

Thermo regulated clothing with phase change materials

Abstract

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. This paper is concerned about the application of phase change materials into the thermal comfort regulation of textile clothing. 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.

Keywords: intelligent textiles, phase change materials, micro encapsulation

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Introduction

Our human body is a thermo-regulated organism. The body constantly generates heat, CO₂ and H₂O 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.

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.

Textiles and comfort

Conventional textile materials such as cotton, hemp, silk, wool and polyester, polyamide and acrylic fibers etc., provide a degree of resistance to body heat loss, which is determined by the number of air pockets present in the fabric. To keep the skin temperature within the desired level, we must put on or take off clothing according to the external temperature. This would become more difficult for a man to spend a lot of finance and time only for the purpose of making himself comfort, in the present information age. Hence there is a huge scope of market for a fabric that suits all climatic conditions. Instead of changing the clothing according to climatic conditions, if the clothing is designed such that it could automatically change to the external stimuli would gather tremendous momentum in clothing market where comfort became major factor. This could be achieved by placing thermal responsive phase change materials with textile ones so that the task is accomplished.

Functions of phase change material (PCM) in clothing

The major functions that a Phase change material (PCM) is ought to perform when incorporated with a textile substrate are

- Cooling – by heat absorption
- Heating – by heat release
- Thermo regulating – resulting in combination of cooling and heating

Phase change materials science

Phase transition

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 (Figure 1).¹

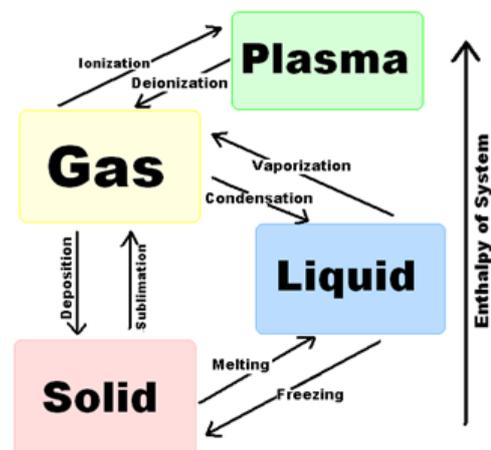


Figure 1 Transformation of a thermodynamic system from one phase to another.

Phase change materials

Phase change materials are a kind of heat storage materials. These heat storage materials can be classified into sensible heat storage materials and latent heat storage materials. Sensible heat storage materials that undergo obvious temperature change during their phase change.¹ Water, steel and stone are common examples. Latent heat storage materials that undergo phase change with slight temperature changes. They could be repeatedly converted from solid to liquid to gas and vice versa. These are technically termed as phase change materials. PCMs that could be used in textiles and clothing must lie in the temperature interval as specified, heat absorbing temperature interval is 20 to 40°C and heat releasing temperature interval is 30 to 10°C. The phase change temperature of hydrated inorganic salts, polyhydric alcohol - water solution, polyethylene glycol (PEG), polytetramethylene glycol (PTMG), aliphatic polyester, linear chain hydrocarbon, hydrocarbon alcohol, hydrocarbon acid, etc., is in this interval.

Phase change materials that have been successfully applied for textiles are explained as follows (Table 1):

Hydrated inorganic salts: They are inorganic salt crystals with

n-water molecules. These salts are lying in the desired interval of 20°C to 40°C to be applied for thermo-regulated clothing. Some of the useful hydrates are shown in the table with their thermal properties (Table 2).

Polyhydric alcohol: The following materials produce endothermic and exothermic effects without a change in state at temperatures far below the melting point of the substances:

- i. 2,2 – dimethyl – 1,3- propanediol(DMP)
- ii. 2 – hydroxymethyl – 2 – methyl – 1,3 – propanediol (HMP)
- iii. 2 – bis – (hydroxyl methyl) – 1,3 – propanediol

However, they are not suitable for manufacture of heat storage textiles due to their temperature range being higher than 40°C. Attempts have been made to mix two or more such elements into compounds whose range may lie undesired level.

Polyethylene glycol: Polyethylene glycol is one of the important phase change material whose melting temperature is proportional to the molecular weight when less than 20000. And above this molecular weight the melting points are almost same. Some of PEGs whose MW lie behind 20000 are listed as follows.

Table 1 Phase change materials

Avg. molecular weight (g/mol)	Melting point (°C)	Melting heat J/g	Crystallization point (°C)	Crystallization heat [J/g]
1000	35.1	137.31	12.74	134.64
2000	53.19	178.82	25.19	161.34
4000	59.67	189.69	21.97	166.45
6000	64.75	188.98	32.89	160.93
10000	66.28	191.9	34.89	167.87

Table 2 Thermal properties hydrated inorganic salts materials

Salt	Melting point (°C)	Melting heat J/g	Density g/m ³		Specific heat capacity (J/g °C)		Heat storage density J/g
			Solid	Liquid	Solid	liquid	
CaCl ₂ ·6H ₂ O	29	190	1800	1560	1460	2130	283
Na ₂ SO ₄ ·10H ₂ O	32	225	1460	1330	1760	3300	300
Na ₂ SO ₄ ·5H ₂ O	43	209	1650	-	1460	2300	345

Phase change behavior of pet

Linear chain hydrocarbons: Linear chain hydrocarbons are byproducts of oil refining which are non-toxic, inexpensive and extensive source of raw materials suitable for usage. They are the most impor-

tant of all the PCMs applied for heat storage and thermo regulated textiles. Their melting and crystallization points range from 10°C to 40°C. Some of the commonly used hydrocarbons are listed in the Table 3.

