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A review of some significant advances in phase change textile materials

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Abstract

The article comprehensively reviews some significant trends in the use of phase change materials in textile applications. Efforts have been directed to determine which of the existing PCM families are more suitable for textile thermoregulation while proposing new solutions. Indeed, many of these materials are either limited by their overall enthalpy of phase change or by their thermal window.Clothing that responds to the environmental changes and adapts accordingly to make the wearer comfort this to be a long time challenge to the Textile engineers. Integrating various material sciences with that of textiles have yielded many tailor made intelligent textile structures. The application of phase change materials into the thermal comfort regulation of textile clothing has been considered. Phase change materials (PCMs) are widely being used in thermal energy storage systems for solar engineering, building materials, heat pumps, spacecraft, and in textile field especially smart and technical textiles.

Key words: Phase change material, Polymers, Latent heat, Intelligent textiles, micro encapsulation, Thermoregulation.

1 Introduction

Our human body is a thermo-regulated organism. The body constantly generates heat, CO_2 and H_2O by the metabolism of food and muscle activity. The human body controls the release speed of heat by blood vessel dilatation temperature. It has been shown that the most comfortable skin temperature is 31.4˚C. When the temperature of any part of the skin differs by within 1.5-3.0˚C of this ideal temperature, the human body is unaware of the warmth or coolness. If the difference is more than ±4.5˚C, the human body feels discomfort. In addition, a core body temperature of 36.5˚C is required, and a rise or fall of 1.5˚C can be fatal. A balance between the rates of heat loss and generated must be maintained.

Phase change materials (PCMs) are able to absorb or release big amount of energy in latent heat (DH) form. The absorbing or releasing of latent heat energy occurs during solid to solid or solid to liquid phase transitions in a narrow range of temperature [1-4]. The use of PCMs among various thermal energy storage systems is highly acceptable because of their high heat of fusion, high density, and enabling a compact energy storage system at isothermal conditions [5-8].

Phase change materials have been used for various applications in thermal energy storage since the 18th century, and many commercial products have been developed to this end. Depending on the field of application, PCMs are selected according to their temperature and phase transition enthalpy. Thus, when their phase change temperatures are relatively low (between −20 and −10°C), these materials are more likely to be used for food storage, while for temperatures between 2 and 15°C, they are generally used for air conditioning, that is, comfort applications [9]. Higher transition temperatures allow these materials to be used for solar energy storage, in agriculture, electronic equipment protection, or textiles [10-15]. Thermal energy storage by solid-liquid phase change has been the subject of a census by Zalba on more than 150 existing PCMs, 45 of which are commercially available [16].

2 Application of phase change materials in thermoregulation clothing

Textiles that are capable of being reactive to the stimuli rendered externally or internally to maintain the desired level of specified applications are called Smart or Intelligent textiles. These structures are of paramount importance because of their specificity and reactive nature. Smart textiles refer to those which could change color, display images, keep controlled micro atmosphere of humans and so on. These enhancements could be brought up either in their fibrous stage, designing stages or by special finishes.

In thermodynamics, phase transition or phase change is the transformation of a thermodynamic system from one phase to another. The distinguishing characteristic of a phase transition is abrupt changes in one or more physical properties, in particular the heat capacity, with a small change in a thermodynamic variable such as the temperature. In the English vernacular, the term is most commonly used to describe transitions between solid, liquid and gaseous states of matter, in rare cases including plasma [17].

Properties of PCM incorporated textiles

Thermal resistance

The thermal properties of PCM incorporated textiles have been studied with the apparatus designed by Pause, which was the only instrument available to assess directly. He made studies with different textile structures with different materials and concluded that the total thermal insulation of new (PCM) exceeds 60% than that of conventional garments. Differential scanning calorimetry is a useful method but it could not directly be translated to thermal resistance behavior. A sample analysis result of PCM coated fabrics is given below [18].

The dynamical thermal properties of PCM textiles are not a constant. It is noticed to differ during the measuring stage itself and hence it is preferred to follow a Gaussian distribution as similar to that of DSC curves.

