Phase Change Materials: Incorporation and Application in Textiles

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ABSTRACT

Fabric as the first and most common layer that is in permanent contact with human skin is a very good interface to provide coverage, as well as heat and cold insulation. Phase change materials (PCM) take advantage of latent heat that can be stored or released from a material over a narrow temperature range. These materials absorb energy during the heating process as phase change takes place and release energy to the environment in the phase change range during a reverse cooling process. Insulation effect reached by the PCM depends on temperature and time. Recently, the incorporation of PCM in textiles by different techniques has grown interest to the researcher. There are large numbers of organic and inorganic PCMs that possess a wide range of melting and solidifying temperature which attracts attention for their applications in different fields of textiles such as sportswear, household accessories, medical textiles, automotive textiles, space textiles etc.

INTRODUCTION

Fundamental principles of science are now increasingly employed for manufacturing innovative textile products. One such principle is 'Phase Change', the process of going from one physical state to another, i.e. from a solid to a liquid. Substances that undergo the process of Phase Change are known as Phase Change

Materials (PCMs). These materials store, release or absorb heat as they oscillate between solid and liquid form. They give off heat as they change to a solid state and absorb as they return to a liquid state. The three fundamental phases of matter: solid, liquid, and gas are known, but others are considered to exist, including crystalline, colloid, glassy, amorphous, and plasma phases. Some of these PCMs change phases within a temperature range just above and below human skin temperature. This property of certain substances is triumphantly harnessed for making protective all-season outfits and for abruptly changing climatic conditions. Fibre, fabric and foam with built-in PCMs store the warmth which body creates, then release it back to body, as it needs it (Shim *et al.*, 2011; Huang *et al.*, 2021).

PCM are considered as smart because they react immediately to changes in environmental temperature and adapt to the prevailing hot or cold condition. Phase change technology originates from the NASA (National Aeronautics and Space Administration's) research program of the 1970s. The aim of this program was to provide astronauts and instruments with better protection against extreme fluctuation of temperature in space and since then research work has been carried out by scientists and now textiles with phase change materials (PCMs) are used in numerous products and applications from apparel, underwear, socks, accessories and shoes to bedding and sleeping bags. PCMs can even be found in specialty items, such as antiballistic vests, automotive, medical or special industrial applications, where warmth and energy play a role (Yang *et al.*, 2023).

I. INCORPORATION OF PHASE CHANGE MATERTIALS IN TEXTILES

The PCMs change phases within a temperature range just above or below human skin temperature would be suitable for application in textiles. This interesting property of PCMs would be useful for making protective textiles in all-season. Since the process of phase change is dynamic therefore, the materials are constantly changing from a state to another depending upon level of physical activity of the body and outside temperature. The thermo-regulating characteristic is possible in man-made fibre by adding PCM microcapsules to a polymer solution prior to fibre extrusion. In the process, PCM microcapsules are integrated inside the fibre itself. Coating lamination, finishing, melt spinning, bi-component synthetic fibre extrusion, injection molding, foam techniques are some of the convenient process for PCMs incorporation into the textile matrix (Pielichowska and Pielichowska, 2014).

1. **Fibre technology**: The incorporation of PCM within a fibre requires first that the PCM be micro-capsulated. PCMs would be added to the liquid polymer, polymer solution, or base material and fibre is then spun according to the conventional methods such as dry or wet spinning and extrusion of molten polymer. The microencapsulated PCM content in the fibre, sheath/core ratio and the content of 4-hole spiral crimp PET fibre affect the temperature regulating ability of the non-woven.

2. **Coating**: A coating composition for textiles includes wetted microspheres containing a phase change material dispersed throughout a polymer binder, a surfactant, a dispersant, an antifoam agent and a thickener. Preferred phase change materials include paraffinic hydrocarbons. The microspheres may be microencapsulated. The coating would be then applied to a textile substrate. In an alternative embodiment, an extensible fabric would be coated with an extensible binder containing microencapsulated phase change material to form an extensible, coated fabric. PCM could be incorporated

into the textiles by coating using polymer such as acrylic, polyurethane, etc. and applied to the fabric (McCullough and Shim, 2016).

3. **Lamination**: In order to improve thermo-physiological wearing comfort of protective garments, PCM would be incorporated into a thin polymer film and applied to the inner side of the fabric system by lamination. The cooling effect of the PCM can delay the temperature rise and, hence, the moisture rises in the microclimate substantially. As a result, the wearing time of the garments can be extended significantly without the occurrence of heat stress as a serious health risk. The longer wearing times will further lead to a significantly higher productivity. The more comfortable wearing conditions will also result in a reduced number of accidents and lower error rates. Besides chemical protective suits, the PCM can also improve the thermo-physiological wearing comfort of other protective garments made of non-wovens such as surgical gowns, uniforms, or garments worn in clean rooms.

4. **Microencapsulation:** Microencapsulation is a process in which tiny particles or droplets are surrounded by a coating to give small capsules many useful properties. In a relatively simplistic form, a microcapsule is a small sphere with a uniform wall around it. The core particles (active substance) from microcapsule can be released under controlled conditions to suit a specific purpose. The core substance from the microcapsule can be released by friction, by pressure, by dissolution through the polymer wall coating or by biodegradation. Most microcapsules have diameters between a few micrometers and a few millimeters (Mondal, 2018).