Table 3 Phase change behavior of linear chain hydrocarbons

Hydrocarbons	No. of carbon atoms	Melting point(°C)	Melting heat J/g	Crystallization point (°C)
n – hexadecane	16	16.7	236.58	16.2
n – heptadecane	17	21.7	171.38	21.5
n – octadecane	18	28.2	242.44	25.4
n – eicosane	20	36.6	246.62	30.6
n – heneicosane	21	40.2	200.64	-

Micro-encapsulation of PCMs

As discussed before, as phase change materials are migrating their states from solid to liquid and vice versa, they tend to flow due to increased segmental mobility of atoms. This may deteriorate the durability of PCM in specified application. For this purpose, the PCMs have to be encapsulated or bound by a thin layer of polymeric or any other material so that the phase transition could be accomplished inside a controlled environment for several repetitive cycles. There is a variety of methods to encapsulate them onto a film in micro dimensions. The following table shows the dimension of microcapsules produced by various techniques (Table 4) (Table 5).

Table 4 Particle size of different micro encapsulation process

Micro encapsulation process	Particle size (10-6m)
Spray – drying	5 – 5000
Fluid bed coating	20 – 1500
Coacervation	2 – 1200
Interfacial polymerization	0.5 – 1000
Sol – gel encapsulation	2 – 20
Layer by layer assembly	0.02 – 20
Solvent evaporation	0.5 – 1000
Rotating disc	5 – 1500

Table 5 Methods of Micro encapsulation

Chemical methods	Physical methods	Physico mechanical methods
Suspension, dispersion and emulsion polymerization	Coacervation	Spray drying
Polycondensation	Layer by layer assembly	Multiple nozzle spraying
	Sol-gel encapsulation	Fluid bed coating
	Supercritical methods	Centrifugal techniques
		Vacuum and electrostatic encapsulation

Manufacturing techniques

Filling or impregnating: In this method, the fibers that are hollow or porous in nature are kept immersed into a solution containing desired concentration of PCMs for specified time, under pressure. This makes the dispersed capsules to migrate from solvent media to fibrous structure and gets fixed into them.

Fiber spinning: Microcapsules of various shapes - round, square and triangular within fibers at the polymer stage. The PCM microcapsules are permanently fixed within the fiber structure during the wet spinning procedure of fiber manufacture. Micro encapsulation gives a softer hand, greater stretch, more breathability and air permeability to the fabrics. The pictures show the acrylic fibers spun with PCMs (Figure 2).

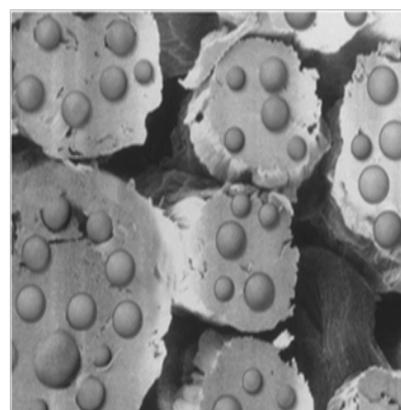


Figure 2 Acrylic fibers spun with PCMs.

Matrix coating during the finishing process: The PCM microcapsules are embedded in a coating compound like acrylic, polyurethane, etc, with certain binders and are applied to the fabric. There are many coating methods available like knife-over-roll, knife-over-air, pad-dry-cure, gravure, dip coating and transfer coating (Figure 3).

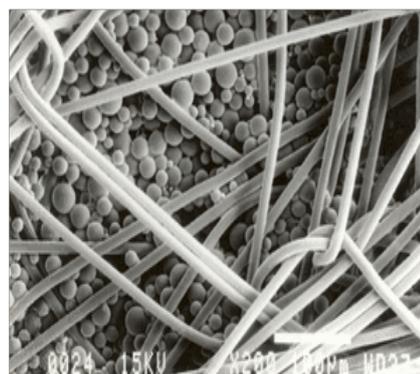


Figure 3 The PCM microcapsules using matrix coating.

Foam dispersion: Microcapsules are mixed into a water-blown polyurethane foam mix and these foams are applied to a fabric in a lamination procedure, where the water is removed from the system by the drying process.

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.^{1,2}

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 (Table 6).

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 weather clothing trials

showed a usual drop of 3°C in the skin temperature for conventional fabrics whereas in PCM engineered one, it is only about 0.8°C.

Table 6 PCM coated fabrics

Materials tested	Acrylic with PCM	Acrylic without PCM	Substrate with PCM	Substrate without PCM
Wt./sq.m	270	250	227	207
Stand thickness(mm)	5.4	5.63	0.63	0.61
Thermal conductivity(w/mK)	0.0398	0.0342	0.1012	0.1782
Thermal resistance(sq.m.K/w)	0.1281	0.1491	0.0057	0.0029
Specific thermal capacity(kj/kg.K)	3.022	2.391	2.468	1.84

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.³⁻⁸

Conclusion

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. 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.

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Conflict of interest

Author declares there is no conflict of interest in publishing the article.

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