Thermo regulating properties: There is no direct method to assess the thermo regulating properties. Researchers have made simulated skin and clothing model and several more methods to investigate in this perspective. It was inferred that the cold whether clothing trials showed a usual drop of 3˚C in the skin temperature for conventional fabrics whereas in PCM engineered one, its is only about 0.8˚C.

Applications

Casuals: Heat storage and thermo regulated textiles can be used as face fabrics, liner fabrics, batting etc. Thermal underwear, jackets, sports garments and skiwear are the latest products in markets based on phase change technology.

Professional clothing: Fire fighter uniforms, bullet proof vests, diver's coveralls, space suits, airman suits, field uniforms, sailor suits etc are specially tailored garments. Special gloves for extremely high or low temperatures are being used.

Home textiles: Interior decorations, curtains, bed clothes, blankets, mattresses, pillows, sleeping bags etc. are some of the potential applications of thermo regulated textiles. Outlast® are the major players in producing products based on these intelligent textiles.

Footwear: Shoe linings, socks, ski boots and golf shoes are made with these materials are right solutions for tremendous heat released during drastic changes in wearer's head, body, hands and feet.

Medical usage: PEG treated fabrics may be useful in medical and hygiene applications where both liquid transport and anti- properties are desirable. These smart textiles can keep the skin temperature within comfort range, so they can be used as bandage for burn and heat/cool therapy [19-24].

The applications of phase change technology has been gathering momentum since 1980s and researches are constantly strengthened with improvements in cutting edges of fabricating phase change materials and applying them in a well defined distribution in textile substrates with precise control engineering techniques [25]. Textile Applications can be widened with a scope of insisting technical textile utilization of current matter of interest. Rigid is the bright future for the industry concerning with making people comfort with all perspectives, no matter how small the target may be. Future studies on military clothing will be focused which has tremendous potential applications of PCM.

3 Methods of synthesis and areas of applications

Thermo-regulation is defined by glossary of textile as the ability of textile material to keep constant temperature under dynamic external environment. Comfort can be categorized as sensorial comfort, thermal or thermophysiological comfort, psychological comfort, and garment fit [26]. Under normal conditions, human body temperature is 37ºC, which occasionally goes up to 40ºC during some physical exercises [27]. Human skin remains comfortable at temperature of 33.4ºC, and body senses discomfort when its goes 4.5ºC above or below comfort temperature [28]. Clothes usually prevent the skin's temperature from abrupt rise or fall from the comfort temperatures [29].

So far comfort and clothing are concerned, physiological, physical, and psychological factors affect the comfort. Moisture buffering and thermal buffering imparts complete comfort to body by providing sensation of cold or heat to the body. PCMs exhibit the property of thermal buffering which can enhance evaporative resistance in certain cases by reducing buffering of moisture [30]. The significance of smart textile in textile sector is growing rapidly because of its increase in demand by society through consumer needs. Smart textiles exhibit its vast applications in textile sector including different types of clothing, technical textiles, and interior textile. Among these three mentioned areas of smart textiles, clothing and technical textiles possess higher usage percentage [31]. In 1980s, PCMs were used by National Aeronautics and Space Administration (NASA) USA in smart clothing materials to make thermo-regulated garments for the protection of apparatus in space to avoid abrupt change in temperature [32-34]. Further this technology was adapted by many well-known companies based in Boulder, Colorado and Outlast technologies who integrated PCMs in textile fibers and applied on textile fabrics via coating [35].

Initially PCMs was applied on small scale in manufacturing of space craft's scale and on large scale in various building parts and sunlight-based energy systems for developing heat energy storage system [36-38]. Both inorganic and organic PCMs are available in large number having phase transition temperature ranging from –5 to 190ºC [39-42]. To enhance thermal comfort effect in buildings and textiles organic PCMs having phase transition temperature ranging from 18 to 65ºC are usually applied. Noctadecane an organic PCM having melting point of 28º C is used for textile application.