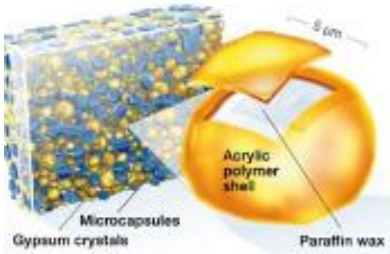
II. APPLICATION OF PHASE CHANGE MATERIALS IN TEXTILES

Fabrics containing micro PCMs have been used in a variety of textile applications such as automotive textiles, domestic textiles, medical products, apparel etc.

1. **Apparel:** Major end-use of textile containing PCM in apparel includes:

- **Life style apparel:** Smart jackets, vests, men's and momen's hats, gloves etc. Some people have jobs where they go to and from cold storage facility or transport vehicle and a warm building or outside environment on an intermittent basis. PCM protective garments improve the comfort of workers as they go through these environmental step changes. It has been observed that garments made with PCMs or "dynamic insulation" will keep a person warm longer than conventional insulation when worn in cold environment.

- **Safety helmets:** These have a thermal resistance of approximately 1.0 m^2 k/w and due to their structure, the heat generated by the wearer can be dissipated only by means of convection. But with the incorporation of micro PCM in the helmet liner leads to substantial reduction of the



microclimate temperature in the head area.

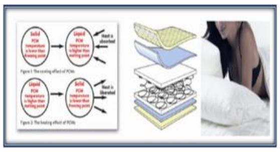
- **Sportswear:** PCM is mainly used in active garments, especially textile clothing which has the thermal regulating properties.

Basically, active wear needs to provide the thermal balance between the heat released and to the environment, when the wearer engaging in sports. The duration of activity of a garment is based on the quantity of applied phase change material. During the sports activity the heat generated by the body cannot be released properly in environment properly, this is the main cause of increasing thermal stress. But when the wearer uses the PCM active garments, the micro capsulation absorbs the heat and release it when it necessary. In snow board gloves, mountain climbing, under wear, cycling and running are the sports where PCM active textile is widely used.

- **Protective garments:** In case of chemical or biological protective clothing a conflict between the protective function of clothing and the physiological regulation of body temperature may occur. The conflict led to discomfort and physical strain and in extreme cases can put the person at risk from heat stress. The Outlast Protective garment (Body Armor) contains the microencapsulated PCM thus providing more comfortable Protective textile. The outlast provide many kinds of protective clothing which contains the microencapsulated PCM ranges from Vest to Body Armor (Salaün, 2019).

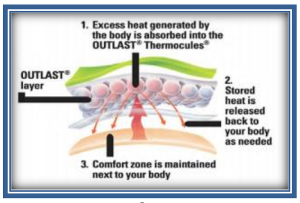
Outlast Thermo-molecules as a coating on textiles   Outlast Thermo-molecules locked into the textile fiber

2. **Household Accessories**: Microencapsulation, which is embedded in pillow, mattress and quilts, controls the bed temperature. It acts when the body temperature rise, these micro capsulations stores the heat and keep body cool and when temperature drops down it release heat to maintain the body temperature at comfort level.



3. **Automotive Textiles:** During the summer, the temperature inside the passenger compartment of an automobile can rise substantially-for instance, when the car is parked outside. In order to stabilize the interior temperature while driving the car, many models are equipped with air conditioning systems; however, providing sufficient cooling capacity requires a lot of energy. On the other side, during the winter months, the driver and the passengers are often confronted with low temperatures, especially as they first get in the car. As result, some models have heating systems installed in the driver's seat which are supplied by the car's battery. Due to additional systems for monitoring and controlling various functions in cars, the power supply needed for their operation has steadily increased over the past years. In order to prevent further demands on the battery's capacity, manufacturers are searching for all kinds of energy savings (Ahrari *et al.*, 2017).

4. **Aerospace:** Phase change technology originates from the NASA (National Aeronautics and Space Administration's) research program of the 1970s. The aim of this program was to provide astronauts and instruments with better protection against extreme fluctuation of temperature in space and since then research work has been carried out by scientists. In aerospace, the PCM is used in space suits and as a cover protection for instruments against the severe temperature changes of outer space (Li and Zhu, 2014).



5. **Medical Products:** PEG-treated fabric may be useful in medical and hygiene applications where both liquid transport and antibacterial properties are desirable, such as surgical gauze, nappies and incontinence products. Textile containing PCM can keep the skin temperature within the comfort range, so they can be used as a bandage. If a therapeutic blanket made of a

flexible PCM composite contains a micro PCM having a transition temperature below normal skin temperature, it can be used for cooling febrile patients in a careful and controlled manner. A careful selection of the phase change temperature makes it possible to avoid the danger of overcooling the patient that is inherent with ice packs. Alternatively, a blanket with PCM can be useful for gently and controllably reheating hypothermia patient. The PCM can also be used in battery warmers, agriculture, building material and geotextile (Iqbal *et al.*, 2019).

CONCLUSIONS

Customer satisfaction, novel products manufacturing and ensuring a fair income is desired for textiles industry producers and activists, such as other industrial fields, and therefore, manufacturing textiles containing PCMs, textiles which are capable of absorbing, storing and gradual releasing of thermal heat, had been taken under account even more than before. PCMs incorporated textiles exhibit exceptional thermal storage properties which make it suitable for their applications in many areas such as: sportswear, building materials, automotive textile, agrotextiles, aerospace textile, geotextile, and medical textile. By the use of PCMs due to their repeatability of phase change and reduction of human need to supply thermal energy from fossil fuels, it can be stated that these materials have positive effects on the environment.

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