wide range of applications because of their characteristic features like chemical inertness, non-toxicity, high storage capacity and low cost [24].

The organic PCMs such as fatty acids can be obtained from renewable or reprocessed raw materials like animal fat and vegetation like beef lard, tallow, palm oil, soybean, coconut etc,. Similarly, like other PCMs, these also have characteristic features such as high latent heat of fusion, fire resistance, nontoxic, volume change, little sub cooling, low cost, chemical & thermal stability even after numerous thermal cycles. Fat & oil based PCMs are less expensive compared with paraffin PCMs which are produced from rudimentary oil. It also releases very little CO_2 during the production process. Additionally, the organic PCMs along with nano materials like silver, copper, graphite nano particles are significantly advantageous in enhancing thermal conduction and phase transition rate by using little latent heat. For instance, 2% of graphite nano particle increase thermal conductivity by 63% by using 8.7% of latent heat [18].

Polyethylene glycols are best example to use as PCM in textile application. They are comprised of groups of hydroxyls (-OH). The rise in molecular weight automatically rises the melting point of PEG [25]. PEG1000, is generally recommended for latent heat storage application and can be used to manufacture PCM filled fiber that are prepared by melt spinning hollow filament fiber followed by injecting the microfluid into the hollow filament. Then the obtained PEG-PP bicomponent fiber reaches the maximum core of 83% by weight and the thermal efficiency of respective undrawn fiber would be 97% which proves that PP sheath has no effect mainly on the phase change performance of confined PEG 1000 [26]. Thermal storage cotton material with solid to solid phase change property was manufactured by direct grafting of poly ethylene glycol on cotton fiber or fabric [27].

The fatty acids also have good development prospects like huge heat capacity, little or no super cooling, excellent thermal and chemical stability, nontoxic, suitable range of melting temperature for building energy conservation, noncorrosive, minute volume change during phase change, etc,. However, the pure fatty acids melting temperature is simple to be appropriate for building energy conservation. While the initial melting temperature of capric acid, stearic acid, myristic acid, lauric acid and palmitic acid are nearly 31, 69, 54, 43 and 62 °C respectively [28].

Inorganic PCMs also have wide range of melting temperature from 8.1 °C to 130 °C and the examples of inorganic PCMs includes the hydrated inorganic salts. However, their latent heat absorbing and releasing interval stuck between 20 – 40 °C and it requires a great deal of heat fusions and had limited life cycles [29]. Inorganic salts PCM have “n” number of water molecules which is the main reason for using it in manufacturing thermo regulatory textiles which exhibits 20 °C to 40 °C range of phase temperature. Sodium sulphate, which is also called as glauber’s salt is more attractive and convenient inorganic PCM among all owing to its striking physical and chemical properties. It could possess the melting temperature of 32.4 ºC and latent heat storage of 254 J/g which is appropriate for textile applications [30].

The utilization of hydrated salts in energy storage systems depend on the heat is advantageous due to their high volumetric storage capacity and excellent thermal conductivity, as well as the price is also economical in the market compared with paraffin waxes. The composition of glauber’s salt by its weight is 56% water and 44% sodium sulphate [31].

Salt hydrates are the alloys of in-organic salts and water. As they are non-combustible, they can be widely used in the preparation of products meant for fire resistant. One of the attractive and important properties of slat hydrates is its excellent latent heat storage capacity. Sometimes the salt hydrates shows melting behavior due to lack in reversible melting and freezing which makes them inappropriate for usage permanently. Nevertheless, such undesired feature can be eradicated with the addition of chemical stabilizers [11].

Finally, the organic and inorganic PCMs are serving the purpose and advantageous in the application of nanotechnology in PCM segment with further advancements. Incorporation of nano materials could possibly enhance the thermal storage properties such as freezing or melting rates, thermal conductivity and thermal stability, even with little quantity of nano material. Thus more and more PCMs are becoming appropriate for varied applications effectively.

Table 2: Properties of Phase Change Materials [23].

Properties	Paraffin Wax	Non-Paraffin Organics	Hydrated Salts	Metallics
Heat of Fusion	High	High	High	Med.
Thermal Conductivity	Very Low	Low	High	Very High
Melt Temperature	-20 to 100+	5 to 120+	0 to 100+	150 to 800+
Latent Heat (KJ/Kg)	200 to 280	90 to 250	60 to 300	25 to 100
Corrosiveness	Non-Corrosive	Mildly Corrosive	Corrosive	It varies based on metals
Thermal property	Thermally stable	Rise in temperature causes deterioration	Unstable for repeated cycles	Thermally stable
Weight	Medium	Medium	Light	Heavy

4. Conclusion
The current paper has shown the detailed working principle of PCMs, their thermal performances along with different types of PCMs available in the present era. So, that it will become easier for the researchers to find appropriate PCM and its working principle.

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