PCMs developers claim that PCMs incorporated textiles offer buffering effect under abrupt weather by maintaining the skin temperature constant and thus providing prolonged comfort to the consumer [43,44]. Further they claim that PCMs can minimize the fabric thickness required for the protection of human body from cold environment. Nowadays, PCMs are applied in various textiles including apparel, bedding, non-woven, and footwear under different trade names TemperTexTM, OutlastTM, and ComforTempVR. Viscose and PAN fibers are successfully incorporated with MPCMs by Outlast Technologies.

3. Working of PCMs

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. Organic PCMs namely paraffins are able to absorb round about 200 J/g of latent heat during its phase transition which is released to surrounding environment during reverse cooling process known as crystallization. The temperature of PCMs does not change significantly during melting and crystallization process.

PCMs melt by absorbing heat with increase in surrounding temperature and get solidified on decrease in temperature of surrounding temperature by releasing the absorbed heat energy to environment. This phase transition phenomenon of PCMs has been determined.

The above phenomenon can be attributed to the breaking of chemical bonding in the molecules of PCMs with increase in temperature which results in melting of material by storing heat energy, which is released subsequently with decrease in temperature during reverse cooling (crystallization process) restoring chemical bond [45].

4. Types of PCMs

Theoretically, PCMs are able to exhibit phase change transitions nearly constant temperature and therefore they have the ability of storing huge amount of heat energy [46]. Currently, the number of known synthetic and natural PCMs is more than 500 and they possess different heat storage capacities and melting points. Paraffin is the most common among all types of PCMs which can be easily microencapsulated and then either applied on textiles via coating or incorporated into fiber [47]. Those PCMs which possess phase transition temperature near to temperature of human skin are explained below in different headings.

Inorganic PCMs
Organic PCMs
Organic paraffins
Polyethylene glycols
Animals and plant-based fatty acids and their derivatives
Polyalcohols and polyalcohol derivatives

8. Applications of PCMs applied in the field of textiles

PCMs exhibit their applications in the following domains [48,49]:
_ Space wears (space suits and gloves)
_ Sports wears (gloves for ice climbing, active wear, under wear for cycling and running)
_ Medical applications (surgical clothing such as gloves, caps, gowns, bedding clothes for patients, wound bandages, and some intelligent products that can maintain patient body temperature in intensive care unit (ICU))
_ Fire retardant textiles (gloves and suits for fire fighters)
_ Bedding and other accessories (mattress covers, pillows, sleeping bags, and blankets)
_ Building textile materials (architecture structure embedded in concrete)
_ Automotive textile (automobile interiors and seat covers)
_ Shoes and other accessories (hiking boots, skiing boots, golf shoes, driver boots, etc.)
_ Other applications (geotextiles and agrotextiles) PCMs containing textile material are considered smart because they exhibit the ability to temperature changes in environment by absorbing latent heat during melting and releasing it during reverse cooling or crystallization process and provide a thermo-regulating effect [50]. 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. This review paper has investigated different types of PCMs, various methods of encapsulation, characterization techniques, different techniques of application on fabric and incorporation into fibers, modelling and simulation, and its main application domains in textile sector.

4 Conclusion

An attempt has been made to determine which of the existing PCM families are more suitable for textile thermoregulation. Most of such materials are either limited by their overall enthalpy of phase change or by their thermal window. Focus has been directed towards the study of binary mixing allowing the widening of the temperature range of the phase change and the consolidation of the enthalpy balance by adding chemical species. PCM was microcapsulated to be applied on to textile substrate, before studying the thermal properties. Materials that are capable of storing and dissipating heat energy at their unique conditions are identified and that could cope up with textile fibrous materials have been successfully implemented by a variety of techniques like micro encapsulation, coating etc. These integrated structures perform the action of either absorbing or releasing heat to keep the person in comfort. This paper elaborates their specified background of successful integration and implementation that serve its best to the customer concerned. There are large numbers of organic and inorganic PCMs that possess a wide range of melting and solidifying temperature which attracts researcher's attention for their applications in different fields. The investigation and analysis of the available organic and inorganic PCMs, different encapsulating techniques, characterization techniques, incorporation into fiber and pad application on textiles with practical applications in the field of smart textiles, have been summarized.

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